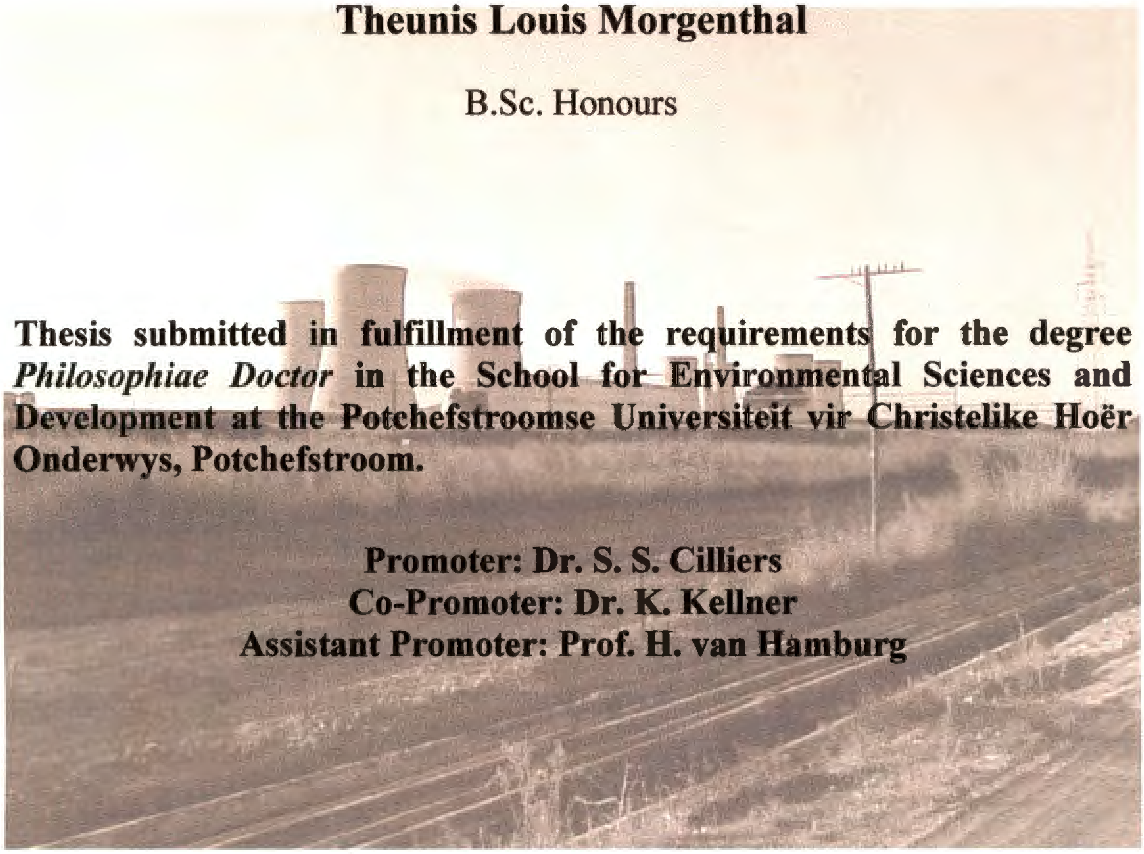
VEGETATION DYNAMICS AND MANAGEMENT MODELS FOR COAL-ASH DISPOSAL SITES AT HENDRINA POWER STATION, MPUMALANGA, SOUTH AFRICA



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B.Sc. Honours

Thesis submitted in fulfillment of the requirements for the degree *Philosophiae Doctor* in the School for Environmental Sciences and Development at the Potchefstroomse Universiteit vir Christelike Hoër Onderwys, Potchefstroom.

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November
2000

Opgedra aan:

Ma,

Pa,

my Verlosser.

"`n Mens vind vreugde daarin as jy die antwoord het"

Spreuke 15: 23

" U woord is die lamp wat my die weg wys, die lig op my pad"

Psalm 119: 105

Acknowledgements

I gratefully acknowledge the following persons and institutions for their assistance and contributions

- My Promoters, for their patience, positive contributions and assistance, and in particular Dr. S.S. Cilliers, for being my tutor during my post graduate studies and the inspiration to become an enthusiastic botanist.
- My parents, for their love and encouragement.
- ESKOM for their financial assistance, the use of their facilities and the permission to use the data as well as the cited reports.
- The rest of the Hendrina research team (Arno de la Rey, Annalizé Vermaak, Wimpie Meyer and Nevil Wright) for their help and encouragement and in particular Saronè De Wet and Johannes Legoete for their assistance with the botanical surveys.
- Annelie Swanepoel for her encouragement and support, and her help with the CANOCO program.
- Mr. Bert Ubbink who helped me with species identification.
- Koos Kotzé, who was responsible for coordinating the project.
- Hendrine Krieg, for the linguistic editing of the manuscript.
- EKO-REHAB for conducting the soil chemical analyses
- The National Botanical Institute (NBI) for identification of unknown plant material.

ABSTRACT

Vegetation dynamics and management models for coal-ash disposal sites at Hendrina Power Station, Mpumalanga, South Africa

Coal-driven power stations in South Africa contribute substantially to the creation of industrial waste areas that require rehabilitation. The monitoring of rehabilitated ash disposal sites is a necessity to determine whether an ecologically sound, self-sustainable ecosystem has developed. The aim of this project is to describe the trajectory of plant community development on rehabilitated ash disposal sites and the factors governing community changes, as well as the development of condition assessment models for the ecological assessment of the vegetation.

The study was conducted on the ash disposal sites at Hendrina Power Station, Mpumalanga Province. The study area consisted of sites on different topographical positions, with different rehabilitation ages and treatments. Phytosociological surveys were conducted and analysed with the Braun-Blanquet method, to describe the vegetation that was used for the study. Frequency, basal cover, density and biomass surveys were conducted in 12 permanent grids over a three-year period from 1997 to 1999. Multivariate analyses techniques, analysis of variance and correlation analyses were used for analyses of quantitative data.

The most abundant species on rehabilitated ash disposal sites were *Eragrostis curvula, Cynodon dactylon, Hyparrhenia hirta, Cyperus esculentus* and *Chamaecrista biensis*. Three different plant communities were described on the natural grassland, on the rehabilitated ash disposal sites and unrehabilitated ash disposal sites. Newly rehabilitated disposal sites illustrated the most change in species abundances and became more similar to older rehabilitated areas during the survey period. The rate of community change of newly rehabilitated areas was significantly higher in comparison to older rehabilitated areas. Older rehabilitated areas were relatively homogenous in plant species composition and no differences in rate of change existed. Trajectories of change were towards a *Hyparrhenia hirta* dominated grassland and followed a similar pattern as old fields on the Highveld. Although no decrease in species diversity was found over the survey period on the rehabilitated ash disposal sites, the species diversity was found to be considerably lower than that of the natural grassland. The most important factors controlling community development were fire frequency, infestations of *Tatera brantsii* (Highveld gerbil) and soil fertility. Important attributes which can be used for ecological assessment included the frequency of perennial grasses and annual forbs, bare ground and basal cover percentages. A state and transition model was develop to explain the dynamics of rehabilitated vegetation, and three species models as well as one model based on functional models were develop for the ecological assessment of rehabilitated vegetation. The vegetation composition on old rehabilitated ash disposal sites was found to be relatively stable due to the dominance of perennial grass species. The biomass of old rehabilitated areas were similar to the biomass of the natural grassland. Regular fires has a negative effect on litter but did not influence grass biomass as such. The densities of a number of species were correlated with biomass parameters. Results indicated that biomass is influenced by dominant species which is supportive of the mass ratio hypothesis.

It is postulated that vegetation stability is a function of environmental stability especially regarding soil chemical properties. Floristic characteristics that promote plant community stability are the adaptability of the species, diversity and species persistence. Only if community stability and environmental stability have been achieved will sustainability on an autotrophic level be possible.

The final conclusion is that vegetation stability has been reached from a species compositional viewpoint and will probably remain stable if the environment remains stable and viable. Diversity of rehabilitated areas is determined by the initial inputs and if the diversity of rehabilitated vegetation is to be increased, the input of adapted species must be increased to enlarge the potential species pool.

Keywords: *ash dams, biomass, ecological monitoring, Grassland Biome, multivariate statistical analysis, phytosociology, plant dynamics, rehabilitation, species diversity, state and transition models*

OPSOMMING

Die Plantegroeidinamika van- en bestuursmodelle vir steenkoolas-uitskotgebiede by Hendrina Kragstasie, Mpumalanga, Suid-Afrika

Steenkoolaangedrewe kragstasies in Suid-Afrika lewer `n groot bydra tot die ontstaan van industriële afval wat gerehabiliteer moet word. Dit is noodsaaklik dat gerehabiliteerde steenkoolas-uitskotgebiede gemoniteer word om vas te stel tot watter mate selfstandige ekologiese volhoubare stelsel gerehabiliteer is. Die doel van hierdie tesis is om die plantegroei dinamika op gemeenskap vlak te beskryf in terme van plantegroei veranderings oor tyd en ruimte, asook om die dryfkragte vir hierdie veranderinge en verskille te bepaal. Verder is dit die doel van hierdie studie om toestandsmodelle te ontwikkel om die plantegroeitoestand ekologies te bepaal.

Steenkoolas-uitskotgebiede by Hendrina Kragstasie, in Mpumalanga is as studiegebied gebruik en het bestaan uit persele in verskillende topografiese posisies, met verskillende rehabiliteringsouderdomme en toegepaste behandelings. Fitososiologiese opnames en dataverwerking is met die Braun-Blanquet metode uitgevoer om die plantegroei van die studiegebied te beskryf Frekwensie, basale bedekking digtheid en biomassa opnames is gedoen in twaalf permanent gemerkte persele oor `n tydperk van drie jaar van 1997 tot 1999. Data is met meerveranderlike en meervoudige statistiese analise en korrelasie metodes verwerk.

Eragrostis curvula, Cynodon dactylon, Hyparrhenia hirta, Cyperus esculentus en *Chamaecrista biensis* was deurgaans die volopste spesies. Drie plantgemeenskappe kon onderskei word, nl. plantegroei van die natuurlike grasveld, gerehabiliteerde plantegroei op Steenkoolas-uitskotgebiede en spontane plantegroei op ongerehabiliteerde steenkoolas-uitskotgebiede. Nuut gerehabiliteerde gebiede het die meeste plantegroei verandering gehad en het tydens die drie jaar meer soortgelyk aan die plantegroei van ou gerehabiliteerde gebiede geraak. Die tempo van verandering op die nuut gerehabiliteerde steenkoolas-uitskotgebiede was ook betekenisvol hoër as die tempo van verandering op ou gerehabiliteerde gebiede. Die rigting van plantegroei ontwikkeling was na 'n *Hyparrhenia hirta* dominante grasveld en volg dus 'n baie soortgelyke suksessie patroon as op verlate ou lande. Alhoewel die spesie diversiteit oor tyd nie op gerehabiliteerde steenkoolas-uitskotgebiede afgeneem het nie, was die diversiteit in vergelyking met `n natuurlike grasveld betekenisvol laer. Belangrike faktore wat gemeenskapontwikkeling beïnvloed het was die frekwensie van veldbrande, *Tatera Brantsii* indringing, en grondvrugbaarheid. Die frekwensie van meerjarige grasse, frekwensie eenjarige kruide, persentasie oop grond en die persentasie basale bedekking is belangrike kriteriums waarmee die ekologiese toestand van gerehabiliteerde gebiede bepaal kan word. `n Toestands-en-Oorgangsmodel is ontwikkel om die dinamika van gerehabiliteerde gebiede voor te stel. Om die toestand van die plantegroei op gerehabiliteerde gebiede te bepaal is ook drie spesie modelle asook een toestandsmodel, wat funksionele groepe gebruik, ontwikkel. Die biomassa van gerehabiliteerde steenkoolas-uitskotgebiede was soortgelyk aan die van `n naburige natuurlike grasveld. Geen noemenswaardige verskille in biomassa tussen die meeste ou gerehabiliteerde steenkoolas-uitskotgebiede en 'n naburige grasveld het bestaan nie. Gereelde veldbrande het tot gevolg gehad dat opgehoopte dooie plantmateriaal afgeneem het. Vuur het egter geen effek op gras biomassa gehad nie. Die digtheid van 'n aantal spesies kon met biomassa gekorreleer word. Sekere dominante spesies het 'n betekenisvolle invloed op biomassa produksie gehad, wat die massa verhouding hipotese ondersteun.

Uit die studie word voorgestel dat stabiliteit 'n funksie is van omgewing stabiliteit veral ten opsigte van grondchemiese eienskappe. Die aanpasbaarheid van spesies, spesies-diversiteit en spesies-volhoubaarheid is floristiese kenmerke wat stabiliteit bevorder. Volhoubaarheid op 'n outotrofiese vlak sal slegs moontlik wees as beide plantegroei en die omringende omgewing stabiel is. Die stabiliteit van gerehabiliteerde Steenkoolas-uitskotgebiede was ook in die dominansie van meerjarige grasse gesetel.

Die finale gevolgtrekking is dat stabiliteit bereik is omdat geen noemenswaardige verandering in spesie samestelling ondervind is nie en dit sal waarskynlik stabiel bly solank die omgewing stabiel en geskik is vir die vestiging van plantegroei. Diversiteit van gerehabiliteerde gebiede word deur die inisiële insette van die saadmengsel en ander bronne bepaal. Die enigste manier hoe diversiteit verhoog sal kan word is om die inisiële saad insette van aangepaste spesies te verhoog om sodoende die potensiële saadpoel te vergroot.

Sluitelwoorde: *asdamme, biomassa, ekologiese monitering, fitososiologie, Grasveldbioom, meerveranderlike statistiese analise, plantegroeidinamika, rehabilitering, spesiediversiteit, Toestands-en-Oorgangmodelle*

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Chapter 1 INTRODUCTION: REHABILITATION ON ASH DISPOSAL SITES

Abstract: Coal remains an important source of electrical power in the world today. This is no exception for South Africa where large quantities of low-grade coal are used to operate electrical power stations. In the process large amounts of ash are created as a by-product. The use of a permanent vegetation cover to reclaim disposal areas is considered to be a successful way of dealing with the environmental problems associated with these areas. Different approaches regarding revegetation of disposal sites are discussed in this chapter to explain the different monitoring outcomes that may exist. The importance of monitoring is also highlighted. A short description of research conducted on rehabilitation in general, and in particular on ash disposal areas, internationally and in South Africa, is provided. A description of the general aims and purpose of this study, as well as an overview of the contents of the study are given.

CONTENTS

1.1 INTRODUCTION

In many countries, coal-driven power stations are the main source of electricity. Coal ash from these power plants also contributes substantially to industrial waste (Bradshaw & Chadwick, 1980 and Ash, 1991). A large quantity of coal ash is also produced in South Africa. The new dispensation of equality and services for all citizens will further increase the use of coal for electricity and therefore the production of ash. Coal ash is, however, not an unusable by-product and alternative uses of coal ash are constantly found. A common method of disposal is to use it as a landfill material, especially to fill open cast coal mines. Santhanam *et al.* (1986) categorised ash utilisation options into three categories, namely:

1.1.1 low value-added uses such as filling material,

1.1.2 medium value added uses where ash is utilised as cement and concrete, and

1.1.3 high value –added uses, for example as a mineral wool or for mineral recovery.

Sampaolo and Relini (1994) investigated the use of coal ash as a component of artificial offshore reef blocks. Despite efforts to recycle ash for other uses, a great amount of ash is discarded as waste, because alternative uses are in many instances uneconomic. An example of these conditions exists at Hendrina Power Station, where large quantities of ash are disposed yearly in tailing lagoons. To abide by the growing awareness of, and new dispensation towards sustainable development, these waste areas must be reincorporated into a productive and environmentally friendly system. The use of vegetation is regarded as an effective solution to environmental problems associated with these areas, and to achieve self-sustainability (Hodgson & Townsend, 1973, Thatcher, 1979 and Van Wyk, 1994). According to Cairns *et al.* (1996), self-sustainability can be regarded as a process of self-maintenance, and the existence of sufficient integrity in the ecosystem so that existing natural processes will keep the ecosystem intact. Slocombe (1990) defines sustainability as the ability of an ecosystem to avoid catastrophic change due to the capacity for creating a self-organising, developing system. Self-sustainability will therefore only be possible if regeneration in populations occur and if ecosystem development takes place. Rehabilitation is also necessary to abide by the need for economical sustainability to ensure that economic development does not deplete, or in this case reduce or degrade natural resources upon which present and future economic growth will depend (Miller, 1994).

1.1.1 The rehabilitation process

In Europe and especially Britain, land is regarded as a scarce resource that must be handled with care. Many rehabilitation scientists also believe that if you cannot recreate the original system, then it is not worth doing rehabilitation work (Bradshaw & Chadwick, 1980). Many reclamation schemes, therefore, aim to return the land to its original use or level of productivity, which under many circumstances was a productive agricultural area (Knabe, 1965; Hodgson & Townsend, 1973 and Bradshaw & Chadwick, 1980). The rehabilitation scheme proposed by Bradshaw and Chadwick (1980) (Figure 1.1) indicated that one of the first steps in rehabilitation is to decide on an ultimate land-use type and to formulate ecological goals according to the ultimate land-use. The policy of a company could, however, be to accept site conditions and establish vegetation at a low input level. Another approach is to improve a derelict site by landscaping and by adding a soil amendment before establishing vegetation. It is, therefore, clear that different approaches exist and rehabilitated sites must be monitored according to the approach that was implemented. According to Knabe (1965) and Bradshaw and Chadwick (1980), the best way of rehabilitation is to plan the end-use even before the onset of waste disposal (Figure 1.1). The restoration scheme and ecological goals for revegetation should be planned according to the envisaged end-use. Monitoring is also indicated as a necessary step in a restoration scheme (Figure 1.1). Bradshaw and Chadwick (1980) implied that, if reclamation practices were planned in the correct way, it would result in a minimum delay between the use of the land for waste disposal and its restoration to an alternative use after closure of the project. If the time span between waste disposal and restoration becomes too long, the area remains unsightly, unproductive and may pose a health risk. Because vegetation rehabilitation schemes are mostly used to overcome problems associated with derelict land, rehabilitation is essentially an ecological problem and should be aimed at the establishment of a stable, self-sustainable ecosystem, irrespective of the management goals (Bradshaw, 1996). A rehabilitation scheme must therefore be evaluated according to the defined efforts and standards that were used. According to Lubke (1995) a great misunderstanding on the different approaches exist regarding restoration, rehabilitation and revegetation as well as other related terms. The following approaches were identified from literature.

1.1.1.1 Rehabilitation

Barnard (1995) indicates rehabilitation as a major component of environmental planning and protection. Allen (1991) defines rehabilitation as the restoration to a proper condition, which according to Barnard (1995) means that restoration aimed to satisfy the demands of sustainable development. The only way rehabilitation, sustainability and a proper condition can be achieved, is if the economic value of the new resource is equal to the value of the resource that will be destroyed during development (Barnard, 1995). It is clear from this definition that economic value is the criterion that is used to indicate rehabilitation. It may, therefore, seem that the emphasis is not necessarily on ecological sustainability but rather that ecological sustainability is a device to achieve economical sustainability. A more ecologically based definition is provided by Mentis and Ellery (1994) who place emphasis on the restoration to a natural dynamic state with ecological communities comprising strongly or weakly interacting species. To comply with this definition, Mentis and Ellery (1994) tested to determine whether established vegetation on disturbed mine land was similar to vegetation on disturbed land not influenced by mining, will converge to a similar climax vegetation state.

1.1.1.2 Reclamation

Reclamation is defined by the American Surface Mining Control and Reclamation Act (SMCRA) (Holl & Cairns, 1994) as those actions which are taken to restore mined land to a post mining land-use which is approved by the division of Mined Land Reclamation. A similar definition is given in the South African Statutes for rehabilitation. The Mineral Act no. 50 of 1991 (South Africa, 1991) defines rehabilitation as the execution of the environmental management program by the holder of a prospecting permit, as referred to in section 39 of the act, to the satisfaction of the Director of Mineral Development.

Allen (1991) defines reclamation as:

"1) bring under cultivation, especially from a state of being under water 2) win back...from a waste condition".

Reclamation is indicated by Harris *et al.* (1996) to be a process by which previously unusable land or degraded soil is returned to a state whereby some use may be made of it as a natural resource.

1.1.1.3 Restoration

Ecological restoration is the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems as they were prior to degradation of any sort (Harris *et al.*, (1996). LaFevers (1977) and Begon *et al.* (1990) suggested that in areas where abiotic conditions have been profoundly altered, restoration as such might not be realistic. In such degraded areas rehabilitation would be more appropriate, with the aim to establish a community that is similar to the original communities or to replace the original community by a quite different biological community.

1.1.1.4 Revegetation

The least ecologically based approach is revegetation. The word indicates the use of vegetation as a manner of phytoremediation. According to Mentis and Ellery (1994) it is the establishment of vegetation of any type.

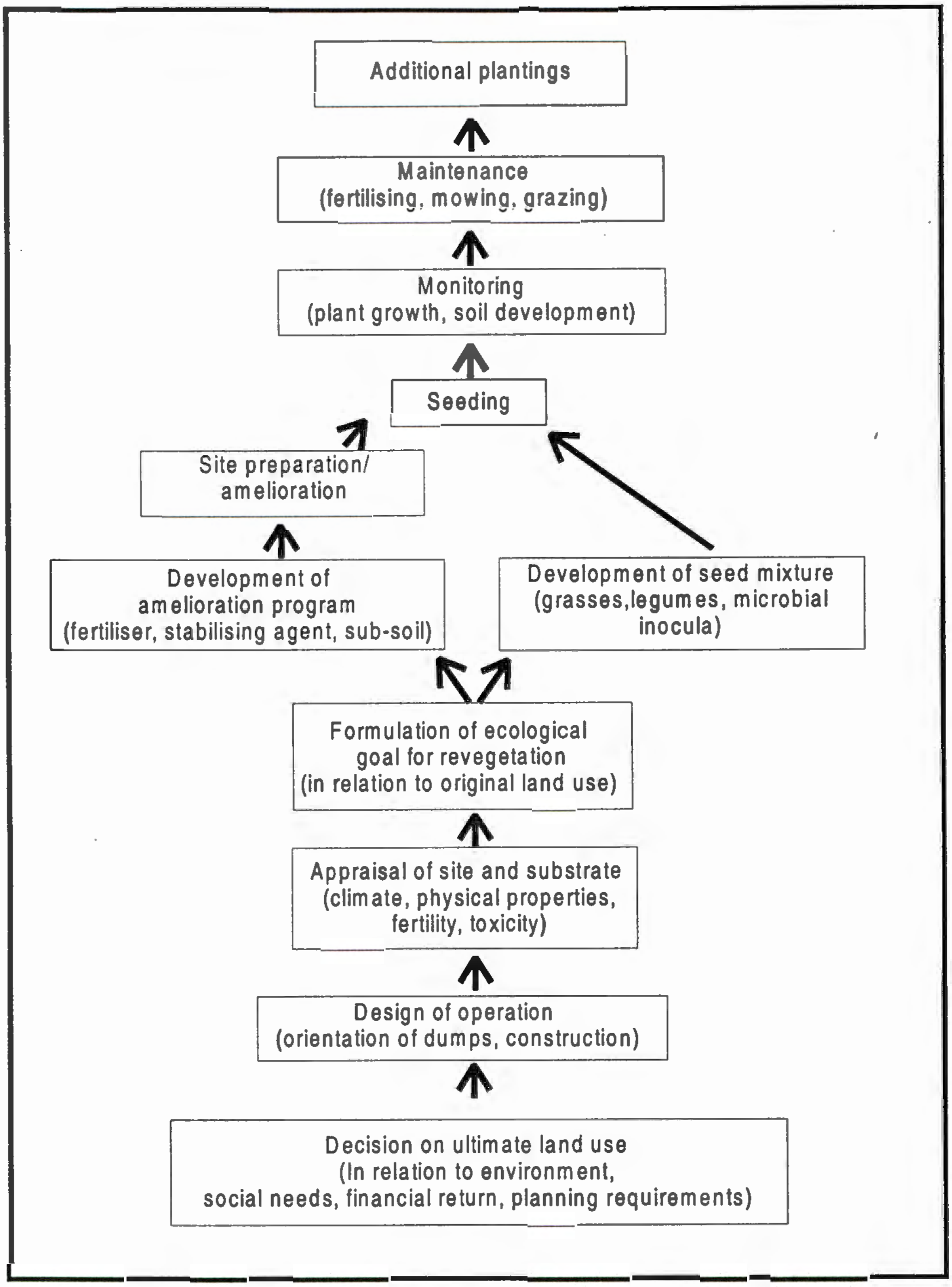

Figure 1.1: Steps involved in the development of a successful rehabilitation scheme (Bradshaw & Chadwick, 1980)

To summarise, it can be reasoned that three possible approaches exist. **Revegetation** implies grassing with a minimum amelioration of the plant medium (Dr. F. van Wyk, pers com.)[1]. **Rehabilitation** indicates a holistic approach to a degree that the ecosystem is restored to an optimum usable condition within economic boundaries (Van Wyk, 1994 and Badenhorst, 1994). Rehabilitation, therefore, includes revegetation as well as habitat amalgamation. American legislation and scientific literature are inclined to use **reclamation** instead of rehabilitation. The third approach is **ecological restoration**, which is more applicable to smaller disturbances, and the full restoration to the ecosystems and biotic communities that were previously present in an area.

The establishment of vegetation at Hendrina Power Station can be regarded as a rehabilitation approach. Vegetation was established recognising ecological principles due to the use of pioneer and climax grass species in the seed mixture. Vegetation was also planted after sufficient amelioration of the growth medium by fertilisation and the covering of the ash with a layer of topsoil. Species used in the seed mixture were mostly indigenous (the rehabilitation process will be discussed in detail in Chapter 2 of this thesis). The aim of the rehabilitation process must therefore be to establish plant communities that are sustainable and ecologically sound ecosystem, although the community structure does not have to be similar to natural areas.

1.1.2 Why derelict land should be rehabilitated?

1.1.2.1 General

Nature would probably look after itself. An important reason why nature is not left to heal its own wounds, is because the process of natural revegetation is impracticably slow and derelict land has it's own particular problems such as nutrient deficiencies or toxicities which time and nature will not be able to heal (Bradshaw & Chadwick, 1980). Another problem is the amount of derelict land that is created by man. Bradshaw (1996) mentioned that the destruction of arable land exceeds the process of land restoration or the natural recovery of disturbed land.

1.1.2.2 Rehabilitation legislation

Enforcement of legislation and to obtain closure certificates is one of the most important reasons why companies undertake revegetation of any sort. LaFevers (1977) suggested that legislation should be used as guidelines to provide a framework, which will ensure consistent and acceptable reclamation planning and practices. According to Bradshaw (1996), a number of laws have been proclaimed in the United Stated and in England to ensure restoration of derelict land. In the United States the reclamation of open cast mines is governed by the Federal

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[1] Dr. F. van Wyk, Eko Rehab, P.O. Box 19752, Noordbrug, 2522.

Surface Mining Control and Reclamation Act of 1977. This act requires a posting of a bond and the drafting of a reclamation plan for the site after mining. Evaluation of rehabilitation success for the release of the bond is determined by achieving a certain percentage of vegetation cover after 5 years from rehabilitation (Holl & Cairns, 1994). Reclamation and restoration of land in the United Kingdom are enforced by the Town and Country Planning Act 1971 and the Minerals Act of 1981 (Bradshaw, 1996).

Government in South Africa has published a number of legislations and proclamations related to rehabilitation of mined land (Van Wyk, 1994). It is only in recent years that the need for proper rehabilitation of derelict land has been realised. Legislation directly related to obligate rehabilitation includes the Atmospheric Pollution Prevention Act no. 45 (South Africa, 1965), the Environment Conservation Act no. 73 (South Africa, 1989) and the Minerals Act no. 50 (South Africa, 1991). The Atmospheric Pollution Prevention Act no. 45 (South Africa, 1965) has specific application for the prevention of dust pollution on mine dumps (article 27), whereas the National Water Act no. 36 (South Africa, 1998a) has application to the prevention of water pollution and sustainable water utilisation. The Conservation of Agricultural Resources Act no. 43 (South Africa, 1983) may also have indirect application for the enforcement of rehabilitation on ash disposal sites.

South Africa's new Bill of Rights (South Africa, 1996) is, however, clear on the demand for sustainable development-

"Everyone has the right:

> To an environment that is not harmful to their health or well-being; and to have the environment protected...prevent pollution and ecological degradation; secure ecologically sustainable development."

The new National Environmental Act no. 107 of 1998 requires industries responsible for pollution and degradation of the surrounding environment around industrial areas to investigate and assess the impact of their activities on the environment, to prevent further pollution and to remedy the effects of the pollution or degradation (South Africa, 1998b).

The rehabilitation of ash dams at ESKOM power stations is therefore an important aspect of the strategy to minimise the impact of power stations on the environment, to facilitate the utilisation of rehabilitated areas and to acquire closure certificates. Research to identify the best rehabilitation strategies will also provide recommendations for future rehabilitation programs (Michael, 1997). Because of the depletion of natural resources and environmental degradation, urgent action is required to clean up and to monitor degradation due to industrial activities (Gardner, 1992).

1.1.3 Monitoring as part of the rehabilitation process

Figure 1.1 indicates that monitoring is an integral part of the rehabilitation scheme. According to Wali & Kollman (1977) it is important to determine the chronosequence in the lithosphere and vegetation of revegetated areas, because it can aid the selection of treatments that can be used to enhance organic matter enrichment and vegetation establishment. During the rehabilitation process, certain ecological principles are applied and if those principles are incomplete, the ecosystem will also not function properly (Bradshaw, 1996). Evaluation and monitoring do not only help to steer the rehabilitation process by detecting shortfalls and maintenance problems, but also create a tool to test and refine our knowledge of rehabilitation itself and the ecological principles controlling it (Smyth, 1997). Rehabilitated vegetation may either develop into a self-sustained ecosystem, or gradually deteriorate and retrogress to a state in which no regeneration of perennial plants and an increase in bare patches occur (Bradshaw & Chadwick, 1980).

The definition of monitoring which is given by Mentis (1989) indicates that changes in observed attributes are the basic criteria used for monitoring:

Monitoring is, therefore, defined as the maintenance of regular surveillance to test the null hypothesis of no change in predefined properties of a system which is vulnerable to impacts, the nature, timing and location of which are not necessarily known. Mentis (1989) also indicates that monitoring is an integral part of scientific management. Long-term bio-monitoring also provides information consistency and is a pro-active management system (Cairns & Niederlehner, 1996).

1.2 LITERATURE OVERVIEW

Extensive international publications exist on rehabilitation of derelict land. An investigation by the Institute for Ecological Rehabilitation (Eco-Rehab)[2] of literature published until 1985/1986 identified 30 000 publications on subjects related to rehabilitation of disturbed land (Van Wyk, 1994).

Research on the initial rehabilitation process concerning the selection of treatment and species were discussed by Salo *et al.* (1996) on saline flue gas sludge ponds in the USA; Piha *et al.* (1995a) on tin mines in Zimbabwe; Piha *et al.* (1995b) on pulverised fuel ash tailings in Zimbabwe and Vangronsveld *et al.* (1995) on old non-ferrous waste dumps in Belgium. Jusaitis and Pillman (1997) noted that most previous studies on rehabilitation of waste fly ash lagoons have concentrated on the agricultural use of fly ash. Studies of Jusaitis and Pillman (1997) also concentrated on glasshouse and field trials and the use of indigenous halophytes and xerophytes of the area for the rehabilitation of ash disposal sites.

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[2] Eko Rehab, P.O. Box 19752, Potchefstroom, 2522

A number of papers have been published on ecosystem and vegetation community development, namely, on old non-ferrous metal waste dumps in Belgium (Vangronsveld *et al.*, 1996); on China clay waste in Britain (Roberts *et al.*, 1981), on limestone quarry walls in Canada (Ursic *et al.*, 1997), on reclaimed coal surface mines in the USA (Holl and Cairns, 1994) and on abandoned coal surface mines, also in the USA (Skousen *et al.*, 1994).

Shaw (1996) (Britain) and Middleton (1995) (USA), investigated the role of seed banks in the rehabilitation of fly ash and coal slurry ponds. Hutnic and Davis (1973) and Bradshaw and Chadwick (1980) gave a detailed account on the restoration of coal surface mines. The rehabilitation of coal ash sites has also been extensively researched in Europe and the United States (see Chapter 8).

Most scientific papers on rehabilitation in South Africa were on gold mine tailings. Phillips (1936) did the first work regarding vegetation of gold mine waste. Thatcher (1979), who also gave a review of rehabilitation work until 1979, studied the vegetation established on the slime dams of the Witwatersrand. Other types of reclamation that are mentioned by Thatcher (1979) include revegetation of open cast mines as well as colliery spoil heaps and dune slacks near Richards Bay. According to Thatcher (1979), a *Hyparrhenia* dominated community can be regarded as the secondary succession climax on slime dams. *Eragrostis curvula* was found to be the most important species growing on the slime dams with the overall basal cover between ten and twelve percent (Thatcher, 1979).

Van Wyk (1994) investigated different strategies for the rehabilitation of disturbed mining areas in South Africa and came to the conclusion that a great ignorance towards the basic ecological aspects of rehabilitation in South Africa still exists. According to Van Wyk (1994) the more similar the new ecosystem is to the surrounding original ecosystem, the greater the chance of success, because the tolerance level of the new ecosystem is compatible to the surrounding environment.

As for disposal sites, very little is published about rehabilitation and the success of rehabilitation on coal ash in South Africa, except for a study by Van Rensburg *et al.* (1998).

1.3 AIMS OF STUDY

This study forms part of a multidisciplinary and interactive study of floristic and faunistic components on rehabilitated ash dams at Hendrina Power Station. The final goal of the entire project is to develop an expert system for the identification of appropriate management strategies for the rehabilitation of ash disposal sites at power stations. The faunistic components include surveys on the soil fauna, small mammal and invertebrate populations and were dealt with by other researchers in our team.

This thesis presents results obtained from descriptive studies on the vegetation communities established on the ash dams in relation to a nearby natural grassland.

1.3.1 Specific aims

The aim of this thesis is to describe the community development over space and time on rehabilitated ash disposal sites. A further aim is to assess the vegetation of the rehabilitated areas ecologically in respect of their ecological stability and to evaluate the rehabilitation process in terms of community characteristics (species composition, life form spectra, diversity and biomass) and dynamics (vegetation change and rate of change). Monitoring was, therefore, an integral part of the study. A requirement of the study is the development of models for the quantitative condition assessment of ash disposal areas. The study also provides recommendations for future rehabilitation on ash disposal areas and the selection of species for rehabilitation.

1.4 OVERVIEW OF CONTENTS

The thesis is divided into a number of chapters dealing with specific themes and hypotheses derived from previous studies on community dynamics. The chapters were written in the format of scientific papers that could be submitted for publication. The content of Chapters 3 to 8 as well as Chapter 10 therefore included an abstract, introduction, materials and methods, results and discussion, conclusions and bibliography. The study area was described once in Chapter 2 to minimise repetition and general methods used were cross-referenced between chapters. Repetition, however, still exists but each chapter should be treated as an entity in itself.

The present chapter provides a general discussion of different approaches in rehabilitation and how they influence the ecological aim of the rehabilitation process. The need for adequate monitoring is discussed. A short literature overview on recent studies regarding rehabilitation, which were published internationally and nationally, is given.

A description of the study area, survey design, and overview of methods used are provided in Chapter 2.

Results from statistical data analyses are dealt with in Chapters 3-9. Results are aimed at providing a description of the plant communities of ash disposal sites at Hendrina Power Station and their dynamics. A list of species encountered on ash disposal sites and an adjacent natural grassland is also given. The following topics are dealt with:

1.4.1 First a phytosociological study is conducted to **identify and give a description of all plant communities** present and to determine how these communities are related (Chapter 3).

1.4.2 A **list of all flowering plants** identified during the three-year period on the ash disposal sites and an adjacent natural grassland is provided in Chapter 4.

1.4.3 Within described plant communities, permanent sample grids were established. According to Eger (1954) and Myster & Picket (1990) early succession on old fields are characterised by their abandonment characteristics. In this study the affect of different treatments with different revegetation ages on **spatial heterogeneity over three years** are investigated. This is achieved by ordination and cluster analysis of each survey year (Chapter 5).

1.4.4 **The change in vegetation composition over time** is further investigated by testing the stability of the vegetation regarding community composition and species abundance (Chapter 6). According to Barbour *et al.* (1987) a stable ecosystem is a system with lack of change in the vegetation composition and the dominance of perennial species. Specific events and conditions at each site could therefore be related to changes or lack of change in vegetation composition. Chapter 6 also investigates the hypothesis that succession among similar sites will be unidirectional (Lepš, 1987) and that sites will converge to a state where all sites share a similar species composition.

1.4.5 A general hypothesis exists in plant successional studies that the rate of change (succession) decreases over time (Myster & Pickett, 1994). **The rate of change of each grid** over the three year is therefore investigated with two well-known indices (Sørensens and Square Euclidean Distance (SED) indices). Vegetation change is also expressed as a **change in diversity at each grid over the three-year survey period** (Chapter 7). Diversity is regularly used as an indication of the stability of an ecosystem and it is hypothesised that diversity will increase with ecosystem development (Bazzaz, 1975).

1.4.6 The **effects of environmental factors on plant community development are** well known (Bradshaw & Chadwick, 1980) and are also investigated in Chapter 8.

1.4.7 The community dynamics are also investigated regarding **biomass production and the effect on environmental conditions and species composition on biomass production** and *vice versa* in Chapter 9. It is hypothesised that biomass will increase with community development (Corbett *et al.*, 1996) and will be affected by the nutrient status of the growth medium and species density.

Two models with which the condition of the vegetation of rehabilitated sites can be assessed are presented and discussed in Chapters 10 and 11. These two chapters, therefore, illustrate and discuss the application value of plant community data for the monitoring of ash disposal sites.

1.4.8 Recent developments regarding rangeland models proposed the use of non-equilibrium principles. A state and transition model is presented, which is based on non-equilibrium ecology. This proposed **state and transition model** describes different states (communities) and how they may change due to certain conditions (Chapter 10).

1.4.9 The development of **condition assessment models** for rehabilitated areas is one of the important aims of this study. Three gradient models, based on dominant species, identified states and community attributes are presented. Newly rehabilitated areas, road verges and, to a lesser extent, a natural grassland are used as benchmarks. A fourth gradient model is also presented, which uses selected community attributes (Chapter 11).

Chapter 12 is a discussion and conclusion of results obtained and also includes management proposals for future monitoring and rehabilitation programs.

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Chapter 2 STUDY AREA AND GENERAL MATERIALS AND METHODS

Abstract: A detailed description is provided of the study area regarding the natural vegetation of the area, the climate of the region, layout of the ash disposal sites, rehabilitation treatments and survey methods used. The study was conducted at Hendrina Power Station and includes a series of four ash disposal sites. The study area is situated in the Grassland Biome, receives summer rainfall and has a warm temperate climate. The ash disposal sites were rehabilitated using four treatments of which three were similar and mostly included indigenous grass species. Quantitative surveys were conducted in twelve permanent grids consisting of three transects each, over a period of three years. Floristic studies conducted included phytosociology, frequency, basal cover, density and biomass. Data were analysed with multivariate analysis, analysis of variance and correlation techniques.

CONTENTS

2.1 STUDY AREA

The study was conducted at one of ESKOM's power stations near Hendrina, Mpumalanga, South Africa. The study sites consist of a series of four ash disposal sites or dams (Figure 2.1) and a fifth dam, which is under construction. Ash disposal site 1 is the dam situated nearest to the power station. Ash disposal sites 2 and 3 were built consecutively to the south of ash disposal site 1, bordering each other by their southern and northern walls (Figure 2.1). Ash disposal site 2 was only used for a while because the stockpiles collapsed. Ash disposal site 4 is situated separately from ash disposal sites 1, 2 and 3 and was still in use when the study was conducted. Construction of a fifth dam between ash disposal sites 3 and 4 was started in late 1997.

The disposal sites are bordered by a number of different land-use areas. The power station forms the northern boundary of the site, while the north-western boundary consists of a railway line and a coal loading station (siding). During south-easterly winds, coal dust is blown onto the north-western walls of the ash disposal site. Maize fields border the south western, southern, and parts of the eastern side of the ash disposal sites. The north-eastern border of the ash disposal sites consists of rehabilitated open cast coal mines and severely disturbed and reclaimed areas resulting from those mining activities.

The construction of ash disposal dams is similar to the construction of tailing dams used in the gold industry. A tailing dam consists of a series of settling lagoons build around the centre of the dam. Fly ash (fine ash fraction carried out of the boiler) is used in the construction of the walls of the ash dams and is pumped in-between the crest wall and dividing wall, while bottom ash and the rest of the fly ash are pumped inside the dividing wall in settling lagoons (Figure 2.2). A penstock is used to regulate the water level in the dam and seepage dams are used to collect runoff from the ash. Catchment paddocks collect all running water from the dam and divert it into collection dams. After use of an ash dam the dam is drained and becomes a terrestrial system. It was, therefore, decided to use the term disposal site after decommissioning rather than dam or lagoon.

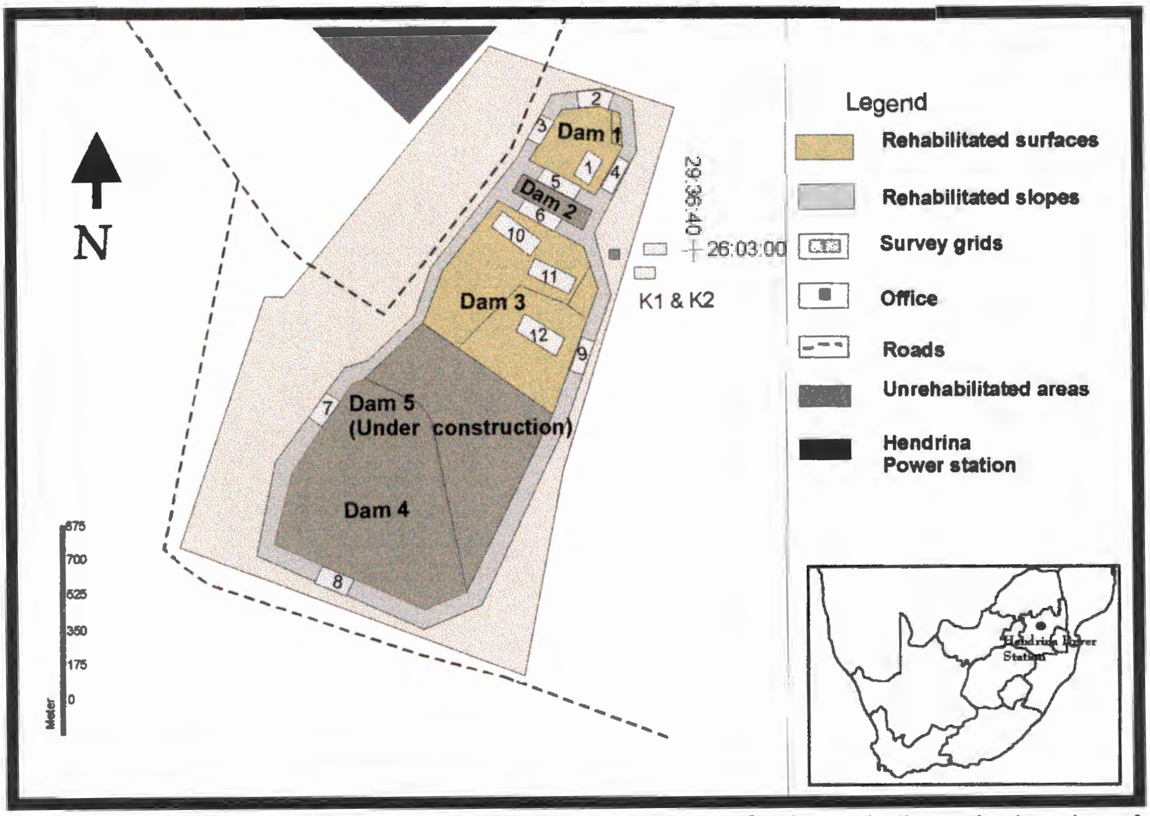

Figure 2.1: Map of the ash disposal sites at Hendrina Power Station to indicate the location of the different ash dams (disposal sites) and permanent survey grids as well as a general locality map (insert) of Hendrina Power Station.

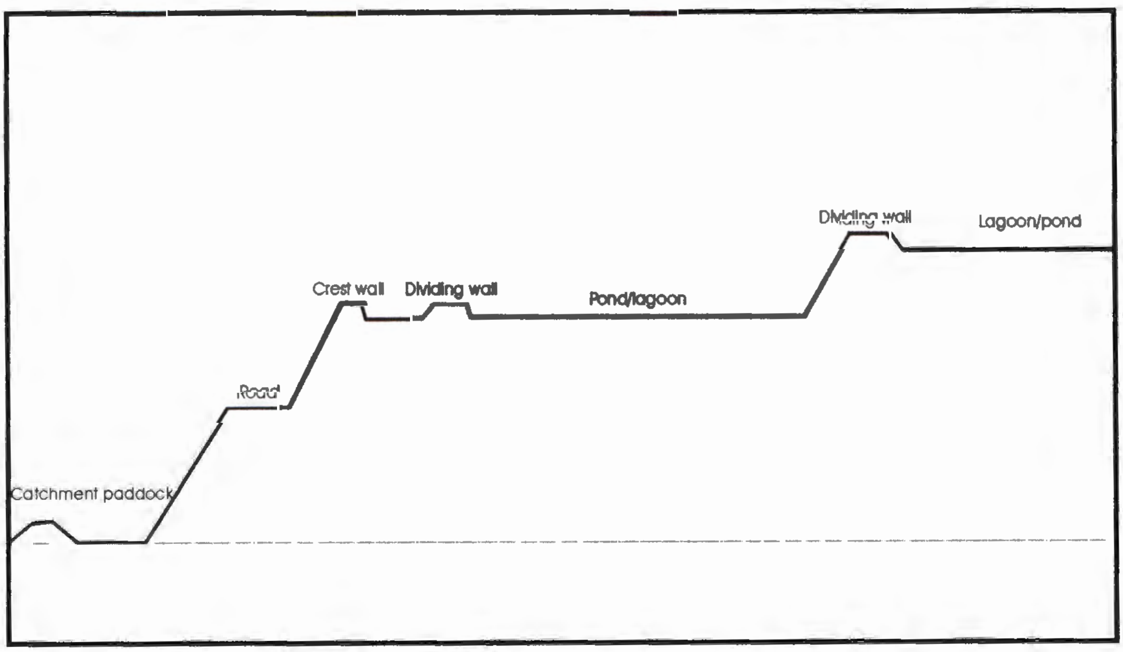

Figure 2.2: Section through an ash dam indicating the different accumulation ponds or lagoons. In the text these areas are referred to as ash disposal sites after decommissioning.

2.1.1 Vegetation

The study area is situated in the Grassland Biome (Rutherford & Westfall, 1986). Acocks (1988) described it as part of the eastern variation of the Bankenveld (Veld Type 61). Grass species of general occurrence include amongst others *Tristachya leucothrix, Eragrostis racemosa, Heteropogon contortus, Trachypogon spicatus, Digitaria tricholaenoides, Themeda triandra, Brachiaria serrata* and *Elionurus muticus*. In the most recently produced vegetation map of southern Africa the vegetation of the region is classified as part of the Moist Sandy Highveld Grassland (Bredenkamp & Van Rooyen, 1996). A large percentage of land has been converted to arable land or is rehabilitated open cast areas. The natural grassland that was studied as a reference point (Figure 2.5.1) was the only remaining area not under cultivation.

The natural grassland that is used as reference point is situated at the eastern border of the ash disposal sites. The size of the natural grassland is however very small and comprises a small area in relation to the ash disposal sites (Figure 2.1). The grassland consists of species typical of the eastern variation of the Bankenveld (Acocks, 1988) (see Chapter 3 and 4 for a detailed description of the vegetation of the natural grassland). No indication of grazing could be seen during the study, although the area could have been utilised for grazing in the past. The natural grassland is however regularly burned due to uncontrolled veld fires and was burned during the winters of 1998 and 1999.

2.1.2 Climate

According to the Köppen classification (Schulze & McGee 1978) the region has a warm temperate climate (coldest month is in June with a maximum and minimum temperature of 18 ^{0}C and -3^{0}C) with a dry winter season and warmest months below 22 ^{0}C but for at least 4 months above 10^{0}C. Data obtained from meteorological measurements at Carolina (45 km east of Hendrina Power Station; 1690 m a. s. l.) for the period 1994-1998 indicated average minimum and maximum temperatures of 7.7°C and 21.8°C respectively for the station (Figure 2.3).

The weather station at the town Hendrina (18km south-east of Hendrina Power Station, 1700 m a. s. l.) had an average precipitation of 767 mm for the period 1990-1998 (Figure 2.4). The total precipitation for 1996, 1997 and 1998 were respectively 958.7 mm, 883 mm and 804 mm and were higher than the average precipitation (Figure 2.4).

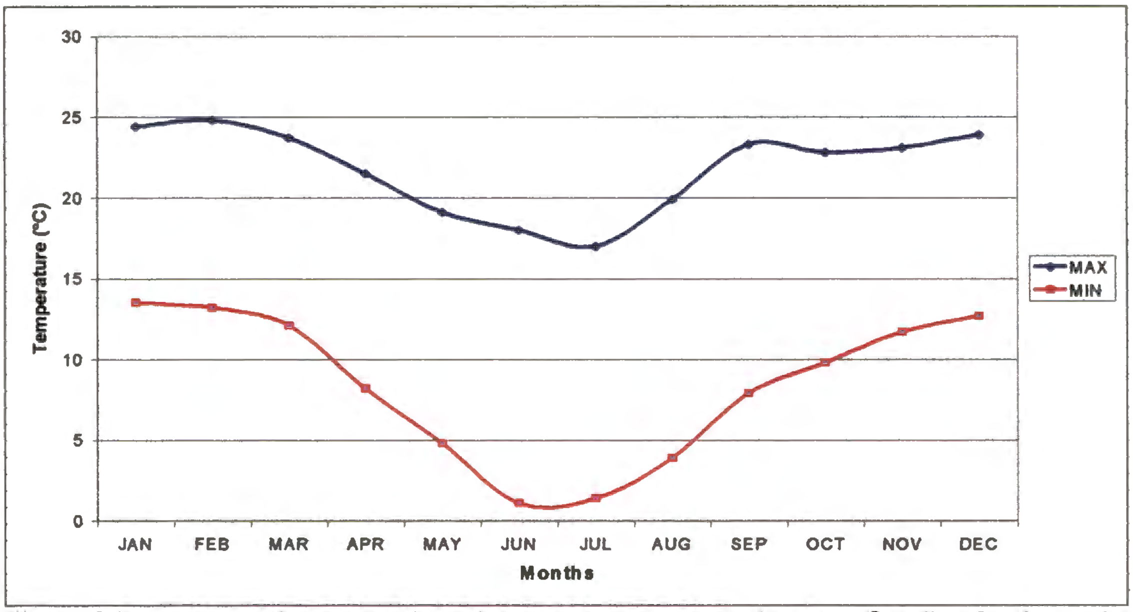

Figure 2.3: Average minimum and maximum temperatures at the town Carolina for the period 1994-1998.

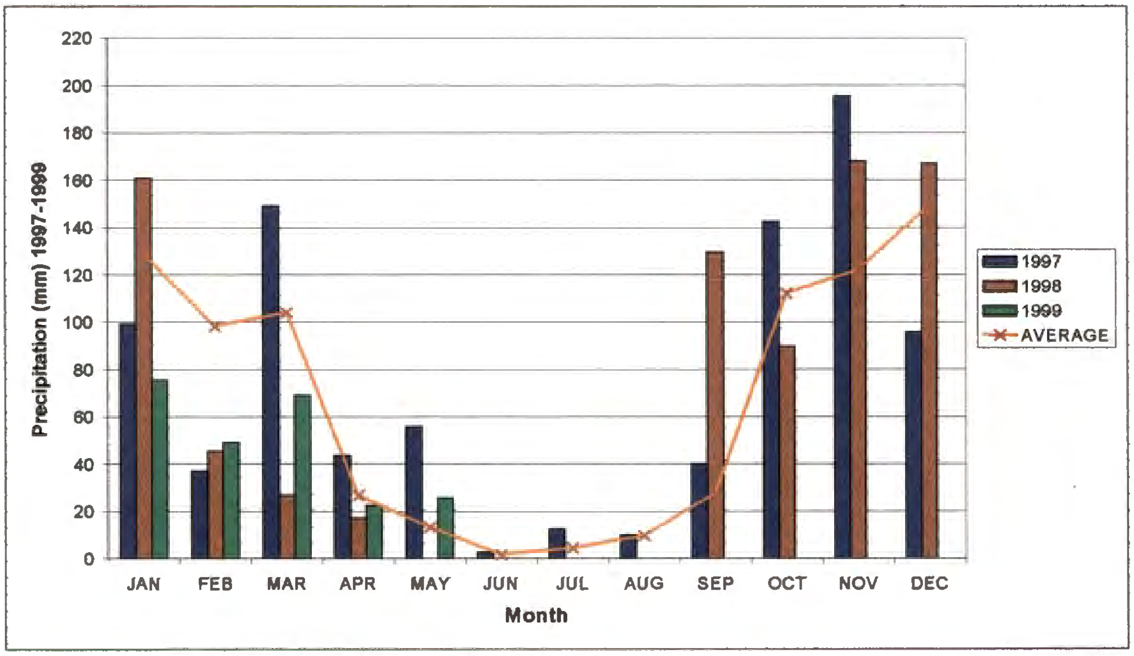

Figure 2.4: Monthly precipitation at the town Hendrina for the period 1997-1999, as well as the average precipitation during the period 1990-1999.

2.1.3 Rehabilitation History

The following information regarding the rehabilitation history was obtained from ESKOM management. Information regarding two separate studies are also given which was provided by Mr M.D. Michael[1] of ESKOM.

The surface of ash disposal sites 1, 2, 3 and 4 covers an area of approximately 215 ha. The primary aim of rehabilitation on ash disposal sites 1 (Figure 2.5.2) and 3 (Figure 2.5.5) was to establish an indigenous grassland but small areas of *Acacia mearnsii* Woodland (Figure 2.5.4) have also developed over the years on these areas. A part of ash disposal site 2 (Figure 2.5.3) is a semi-wetland containing dense stands of *Arundo donax* and *Pennisetum clandestinum.*

The first known revegetation work at Hendrina Power Station was undertaken in November 1986 as small experimental strips on the plateau of ash disposal site 1. The seeds were scattered by hand in rows running in a north to south direction and then lightly rotavated with a rotavator mounted behind a tractor. Different species were sown along each strip. A list of species used is given in Table 2.1. No results from these experiments are known, but very few of these species were found on the plateau of ash disposal site 1 during this study.

The plateau of ash disposal site 1(Figure 2.5.2) was further revegetated in the 1980's (probably after 1986 but no exact date could be provided) with *Cortaderia jubata* and *Pennisetum clandestinum* (Treatment A; Table 2.2). During 1994 the *Cortaderia jubata* plants were removed and a 50mm layer of topsoil was added. The *Cortaderia jubata* plants was removed because they posed a health risk (can cause respiratory problems) (M.D. Michael, pers. com[1]) and is also regarded as an aggressive invader plant on disturbed land (Henderson, 1995). In the rehabilitation process a mixture of topsoil and sub-soil originating from different soil depths were used. The soil that was used was probably from a soil form with a plinthic horizon (Soil Classification Work Group, 1991), because the soil layer currently consists of numerous iron and manganese oxide concretions.

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[1] Mr. M.D. Michael, Technology Services International, Private Bag 40175, Cleveland, 2022

Table 2.1: Species used during a rehabilitation experiment on the plateau of ash disposal site 1 during November 1986

Lotus corniculatus 'Viking' (Birdsfoot Trefoil)
Agrostis sp. 'Colonial bent'
Atriplex sp. (Creeping Salt Bush)
Cenchrus ciliaris 'Molopo' (Blue Buffalo)
Chloris gayana 'Katambora' (Rhodes)
Cynodon dactylon 'Bermuda' (Couch grass)
Digitaria eriantha (Smuts finger)
Eragrostis curvula 'Ermelo' (Weeping Love grass)
Eragrostis tef 'Ordinary Brown' (Tef)
Festuca arundinacea? (Festue Tall)
Lolium sp.? 'Titania' (Italian Rye grass)
Medicago sativa 'Pierce' (Lucerne)
Pennisetum americanum (Millet babala)
Secale cereale 'Condesa' (Rye Grass)
Sorghum sp. 'Haymaster' (Sorghum)
Trifolium sp. 'Mount Barker' (Subterranean Clover)
Vicia dasycarpa 'Penngift' (Crown vetch)

Rows were hand sown and lightly rotovated.
Each species was planted per row.
Half of *Vicia dasycarpa* was inoculated with a bacterial strain.

Figure 2.5.1

Figure 2.5.2

Figure 2.5.3

Figure 2.5.4

Figure 2.5.5

Figure 2.5.6

Figure 2.5: Photographs illustrating the nearby natural grassland (Figure 2.5.1), ash disposal site 1 (Figure 2.5.2), ash disposal site 2 (Figure 2.5.3), a slope of ash disposal site 1 on which grid 4 is situated (Figure 2.5.4), ash disposal site 3 indicating the locality of grid 12 (Figure 2.5.5) and grid 8 on the slope of ash disposal site 4 (Figure 2.5.6) at Hendrina Power Station.

The second series of revegetation works were done at the beginning of the 1990 growing season on the plateau of ash disposal site 3 (Figure 2.5.5). The ash was ameliorated with a 50 cm layer of topsoil and fertilised at 250 kg/ha of super phosphate and 200 kg/ha of 4:3:4(30) with zinc fertiliser. An area of 15 ha was sown with a seed mixture of 16 species of grasses (Treatment B; Table 2.2). An evaluation of the rehabilitated area was undertaken in July 1991 and the total basal cover of the area was 8.4%. Species with a significant basal cover are given in Table 2.3. A total number of 25 species was recorded along transects of 500 points. The total aboveground biomass was determined as 956 kg/ha (Michael, 1991). The remaining areas on the plateau of ash disposal site 3 were rehabilitated during 1991-1992 with a similar treatment used during 1990 (Treatment B; Table 2.2).

Most of the slopes of ash disposal sites 1 and 3 were rehabilitated during 1992 (Treatment B, Table 2.2) and 1994 (Treatment C; Table 2.2) (Figure 2.5.4). The slopes of ash disposal sites were contoured and ameliorated with a 8-10cm soil layer. A seed mixture of 12 species similar to the seed mixture used during the 1990 rehabilitation initiative was also used during 1994 (Treatment C; Table 2.2). *Cynodon dactylon* was also planted at regular intervals (4m) along strips of 450mm wide for erosion control and stabilisation of the slopes. The topsoil used, probably originated from soil of the Clovelly and Westleigh soil forms (Soil Classification Work Group, 1991).

The middle slope of ash disposal site 4 was rehabilitated during the 1996/1997 growing season (Treatment D; Table 2.2) (Figure 2.5.6). The slopes of ash disposal site 4 were rehabilitated in a similar manner as the rehabilitation treatment of 1992, but *Pennisetum clandestinum* sods instead of *Cynodon dactylon* was used. The topsoil used on the slopes of ash disposal site 4 originated from soil of the Hutton soil form (Soil Classification Work Group, 1991), on which maize has previously been planted.

2.2 MATERIALS AND METHODS

Surveys for this study were conducted during the period December 1996-March 1999. A number of survey methods were used to monitor and evaluate the rehabilitation at Hendrina Power Station. These methods will be discussed in depth in the chapters that follow. Qualitative and quantitative survey methods were used and the study was purely descriptive in nature.

Table 2.2: Rehabilitation treatments on Hendrina Power Station ash dams

	Treatment A: 1980 (Plateau of site 1)	Treatment B: 1990-1992 (Plateau of site 3)	Kg /ha	Treatment C: 1994 (Slopes of site 3)	Kg/ha	Treatment D: 1996-1997 (Slopes of site 4)	Kg/ha
Species	*Pennisetum clandestinum* sods	*Cenchrus ciliaris*	2	*Chloris gayana*	2	*Chloris gayana*	2
	Cortaderia jubata young plants	*Chloris gayana*	1	*Chloris virgata*	1	*Cynodon dactylon*	1
		Chloris virgata	1	*Cynodon dactylon*	2	*Digitaria eriantha*	2
		Cynodon dactylon	1	*Digitaria eriantha*	2	*Enneapogon cenchroides*	2
		Digitaria eriantha	2	*Enneapogon cenchroides*	2	*Eragrostis curvula*	3
		Enneapogon cenchroides	2	*Eragrostis chloromelas*	1	*Eragrostis echinochloidea*	1
		Eragrostis chloromelas	0.5	*Eragrostis curvula*	3	*Eragrostis lehmanniana*	2
		Eragrostis curvula	2	*Eragrostis echinochloidea*	1	*Eragrostis tef*	3
		Eragrostis echinochloidea	2	*Eragrostis lehmanniana*	1	*Panicum maximum*	1
		Eragrostis lehmanniana	0.5	*Eragrostis tef*	3	*Pogonarthria squarrosa*	1
		Eragrostis tef	2	*Hyparrhenia hirta*	1	*Themeda triandra*	2
		Fingerhuthia africana	2	*Themeda triandra*	1		
		Heteropogon contortus	0.5	*Cynodon dactylon* sods		*Pennisetum clandestinum* sods	
		Hyparrhenia hirta	2				
		Panicum maximum	1				
		Themeda triandra	0.5				
Topsoil	50 mm Topsoil (1995)	50 cm		10 cm		10 cm	
Fertilisation		Super Phosphate (10.5 %P)	250	Super Phosphate (10.5 %P)	250	Super Phosphate (10.5 %P)	250
		4:3:4 (30) Zn	200	4:3:4 (30) Zn	200	4:3:4 (30) Zn	200
		KAN	150	KAN	150	KAN	150

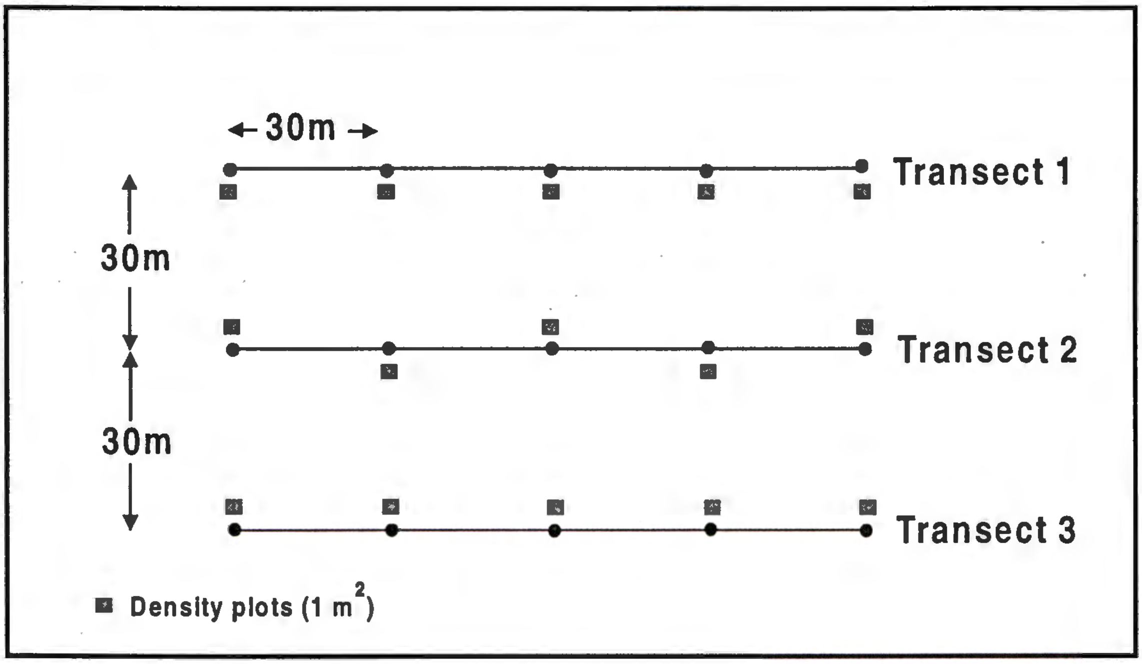

Figure 2.6: Experimental design of permanent survey grids used on ash disposal sites at Hendrina Power Station.

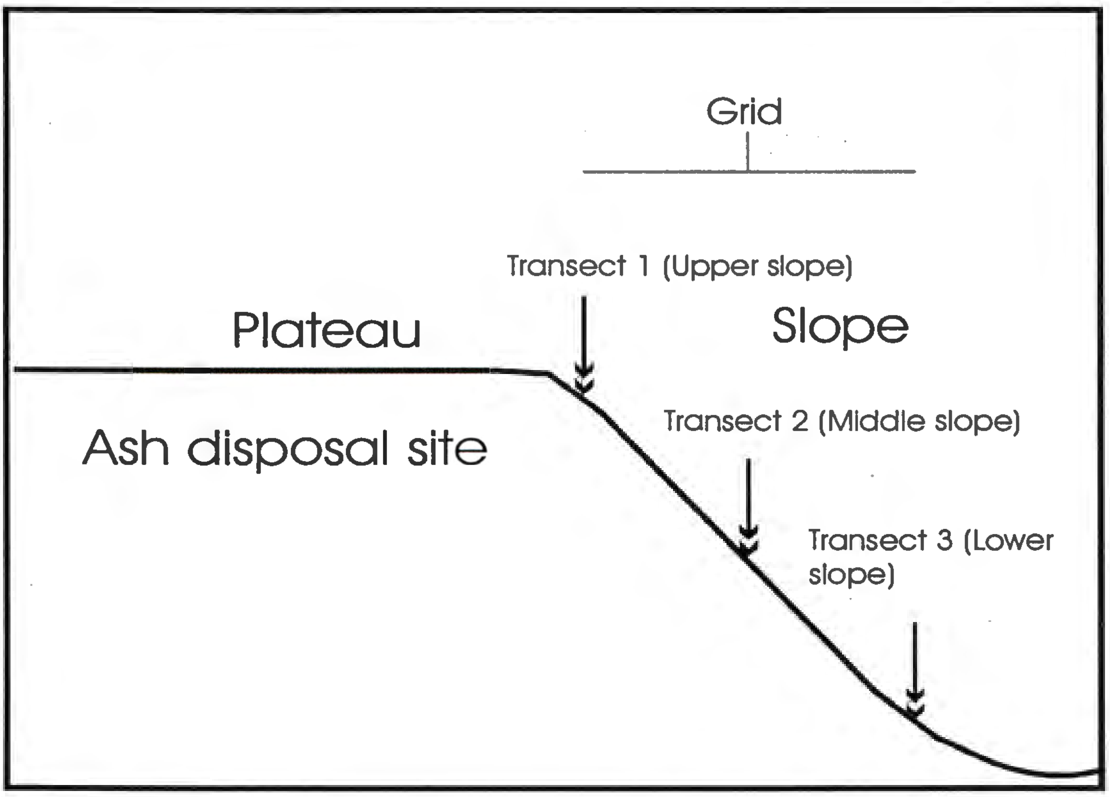

Figure 2.7: Section through a side of the ash disposal sites indicating the lay out of a grid on the slopes and the different topographical positions on ash disposal sites at Hendrina Power Station.

Table 2.3: Basal cover of species found during a survey conducted on ash disposal site 3 (rehabilitated during October 1990) during the summer of 1991 (Michael, 1991) on Hendrina Power Station

Species	% Basal cover
Eragrostis tef	3.6
Cyperaceae sp. (*Cyperus esculentus*)	1.4
Cynodon dactylon	1
Eragrostis curvula	0.8
Eleusine coracana subsp. *africana*	0.4
Enneapogon cenchroides	0.4
Hyparrhenia hirta	0.2
Chamaecrista biensis	0.2
Eragrostis echinochloidea	0.2
Chloris virgata	0.2
Total percentage basal cover	8.4
Total amount of observations	500

2.2.1 Design of permanent grids

Fourteen grids were originally set up, but because of limited survey time grids 5 and 6 were abandoned. The remaining 12 grids were distributed throughout the survey area (Figure 2.1). Ten permanent grids were randomly established on the ash disposal sites and 2 grids were constructed in a nearby natural grassland (Figure 2.5.1), which were used as reference points. Although this grassland is small in size and surrounded by rehabilitated open cast coal mines and maize fields, it was still the best representative example of natural grassland in the area. No indication existed that the veld was grazed although past grazing could have taken place because of the close proximity to informal farm settlements. According to mine personnel the veld is regularly burned every two to three years. During the survey period the natural grassland was burned once during 1999. Table 2.4 gives a summary of the position and habitat characteristics of the 14 grids surveyed. Each grid consists of three transects spaced 30 m apart (Figure 2.6). Five survey plots were also allocated 30 m apart along each transect (Figure 2.6). All quantitative surveys were performed in these permanent grids.

Table 2.4: Summary of the position and habitat characteristics of the fourteen survey grids on ash dams at Hendrina Power Station

Grid	Transect	Rehabilitation year	Age(1997)	Treatment	Location	Slope	Aspect	Fire frequency('96-'98)*
1	1	1995	2	A	Ash dam 1	Plateau	Plateau	2
1	2	1995	2	A	Ash dam 1	Plateau	Plateau	2
1	3	1995	2	A	Ash dam 1	Plateau	Plateau	2
2	1	1994	3	C	Ash dam 1	Upper slope	North	2
2	2	1994	3	C	Ash dam 1	Middle slope	North	2
2	3	1994	3	C	Ash dam 1	Lower slope	North	2
3	1	1994	3	C	Ash dam 1	Upper slope	Northwest	2
3	2	1994	3	C	Ash dam 1	Middle slope	Northwest	2
3	3	1994	3	C	Ash dam 1	Lower slope	Northwest	2
4	1	1994	3	C	Ash dam 1	Upper slope	East	2
4	2	1994	3	C	Ash dam 1	Middle slope	East	1
4	3	1994	3	C	Ash dam 1	Lower slope	East	1
7	1	not rehabilitated	0	none	Ash dam 4	Upper slope	West	0
7	2	1997	1	D	Ash dam 4	Middle slope	West	0
7	3	1992	5	C	Ash dam 4	Lower slope	West	0
8	1	not rehabilitated	0	none	Ash dam 4	Upper slope	South	0
8	2	1997	1	D	Ash dam 4	Middle slope	South	0
8	3	1992	5	C	Ash dam 4	Lower slope	South	0
9	1	1992	5	B	Ash dam 3	Upper slope	East	1
9	2	1992	5	B	Ash dam 3	Middle slope	East	1
9	3	1992	5	B	Ash dam 3	Lower slope	East	1
10	1	1991	6	B	Ash dam 3	Plateau	Plateau	2
10	2	1991	6	B	Ash dam 3	Plateau	Plateau	2
10	3	1991	6	B	Ash dam 3	Plateau	Plateau	2
11	1	1992	5	B	Ash dam 3	Plateau	Plateau	2
11	2	1992	5	B	Ash dam 3	Plateau	Plateau	2
11	3	1992	5	B	Ash dam 3	Plateau	Plateau	2
12	1	1990	/	B	Ash dam 3	Plateau	Plateau	1
12	2	1990	7	B	Ash dam 3	Plateau	Plateau	1
12	3	1990	7	B	Ash dam 3	Plateau	Plateau	1
K1	1	natural vegetation	/	/	natural vegetation	gentle	East	1
K1	2	natural vegetation	/	/	natural vegetation	gentle	East	1
K1	3	natural vegetation	/	/	natural vegetation	gentle	East	1
K2	1	natural vegetation	/	/	natural vegetation	gentle	East	1
K2	2	natural vegetation	/	/	natural vegetation	gentle	East	1
K2	3	natural vegetation	/	/	natural vegetation	gentle	East	1

* Fire history before survey period (1997-1999) uncertain

Additionally three 100m transects were conducted along road verges in the vicinity of the ash disposal sites, which will be used as benchmarks during construction of condition assessment models. The decision to do additional surveys along a road verge was because the natural grassland originally intended as a control or benchmark was found to be incomparable with the vegetation on the ash disposal sites (Morgenthal *et al.*, 1999).

The position and arrangement of the transects on the slopes were always used in the context as explained in Figure 2.7. The arrangement of the transects on the plateaus depended, however, on their location and did not have a fix orientation.

2.2.2 Botanical surveys conducted

2.2.2.1 The Braun-Blanquet method was used for the identification and classification of plant communities (Mueller-Dombois & Ellenberg, 1974 and Kent & Coker, 1994). A total of 115 relevés, subjectively selected in as many habitats as possible, characterising different homogenous areas, were sampled on ash disposal sites and a natural grassland.

2.2.2.2 Descending point surveys were conducted along approximately 120m transects with a rope marked with 1m intervals, as described by Brown (1954) and Mueller-Dombois & Ellenberg (1974) and adapted to be conducted along a transect. From these surveys the percentage frequency and basal cover were calculated. Descending point surveys were conducted at least every three months. The descending point survey of the January-March surveys was mostly used, but data from other seasons were also used to a lesser extent.

2.2.2.3 Density surveys were conducted annually. Plant densities of all rooted plants in $1m^2$ quadrats were counted at intervals of 30m. Five quadrats were counted along each transect. The plant densities of the five quadrats were summed to give a representative value over the total transect (Brown, 1954 and Mueller-Dombois & Ellenberg, 1974).

2.2.2.4 Biomass surveys were conducted annually from 1997 to 1999 during April/May of each year. All plants rooted in 0.25 m^2 quadrats, spaced at 30m intervals along each transect, were cut. The biomass was dried for 24 hours at approximately $65^{\circ}C$ and weighed.

The importance values of species were calculated by summation of the relative frequency, relative basal cover and relative density of each species (Goff & Cottam, 1967, Mueller-Dombois & Ellenberg, 1974). The calculation of importance values based these measurements has been widely used by earlier ecologists (Goff & Cottam, 1967). Goff & Cottam (1967) argued that, although importance values obscure some ecological information of species, it allows a more direct way of comparison of species proportions in a sample. Importance values therefore give a good summary of the biological influence of each species in a sample. Importance values were also successfully used recently by Skousen *et al.* (1994) to evaluate the natural revegetation of woodland communities on abandoned open coal mine sites.

Materials and methods will be discussed in detail in each chapter. Results from Chapters 5-8 are based on the importance values of species. The condition assessment model from Chapter 10 is based on frequency data. Taxa names conform to those of Arnold and De Wet (1993) and Retief and Herman (1997). Soil chemical and physical analyses were conducted on soil samples taken during 1997 with a soil auger at depths of 0-10cm and 10-20cm (see Chapter 8). The use of soil forms conform to those described by the Soil Classification Work Group (1991).

2.2.3 Data analysis of botanical data

2.2.3.1 Phytosociological data were analysed with the TWINSPAN algorithm (Hill, 1979a) and further refined with Braun-Blanquet procedures (Mueller-Dombois & Ellenberg, 1974 and Kent & Coker, 1994) with the BBPC-program (Bezuidenhout *et al.*, 1996). The DCA ordination technique (Hill, 1979b) was in a step-wise manner applied to data to indicate the relationship between communities. Species diversity was compared overall with one-way analysis of variance (one-way ANOVA) (Sokal & Rohlf, 1969) and variation between groups was tested with Tukey's test for equal (Sokal & Rohlf, 1969) and unequal populations sizes (Spjotvoll & Stoline, 1973). A Box-Cox transformation was applied to species richness data (Box & Cox, 1964) due to skewness (=1.567) in the data.

The following data analysis techniques were used to analyse quantitative data:

2.2.3.2 Multivariate analysis: Unweighted pair-group average cluster technique with square Euclidean distances (Gauch, 1982).
Indirect ordination: PCA (Gauch, 1982); DCA (Hill, 1979b).
Direct ordination: RDA, CCA (Ter Braak, 1987-1992).

2.2.3.3 Statistical analysis: Parametric: One way ANOVA (Sokal & Rohlf, 1969), Tukey's test for equal populations (Sokal & Rohlf, 1969); Tukey's test for unequal populations (Spjotvoll & Stoline, 1973); Newmans-Keuls test and t-test for independent variables (Sokal & Rohlf, 1969); for time series data a repeated measurement ANOVA was used.
Non-Parametric: The Kruskal Wallis median test and Mann Whitney U tests and Friedman's ANOVA for comparison of data between repeated measurements (Sokal & Rohlf, 1969).

2.2.3.4 Correlations — Pearson's Product moment and Spearman's rank correlations (Sokal & Rohlf, 1969); the Friedman's ANOVA was used for data analysis along a time series.

2.2.3.5 Indices used — Sørensens similarity coefficient; square Euclidean indices (Kent & Coker, 1994); Shannon diversity index (Magurran, 1988).

All parametric analyses assumed that data were normally distributed and were of homoscedasticity. The Kolmogorov-Smirnov test was performed to determine if data fitted the normal distribution (Sokal & Rohlf, 1969). The degree of homoscedasticity between groups was tested with the univariate tests of Cochran, Hartley and Bartlett (Winer, 1971). Results were considered statistically significant if $P \leq 0.05$, except where otherwise indicated. All tests related to analysis of variances and correlations were conducted with STATISTICA for Windows (1995). Sørensens similarity coefficients and Shannon diversity index values were calculated with the MVSP (MultiVariate Statistics Package) computer program (Kovach, 1983-1993).

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Chapter 3 A COMMUNITY ANALYSIS OF THE VEGETATION ON ASH DISPOSAL SITES*

Abstract: The aim of this phytosociological study is to determine the community structure of vegetation in the study area and to indicate how the communities are related based on their species composition.

A Braun-Blanquet survey and data analysis method is used to identify and classify vegetation communities on ash disposal sites and an adjacent natural grassland. Relevés were placed in 113 survey plots. The TWINSPAN classification algorithm is used as first approximation and the results are subsequently refined using Braun-Blanquet procedures. The DCA ordination technique is also used to determine the relationship between communities and whether gradients exist in the study area. The α-diversity between the communities is statistically compared using the Shannon diversity indices and species richness.

The natural grassland sites, rehabilitated ash disposal sites and unrehabilitated ash disposal sites form three separate communities. The two sub-communities that are described on rehabilitated ash disposal sites are distinguished mainly with respect to age of rehabilitation and level of disturbance. Community structure at a variant level, is largely determined by the different treatments (seed mixtures and soil amelioration) that were used in the rehabilitation of the ash disposal sites. Plant communities on recently rehabilitated sites are similar to plant communities on dumps of domestic refuse on some of the disposal sites. Based on the variants described, three homogenous areas on the old rehabilitated sites, which were rehabilitated more than three years ago, could be identified. Vegetation is relatively homogenous and variants are closely related. Differences in rehabilitation treatment, age of rehabilitation and man-made disturbances are some of the important factors determining the establishment of different communities on ash disposal sites. Significant statistical differences exist in the diversity at a community and variant level. Associations on the ash disposal areas are strongly based on the dominance of particular species rather than specific indicator species.

* Submitted for publication to the *South African Journal of Botany*

CONTENTS

3.1 INTRODUCTION

An important approach in plant ecological surveying is to classify the vegetation of an area into groups based on similar species composition. This reveals the community structure of the vegetation, which is important in ecological interpretation and hypothesis generation (Gauch, 1982). It will be a meaningful starting point to this study to give an account of the plant communities based on their floristic composition. It is believed that a phytosociological approach is a prerequisite for further descriptive and experimental studies of an area to identify homogenous areas and gives a basic account of the species composition of an area and how these species are associated with each other and the habitat they occupy.

Community based analysis was used by Skousen *et al.* (1994) to evaluate the natural vegetation change on abandoned mined land sites, while Palaniappan (1974) evaluated communities on tin mine tailings near Kuala Lumpur, West Malaysia, using a phytosociological approach. Usui & Suzuki (1973) also used a phytosociological approach to describe the ecology and problems associated with revegetated woodlands and grasslands on steep mountain slopes at a copper mine in Japan. In South Africa, Thatcher (1979) undertook a community-based study of vegetation, established on gold mine slime dams of the Witwatersrand, but the data was obtained quantitatively. Phytosociology was used extensively by Kooij *et al.* (1990), Bezuidenhout (1993), Coetzee *et al.* (1995) and various other researchers to describe and classify the vegetation of the Grassland Biome in South Africa. These studies form a sound basis for the sustainable management of natural grasslands in South Africa. Investigations of the vegetation of disturbed areas in the Grassland Biome should use the studies in natural areas as comparison. The phytosociological approach was also used to describe and classify ruderal, semi-natural and natural vegetation of urban areas in two cities in the North Western Province, (Van Wyk *et al.* 1997, Cilliers & Bredenkamp 1999a and Cilliers & Bredenkamp 1999b).

It is the aim of this chapter to identify, classify and describe the plant communities occurring on parts of the ash disposal sites and surrounding natural grassland, and to correlate communities qualitatively to habitat variables. This approach could therefore give important answers to the community development after the initial rehabilitation effort. The phytosociological approach will also give a different dimension to the evaluation of the survey area because this approach is based on the total floristic composition. A more detailed floristic description of communities and rehabilitation stages will therefore be obtained.

3.2 MATERIALS AND METHODS

The phytosociological study of ash disposal areas at the Hendrina Power Station was conducted on three occasions, during December 1996 (35 sample plots; 4x4 m), March 1997 (30 sample plots 10x10m) and March 1998 (48 sample plots; 4x4m). The phytosociological study was conducted according to the Braun-Blanquet method (Mueller-Dombois & Ellenberg, 1974 and Kent & Coker, 1994). In total, 113 relevés distributed through space and time were sampled. Although special emphasis was given to the plant communities in the permanent grids (Chapter 2, Table 2.4) a number of relevés were placed outside the permanent grids to give a broader description of communities. Relevés conducted within the sampling grids were not fixed but were randomly distributed within the grid. The location and survey-year of each relevé is indicated in the phytosociological table (Table 3.1). During the initial survey in December 1996 relevés were only sampled in grids 1, 4, 10 12 and the natural grassland, as well as a number of locations outside the permanent grids. During 1997 and 1998 a minimum of 2 relevés per grid were sampled during each survey on grids 1-12 and the natural grassland.

The TWINSPAN classification algorithm (Hill, 1979a) was used to analyse phytosociological data, as a first approximation. The TWINSPAN classification was refined further by application of Braun-Blanquet procedures (Mueller-Dombois & Ellenberg, 1974 and Kent & Coker, 1994) by means of the BBPC-program (Bezuidenhout *et al.,* 1996). The final results are presented in a phytosociological table (Table 3.1). Species with a low constancy and occurrence are listed in Table 3.2. Plant associations were informally named by using the most prominent indicator and dominant species as names for associations.

The DCA ordination algorithm (Hill, 1979b) was also applied to data to illustrate possible floristic relationships between communities, and to detect possible habitat or disturbance gradients associated with vegetation gradients. Because of the heterogeneity of the data set, a stepwise ordination approach was conducted on the data according to Mucina & Van Tongeren (1989). Four ordination steps were conducted on the data to clarify community structure, community-habitat relationships and to reduce the heterogeneity of the data set. No down-weighting of rare species was attempted. Axes were rescaled four times according to the default in the CANOCO

3.11 computer package (Ter Braak, 1987-1992). Scatter diagrams were redrawn from the solution file obtained from the CANOCO program. Rescaling attempts to equalise the breadth of species response curves along the axes by equalising the within-sample variances of the species (Ter Braak, 1987-1992). Taxon names conform to those in Arnold & De Wet (1993).

Midpoint values of the Braun-Blanquet cover-abundance classes (Mueller-Dombois & Ellenberg, 1974) were used to analyse α-diversity according to the species richness and Shannon diversity indices (Kent & Coker, 1994) of the different communities (Table 3.3). Shannon index values and evenness were calculated with the Multivariate Statistics Package (MVSP) computer program (Kovach, 1993) using a Ln conversion. Average species richness and Shannon Diversity Indices were statistically compared with the t-test for independent variables and ANOVA as well as with Tukey's test (Spjotvoll & Stoline, 1973) for unequal populations at community, sub-community and variant level with the STATISTICA for Windows (1995) package. A Box-Cox transformation was applied to species richness data (Box & Cox, 1964) due to skewness (=1.567) in the data. The transformation procedure calculated lambda (λ) values with which data can be transformed according to the equation:

$$Y=(x^{\lambda}-1)/\lambda*H^{(\lambda-1)}$$

Y= transformed value

X= untransformed value

H= geometric mean

λ= lamda

The statistical significance of data was accepted at a p-value$\leq$ 0.05.

3.3 RESULTS

The vegetation of the study area is classified into three communities, two sub-communities, six variants and two sub-variants (Table 3.1).

1 *Brachiaria serrata-Setaria sphacelata* Community

2 *Eragrostis curvula-Cynodon dactylon* Community

2.1 *Hyparrhenia hirta-Eragrostis curvula* Sub-community

2.1.1 *Chamaecrista biensis* Variant

2.1.2 *Lespedeza cuneata-Hyparrhenia hirta Variant*

2.1.2.1 *Stylosanthes fruticosa-Cynodon dactylon* Sub-variant

2.1.2.2 *Acacia mearnsii* Sub-variant

2.1.3 *Lepidium bonariense-Eragrostis trichophora* Variant

2.2 *Amaranthus hybridus-Cyperus esculentus* Sub-community

2.2.1 *Portulaca oleracea-Bidens formosa* Variant

2.2.2 *Panicum maximum-Digitaria eriantha* Variant

2.2.3 *Eragrostis tef-Enneapogon cenchroides* Variant

3 *Spergularia media* Community

Table 3.1: The phytosociological table of plant communities at ash disposal sites at Hendrina Power Station

RELEVÉ NUMBER	28	29	61	84	62	82	83	1	5	6	8	9	10	94	96	12	13	14	15	16	60	88	89	90	91	92	93	44	45	104	99	100	47	98	35	25	111	49	102	103	107	56	57	95	55	58	59
GRID	C	C	C	C	C	C	C	10	10	10	10	10	10	10	10	12	12	12	12	12	12	12	12	12	11	11	11	5	5	5	6	6	6	6	D3S	D1S	73	73	9	5	83	10	10	10	11	11	12
Survey year	96	96	97	98	97	98	98	96	96	96	96	96	96	98	98	96	96	96	96	96	97	98	98	98	98	98	98	97	97	98	98	98	97	98	96	96	98	97	98	98	98	97	97	98	97	97	97
Community	1							2																																							
Sub-community								2.1																																							
Variant								2.1.1																																							
Sub-variant																																															
SPECIES GROUP A																																															
Brachiaria serrata	A	A	1	+		A	+																																								
*Heteropogon contortus**	A	A	3	1		1	B																							1	+	+															
Tristachya leucothrix		1	A	1		B	B																																								
Setaria sphacelata var. *torta*			A	4	+	1	1																																								
Vernonia oligocephala	1	1	1	A	1		1																																								
Hermannia transvaalensis	+	A	+	R	+																								+																		
Berkheya setifera	A	+	+	1																																											
Acalypha angustata var. *glabra*	1		+	1		1	+																																								
Elionurus muticus	1	3				+	+																																								
Acrotome hispidum	1			R		+																																									
Anthericum spp.	1	+				+	+																																								
Eragrostis racemosa	+		+			1	+																																								
Pentanisia angustifolia	+	1				+	+																																								
Senecio affinis		+		+			+																																								
Setaria nigrirostris	1	1		A																																											
Trachypogon spicatus			1		+		+																																								
Blepharis inocua			+	+			+																																								
Microchloa caffra				1		1	1																																								
Anthospermum rigidum subsp. *pumilum*		+					+																																								
Walafrida densiflora			+		+																			R					+																		
Lobelia flaccida subsp. *flaccida*					R		1																																								
SPECIES GROUP B																																															
Stylosanthes fruticosa																																															
Rhynchosia sp.																																															
Cleome monophyla										+																									R			+									
Bidens bipinnata#																												R	+														+			+	
Vigna vexillata	+							1				R		+																							+										
Oxalis spp.	+																	R			+	R								+								+					+				+
*Pogonarthria squarrosa**															+																													+	+		
Setaria pallide-fusca																													1																	+	R
Hyparrhenia tamba																																						R									
Imperata cylindrica																																															
SPECIESGROUP C																																															
Acacia mearnsii#																												+	+																		
SPECIES GROUP D																																															
Lespedeza cuneata#																																															
*Chloris gayana#**																															+	+	1		+	A											
Eragrostis plana						+	+							+																	R		+				R		R							+	
SPECIES GROUP E																																															
Lepidium bonariensis#																														+									+								
Acanthospermum glabrum																																															
Hypochoeris radicata#																																															
Verbena bonariensis#			+								1																											1			1						

RELEVÉ NUMBER	30	31	34	101	32	38	39	69	71	70	40	41	75	76	43	78	79	80	46	65	53	86	74	54	85	52	87	108	113	114	115	24	42	81	27	72	105
GRID	D3S	D3S	D3S	D3S	D1P	2	2	2	2	2	3	3	3	3	4	4	4	4	6		9	9	9	9	9	9	9	72	72	72	72	4	4	4	D1S	D1S	D1S
Survey year	96	96	96	98	96	97	97	97	98	98	97	97	98	98	97	98	98	98	97	97	97	98	98	98	98	97	98	98	98	98	98	96	97	98	96	98	98
Community																																					
Sub-community																																					
Variant	2.1.2																																				
Sub-variant	2.1.2.1																															2.1.2.2					
SPECIES GROUP A																																					
Brachiaria serrata																																					
*Heteropogon contortus**				R						+									+		+						R										
Tristachya leucothrix																																					
Setaria sphacelata var. *torta*																																					
Vernonia oligocephala																																					
Hermannia transvaalensis																																					
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Anthospermum rigidum subsp. *pumilum*																																					
Walafrida densiflora																																					
Lobelia flaccida subsp. *flaccida*																																					
SPECIES GROUP B																																					
Stylosanthes fruticosa	1			R					1		+	+	1	1								+				+							+				
Rhynchosia sp.		3			+							A			+						1		A				A										
Cleome monophyla	+		1								+	+								R	+								R	+	+						
Bidens bipinnata#	1		+		+						+	1	1	+						+		+	R			1	+						+				
Vigna vexillata	R	+									1	1	R							R	+			1		+	+										
Oxalis spp.					+						+	+	R								R			R		+		R	R	R	R	R					+
*Pogonarthria squarrosa**		R						+												+	+					+	+	R		A	+						
Setaria pallide-fusca						R														1	+	+			+		+		+		+						
Hyparrhenia tamba				+		+	4	1				+																									
Imperata cylindrica						1			1			+																								+	
SPECIESGROUP C																																					
Acacia mearnsii#																												+				1	B	4	1	3	1
SPECIES GROUP D																																					
Lespedeza cuneata#	1	1	R	+	1	+	1	+	A	+	A	A	R	1	1	B	A	A			A	+	1	R								B	1	+	B	1	3
*Chloris gayana#**	+	1			1	A			A		A	1	1	A	R				A									+	+	A	+		+			1	+
Eragrostis plana								1		+	+	+			1	+			+	A			+										A			+	
SPECIES GROUP E																																					
Lepidium bonariensis#				+										+								+			R		R										
Acanthospermum glabrum																																					
Hypochoeris radicata#																												+									
Verbena bonariensis#																									+										R		

RELEVÉ NUMBER	17	18	19	20	21	22	23	36	37	66	67	68	33	2	3	4	7	11	97	26	106	48	50	51	109	63	64	110	112
GRID	1	1	1	1	1	1	1	1	1	1	1	1	D3S	R	R	R	R	R	R	Dryn	Dryn	73	82	82	82	ONG	ONG	ONG	ONG
Survey year	96	96	96	96	96	96	96	97	97	98	98	98	96	96	96	96	96	96	98	96	98	97	97	97	98	97	97	98	98
Community																										3			
Sub-community														2.2															
Variant	2.1.3													2.2.1						2		2.2.3							
Sub-variant																				2.2.2									
SPECIES GROUP A																													
Brachiaria serrata																													
*Heteropogon contortus**																													
Tristachya leucothrix																													
Setaria sphacelata var. *torta*																													
Vernonia oligocephala																													
Hermannia transvaalensis			R		R																								
Berkheya setifera																													
Acalypha angustata var. *glabra*																													
Elionurus muticus																													
Acrotome hispidum																													
Anthericum spp.																													
Eragrostis racemosa																													
Pentanisia angustifolia																													
Senecio affinis																													
Setaria nigrirostris																													
Trachypogon spicatus																													
Blepharis inocua																													
Microchloa caffra																													
Anthospermum rigidum subsp. *pumilum*																													
Walafrida densiflora											R																		
Lobelia flaccida subsp. *flaccida*																													
SPECIES GROUP B																													
Stylosanthes fruticosa																													
Rhynchosia sp.	+																												
Cleome monophyla																				R		+	+	+					
Bidens bipinnata#																	A		R		+								
Vigna vexillata					+																			+					
Oxalis spp.									R						+	+						+	+	+					
*Pogonarthria squarrosa**																									+				
Setaria pallide-fusca																					+			1					
Hyparrhenia tamba																													
Imperata cylindrica																													
SPECIESGROUP C																													
Acacia mearnsii#																									+				
SPECIES GROUP D																													
Lespedeza cuneata#																													
*Chloris gayana#**																					R				R				
Eragrostis plana									+			+																	
SPECIES GROUP E																													
Lepidium bonariensis#	+	A	+	+		+	+	1	R		+																		R
Acanthospermum glabrum		+		+				1	+		+	R																	
Hypochoeris radicata#				R			R			+	+		+																
Verbena bonariensis#	+	+	+				R																						

Table 3.1 (continue)

RELEVÉ NUMBER	228 289 614 842 682 283 1 5 6 8 19 99 10 14 16 12 13 14 15 16 60 88 89 90 91 92 93 94 45 14 109 90 47 98 35 25 11 149 102 103 57 56 97 55 58 59 30 31 34 31 32 38 39 69 71 70 40 41 75 76 43 78 79 80 86 45 56 53 86 74 54 85 72 57 88 53 18 04 11 13 14 25 44 82 21 77 12 05 17 18 19 20 21 22 23 36 37 66 67 68 33 2 3 4 7 11 97 126 06 48 50 51 09 63 64 10 12
GRID	C C C C C C C 0 0 0 … 2 2 … 1 1 1 5 5 5 6 6 6 6 D3S D1S 7 3 7 3 9 5 8 3 1 0 … D3S D3S … S P 2 2 2 2 3 3 3 3 4 4 4 4 6 9 9 9 9 9 9 9 7 2 7 2 … 4 4 4 D1S D1S D1S 1 1 1 1 1 1 1 1 1 1 1 D3S R R R R R R Dyn Dyn 7 3 8 2 8 2 8 2 ON G ON G ON G ON G
Community	1 — 2 — 3
Sub-community	2.1 — 2.2
Variant	2.1.1 — 2.1.2 — 2.1.3 — 2.2.1 — 2 — 2.2.3
Sub-variant	2.1.2.1 — 2.1.2.2 — 2.2.2
SPECIES GROUP F	
Portulaca oleracea	1 1 1 +
Bidens pilosa#	+ + R + + 1 1
Iris sp.#	+ 1 + 1
Ipomoea purpurea#	R + +
Mirabilis jalapa#	+ +
SPECIES GROUP G	
*Panicum maximum**	1 + B A
SPECIES GROUP H	
*Eragrostis tef#**	B 3 A +
*Enneapogon cenchroides**	R R + + R + B A 1 +
Zea mays#	1 1 +
Eleusine coracana subsp. africana	1 1 +
SPECIES GROUP I	
Amaranthus hybridus#	+ R + + 1 1 + + 1 + A A +
Chenopodium album#	+ R + R + R + R 1 + + + + + 1 R R + R
SPECIES GROUP J	
*Pennisetum clandestinum#**	1 1 1 A A 1 1 A A B 1 A 1 A A 1 A A B A A 3 B + A B 1 5 A 3 3 3 3 1 B 3 A 3 A 3 1 4 A 1 + A
Asclepias fruticosa	+ + + + + + + R + + + + R 1 +
SPECIES GROUP K	
*Hyparrhenia hirta**	+ A 1 A A 3 B + A 3 A + B 3 A + + + A A 1 1 1 B 4 + A A A B B B + A A 4 3 3 3 3 4 B 3 1 A 1 A 1 B A B A B B 3 B B B A B R R + B A 3 3 B + + A + A 1 A + + R 1 R +
*Eragrostis chloromelas**	+ B R 1 + + A + 1 1 1 B + 1 + A B + + + + 3 + + + + 1 R A 1 3 1 R B 1 B 3 1 1 B 1 + + + + +
Aristida congesta subsp. congesta	R + + + 1 + + + + + + R R 1 1 1 + + + 1 1 R 1 1 1 + + + +
Eragrostis trichophora	+ + + + A B 1 + 1 1 1 + 1 + 3 + + A 1 + 1 + B 1 A A A A A 1 + 1 1 1 + B B B B 1 1 1 1
Pelargonium luridum	1 + + R R + + + R + R R + R + R R R +
Conyza canadensis#	+ 1 + R R + R R
SPECIES GROUP L	
*Eragrostis curvula**	3 1 3 + 3 4 A 3 3 4 3 4 4 B 4 4 3 1 A B A A A 1 + A 1 3 3 + B A B 4 A B 3 1 A B 3 A 1 A B 1 1 B A B B B B A 3 4 B B B 3 A 1 A A A A A A A 1 A 4 3 3 3 1 R A B 1 A A A 1 B B A + + + 1 + 1 A
*Cynodon dactylon**	1 1 A 1 A B 1 + + R + + 1 1 + + 1 1 + 1 B B B B A 3 B B 1 + 1 A 1 A 1 1 1 + A + A 1 + 3 1 1 A 1 A A + + A + 1 B 1 + 1 1 1 1 1 + 1 A 1 A 1 1 + + 1 1 1 1 3 A 1 1 1 1 1 4 4 B 3 4 A + 1 + +
Cyperus esculentus	1 + + 1 1 + + + 1 1 1 1 1 + + + + A 1 + + 1 + + A + 1 + 1 1 + + 1 + + + 1 R + 1 1 1 1 1 1 1 + + 1 + + + 1 1 1 + 1 1 + + A 1 1 1 + 1 1 + + + + + 1 1 1 + R 1 + A 4 B + 1 4 + A 3 3 3
Chamaecrista biensis	+ B A 1 + + 1 A A A 3 1 1 A B B B B 1 1 3 A 3 B 4 B A 3 + 1 + A 3 + B B A A 1 1 1 + + 1 1 1 + 1 1 + 1 A 1 R A + 3 1 3 A + 1 1 + 3 + 1 + R + + + + + 1 A A B 3 + + + + + +
Tagetes minuta#	+ 1 R + 1 1 1 + + A A 1 + + 1 + A + + 1 1 1 + R A R + + 1 1 A 1 1 + + + R A + + 1 1 1 + 1 + + + 1 B 3 B + B 1 1 R 1 1 1 A
*Digitaria eriantha**	+ + A B + + + + + 1 1 R 1 1 1 + + 1 + + + 1 + + + R + + 1 A + R + + 1 1 R + + A A
Bidens formosa#	+ + + + R + + + + 1 + + + + R R + + + 1 1 1 A + 4 A
Commelina africana	+ R + 1 R + R + + + R +
Commelina benghalensis#	+ + + 1 + 1 A 1 +
SPECIES GROUP M	
Conyza bonariensis#	+ A A 1 + + 1 + + + + + R R 1 A A + A 1 A R + + + + R + + + + R 1 + R + + + + + 1 + + + 1 + 1 R + 1 + A + A A + 1 1 1 + A 1
Pseudognaphalium undulatum	+ 1 R A 1 1 R + 1 + + R R + + + R R R + 1 R R + 1 + + R + 1 +
*Themeda triandra**	4 3 3 + + + + + + R + R 3 R + + R R + +
Schkuhria pinnata#	R R + R 1 + + + 1 + + R + + 1 + + + + + + 1 A + R 1 R R + +
SPECIES GROUP O	
Spergularia media#	1 1 A 1

Table 3.2 :Species with no significant or low occurrence in communities at ash disposal sites at Hendrina Power Station

Species	Relevè numbers and awarded cover-abundance values								
Urochloa mosambisensis	58(+)	30(R)	52(+)	113(R)	18(+)	109(R)	51(1)	7(1)	11(+)
Paspalum dilatatum	35(+)	30(+)	31(+)	114(R)	18(+)	17(+)	22(+)	2(R)	
Cirsium vulgare#	44(+)	45(+)	107(+)	114(R)	33(+)	108(+)	109(+)		
Tephrosia polystachya	94(+)	55(+)	56(+)	52(+)	67(+)	90(R)	78(A)		
Senecio consanguineus	45(+)	107(R)	85(1)	87(1)	31(+)	109(R)			
Sporobolus africana	83(+)	47(+)	102(+)	46(1)	78(+)	115(+)			
Sonchus oleraceus#	49(+)	17(R)	33(+)	108(+)	26(+)	109(+)			
Senecio harvelanus	102(+)	103(R)	20(+)	21(R)	22(R)	33(+)			
Datura stramonium#	15(+)	16(+)	22(R)	62(+)	50(+)	51(+)			
Walafrida densiflora	61(+)	62(+)	45(+)	98(R)	67(R)				
*Eragrostis echinochloidea**	15(+)	57(+)	56(1)	56(A)	114(+)				
Bromus catharticus#	45(R)	103(+)	54(+)	85(+)	11(+)				
Hibiscus trionum	38(R)	65(R)	65(R)	105(R)	26(+)				
Oenothera rosea#	35(R)	30(R)	32(+)	20(+)	8(R)				
Melinis repens	55(+)	34(+)	101(R)	36(+)	68(+)				
Cyperus usitatus var. *usitatus*	92(+)	93(+)	34(1)	22(+)					
Zornea milneana	28(+)	82(+)	83(+)	21(+)					
Corchorus confusus	32(1)	34(1)	87(R)	27(+)					
Pseudognaphalium luteo-album	102(+)	103(R)	107(+)	104(+)					
Oenothera tetraptera#	15(+)	8(R)	17(+)						
Pelargonium minimum	16(+)	18(+)	22(+)						
Agrostis erlantha	45(+)	47(+)	49(+)						
Sida sp	29(+)	22(+)	48(+)						
Tamarix sp#	44(+)	46(R)	54(+)						
Gomphrena celosioides#	98(+)	22(R)	23(1)						
Panicum coloratum	49(R)	109(+)							
Guilleminea densa#	92(1)	2(+)							
Helichrysum rugulosum	84(+)	83(+)							
Indigofera filipes	57(R)	2(A)							
Conyza podocephala	62(+)	6(+)							
Tephrosia capensis	84(+)	82(+)							
Becium obovatum	29(B)	62(1)							
Cymbopogon sp	103(+)	46(+)							
Diheteropogon amplectans	82(A)								
Argyrolobium lotoides	29(1)								
*Rhus lancea**	111(1)								
Gladiolus sp#	3(+)								
*Chloris virgata**	51(+)								
Cleome monophyla	45(+)								
Crinum bulbispermum	4(+)								
Eragrostis barbinodis	29(+)								
Eragrostis capensis	28(+)								
Euphorbia clavarioides var. truncata	82(+)								
Euphorbia striata var. striata	29(+)								
Helichrysum nudifolium	83(+)								
Gnidia caffra	83(+)								
Felicia muricata	29(+)								
Gerbera galpinii	26(+)								
Indigofera torulosa	34(+)								
Hermannia depressa	28(+)								
Ipomoea crassipes	29(+)								
Ipomoea ommaneyi	82(+)								
Kohautia amatymbica	83(+)								
Nidorella anomala	45(+)								
Pearsonia cajanifolia	82(+)								
Peucedanus magalismontanum	29(+)								
Plantago virginica#	83(+)								
Pollichia campestris	82(+)								
Digitaria tricholaenoides	83(+)								
Stoebe vulgaris	28(+)								
Striga bilabiata	29(+)								
Taraxacum officinale#	102(+)								
Tragopogon dubius#	22(+)								
Epilobium salignum#	107(R)								
Portulaca kermesina	3(R)								
Ziziphus zeyheriana	61(R)								
Hibiscus microcarpus	61(R)								
Dicoma anomala	61(R)								
Oenothera indecora#	20(R)								
Melilotis alba#	58(R)								
Digitaria ternata	87(R)								
Scabiosa columbaria	36(R)								
Solanum nigrum#	21(R)								
Hibiscus aethiopicus	61(R)								

Abbreviations used in Tables 3.1 and 3.2

C: Natural grassland used as control

Only a number: grid number as indicated in Table 2.4 (Chapter 2)

D followed with a number: Disposal area as indicated in Figure 2.1 (Chapter 2)

S: Slope

P: Plateau

72 or 82 indicate the middle transect of grid 7 or 8

R: Ruderal vegetation on domestic dumps

Dryn: Drainage channel

ONG Unrehabilitated area

exotic

* Used in a seed mixture

Table 3.3: Midpoint values used to calculate α-diversity (Mueller-Dombois & Ellenberg, 1974).

Braun-Blanquet scale	Range of cover %	Midpoint values
5	75-100	0.875
4	50-75	0.625
3	50-25	0.375
2B	25-12.5	0.1875
2A	5-12.5	0.0875
1	1-5	0.025
+	<1	0.005
r	<<1	0

3.3.1 Description of communities

1 *Brachiaria serrata-Setaria sphacelata* Community

The *Brachiaria serrata-Setaria sphacelata* Community is characterised by Species Group A (Table 3.1) and represents an adjacent natural grassland, which was the type of vegetation that previously occurred on the area where the ash disposal areas are situated. Diagnostic species that represent this community are the grasses *Brachiaria serrata, Setaria sphacelata* var. *torta, Tristachya leucothrix* and *Elionurus muticus.* The community is also represented by a rich variety of forbs of which the most dominant species include *Vernonia oligocephala, Hermannia transvaalensis, Acrotome hispida and Pentanisia angustifolia.* The grass *Heteropogon contortus* is also a common species in this community. The *Brachiaria serrata-Setaria sphacelata*

Community shows little resemblance to plant communities on the ash disposal areas and Species Group M (Table 3.1) includes the only species occurring in both areas.

The habitats of the *Brachiaria serrata-Setaria sphacelata* Community can be described as a gentle east-facing ridge. The soil is shallow (< 500mm) to non-existent. The clay content of the soil is 18 % (average). The natural grassland is fenced and no indication that the grassland is utilised for grazing could be seen during the study. Veld fires occur occasionally (approximately every 2 years) in the area. During the study period the area was burned in the winter months of 1998 and 1999.

The *Brachiaria serrata-Setaria sphacelata* Community can be related to the *Themeda triandra-Setaria sphacelata* Grassland described by Coetzee *et al.* (1995) for the Ba and Ib land types of the Pretoria- Witbank- Heidelberg area. Both communities also occur on shallow (< 500mm deep) loam soils (clay = 15-20%).

2 *Eragrostis curvula-Cynodon dactylon* Community

The *Eragrostis curvula-Cynodon dactylon* Community is characterised by Species Group L (Table 3.1). Diagnostic species include the grasses *Eragrostis curvula* and *Cynodon dactylon* (of which both are prominent throughout the community) and the forbs *Cyperus esculentus and Chamaecrista biensis.*

The *Eragrostis curvula-Cynodon dactylon* Community occurs on all rehabilitated ash disposal sites in the study area. Most of the qualitative floristic studies on the ash disposal sites were conducted in this community. Two sub-communities, six variants and two sub-variants could be recognised in this community.

2.1 *Hyparrhenia hirta-Eragrostis curvula* Sub-community

The *Hyparrhenia hirta-Eragrostis curvula* Sub-community is characterised by the species from Species Group K (Table 3.1). The abundant occurrence of *Hyparrhenia hirta* is characteristic for this sub-community. In most cases *Eragrostis curvula* (Species Group L, Table 3.1) occurs as the dominant grass species, together with *Hyparrhenia hirta.*

The habitat of this sub-community includes rehabilitated areas older than one year, together with areas with low anthropogenic disturbances.

Three variants were identified in this sub-community of the *Eragrostis curvula-Cynodon dactylon* Community.

2.1.1 *Chamaecrista biensis* Variant

No diagnostic species can be allocated to this variant but the absence of species in Species Groups B, C, D (Table 3.1) and the grass *Pennisetum clandestinum* (Species Group J, Table 3.1) characterise the *Chamaecrista biensis* Variant. The dominant species include the grasses *Eragrostis chloromelas* and *Hyparrhenia hirta* (Species Group K, Table 3.1), *Cynodon dactylon*, *Eragrostis curvula* and the forb *Chamaecrista biensis* (Species Group L, Table 3.1).

The variant can be found primarily on the plateau of ash disposal site 3 (Chapter 2, Figure 2.1), which was rehabilitated during 1990 and 1991. A list of species used for rehabilitation on the plateau of ash disposal site 3 is given in Table 2.2 (Chapter 2). The *Chamaecrista biensis* Variant, however, also occurs on some of the slopes, especially the southern slope of ash disposal site 1 (Chapter 2, Figure 2.1) and the northern slopes of ash disposal site 3 (Chapter 2, Figure 2.1). The small mammal, *Tatera brantsii* also has a high occurrence in the area of the *Chamaecrista biensis* Variant. It's burrowing activities has lead to considerable mixing of the topsoil with the ash.

2.1.2 *Lespedeza cuneata-Hyparrhenia hirta* Variant

Species Group D (Table 3.1) characterises this variant. The shrub *Lespedeza cuneata* and the grasses *Chloris gayana* and *Eragrostis plana* are the diagnostic species for the *Lespedeza cuneata-Hyparrhenia hirta* Variant. Dominant grasses include *Hyparrhenia hirta* (Species Group K, Table 3.1), *Eragrostis curvula* (Species Group L, Table 3.1) and *Pennisetum clandestinum* (Species Group J, Table 3.1).

The *Lespedeza cuneata-Hyparrhenia hirta* Variant is associated with most of the slopes rehabilitated during 1992 and 1994. One of the major differences between the treatment associated with the *Chamaecrista biensis* Variant and this variant was that in this case *Cynodon dactylon* and *Pennisetum clandestinum* sods were established at 4m intervals to stabilise the slopes (Chapter 2, Figure 2.4).

Of major interest is the occurrence of the legume *Lespedeza cuneata* in this variant. *Lespedeza cuneata* is an exotic species which is recommended for rehabilitation on acidic to neutral soils in a warm climate (Bradshaw & Chadwick, 1980). Kalburtji & Mosjidis (1992) investigated the effect of *Lespedeza cuneata* on the growth of warm season grasses. It was found that *Lespedeza* residues had a slight inhibiting effect on *Cynodon dactylon* (Bermuda grass) growth.

Two sub-variants can be distinguished based on vegetation structure.

2.1.2.1 *Stylosanthes fruticosa-Cynodon dactylon* Sub-variant

This sub-variant is the grassland variation of the *Lespedeza cuneata-Hyparrhenia hirta* Variant and is characterised by Species Group B (Table 3.1). The *Stylosanthes fruticosa-Cynodon dactylon* Sub-variant is especially rich in herbaceous legumes, like *Stylosanthes fruticosa, Vigna vexillata* and *Rhynchosia* sp., which are mainly diagnostic for this sub-variant. Other diagnostic species include the annual *forbs Cleome monophylla* and *Bidens bipinnata,* and the grasses *Pogonarthria squarrosa, Setaria pallide-fusca* and to a lesser extent *Hyparrhenia tamba* and *Imperata cylindrica.*

2.1.2.2 *Acacia mearnsii* Sub-variant

The second sub-variant of the *Lespedeza cuneata-Hyparrhenia hirta* Variant is a low semi-open woodland of which the exotic tree *Acacia mearnsii* (Species Group C, Table 3.1) is the only diagnostic species. The dominant grasses are *Eragrostis curvula* (Species Group L, Table 3.1) and *Hyparrhenia hirta* (Species Group K, Table 3.1). *Cynodon dactylon* (Species Group L, Table 3.1) also has lower cover-abundance values in the *Acacia mearnsii* Sub-variant than in the *Stylosanthes fruticosa-Cynodon dactylon* Sub-variant.

Although *Acacia mearnsii* is a serious invader species in South Africa (Henderson, 1995), it is believed that the *Acacia mearnsii* Sub-variant made a great contribution to the diversification of the ash disposal sites. If this sub-variant is conserved on the ash disposal areas, the exclusion of fire is important due to the weak fire persistency of *Acacia mearnsii.*

This sub-variant probably originated from the presence of *Acacia mearnsii* seed in the topsoil that was used in the rehabilitation process.

2.1.3 *Lepidium bonariense-Eragrostis trichophora* Variant

Species Group E (Table 3.1) characterises the *Lepidium bonariense-Eragrostis trichophora* Variant which include the forbs *Lepidium bonariense, Acanthospermum glabratum, Hypochaeris radicata* and *Verbena bonariensis.* One of the most conspicuous features of this variant is the dominant occurrence of *Pennisetum clandestinum* (Species Group J, Table 3.1) and the lower cover-abundance of the grass *Hyparrhenia hirta* (Species Group K, Table 3.1). *Digitaria eriantha* (Species group L, Table 3.1) is also absent in the *Lepidium bonariense-Eragrostis trichophora* Variant. Other dominant species are the annual forbs *Conyza bonariensis* (Species Group M, Table 3.1) and *Tagetes minuta* (Species Group L, Table 3.1).

The habitat of this variant is similar to the habitat of the *Chamaecrista biensis* Variant. The most important factor contributing to the difference between the two variants is the type of treatment followed during the rehabilitation process. The *Lepidium bonariense-Eragrostis trichophora*

Variant was not revegetated with a seed mixture like the *Chamaecrista biensis* Variant, but was planted with *Pennisetum clandestinum* and *Cortaderia jubata* during 1980's. During 1995 the *Cortaderia*-plants were removed due to the health risk it imposes on people (M.D. Michael, pers. com.)[1] and a layer of topsoil was added consisting of a large amount of concretions (gravel).

2.2 *Amaranthus hybridus-Cyperus esculentus* Sub-community

The *Amaranthus hybridus-Cyperus esculentus* Sub-community is characterised by Species Group I (Table 3.1) and the absence or low constancy of species in Species Groups K and M (Table 3.1) in this sub-community. The annual forbs, *Amaranthus hybridus* and *Chenopodium album* are diagnostic for this sub-community. This sub-community can be described as a ruderal vegetation type, which is characterised by the dominance of the forbs *Cyperus esculentus* and *Tagetes minuta* (Species Group L, Table 3.1). The concept of ruderal vegetation is similar to pioneer vegetation but with broader applicability. Grime (1979) defines ruderal vegetation as species that are able to grow in severely disturbed habitats. Although the concept was first applied to any disturbance including natural catastrophies, it has become synonymous with man-made habitats. This is probably due to the large-scale effect of anthropogenic disturbances on vegetation (Cilliers & Bredenkamp, 1999a).

The *Amaranthus hybridus-Cyperus esculentus* Sub-community is subdivided into three different variants. The first variant represents disturbed areas where domestic refuse was dumped, the second variant occurs along a drainage line on ash disposal site 1 and the third represents newly rehabilitated areas.

2.2.1 *Portulaca oleracea-Bidens formosa Variant*

The *Portulaca oleracea-Bidens formosa* Variant is associated with species from Species Group F (Table 3.1). Most of the dominant species include the annual forbs such as *Tagetes minuta* and *Bidens formosa* (Species Group L, Table 3.1). This variant is also characterised by a number of garden escapes' for example *Iris* sp. and *Mirabilis jalapa* (Species Group F, Table 3.1).

This variant established due to domestic refuse that was dumped on top of rehabilitated areas on ash disposal site 3. This variant occurs as small mosaics in the *Chamaecrista biensis* Variant (2.1.1) of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community. A combination of ruderal species such as *Portulaca oleracea* (Species Group F, Table 3.1), *Bidens formosa, Cyperus esculentus* and *Tagetes minuta* (Species Group L, Table 3.1); garden plants like *Iris* sp. (Species Group F, Table 3.1) and *Gladiolus* sp. (Table 3.2), and perennial grasses from the seed mixture namely *Eragrostis curvula, Cynodon dactylon* (Species Group L, Table 3.1)

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(dominant), *Eragrostis chloromelas* and *Hyparrhenia hirta* (Species Group K, Table 3.1) can be found in the *Portulaca oleracea-Bidens formosa* Variant.

2.2.2 *Panicum maximum-Digitaria eriantha* Variant

This community occupies a small area in a drainage line on the north-eastern slope of ash disposal site 1 and is characterised by *Panicum maximum* (Species Group G, Table 3.1). The dominant grasses are *Pennisetum clandestinum* (Species Group J, Table 3.1) and *Digitaria eriantha* (Species Group L, Table 3.1). The sedge *Cyperus esculentus* (Species Group L, Table 3.1) also occurred in two relevés of this variant.

Both *Panicum maximum* (Species Group G, Table 3.1) and *Digitaria eriantha* (Species Group L, Table 3.1) were present in the original seed mixture. The contributing environmental factor for the establishment of this plant community is different from the other two variants of the *Amaranthus hybridus-Cyperus esculentus* Sub-community. High moisture conditions due to the collection of water on the plateau of ash disposal site 1 can be regarded as the most important habitat factor. These species, especially *Panicum maximum,* require moist conditions to establish successfully on ash disposal sites.

Other areas where high moisture conditions prevailed, species such as *Pennisetum clandestinum* (Species Group J, Table 3.1) was found to outcompete the surrounding vegetation to form pure stands of this grass. Other grass species that occur in these moist areas were *Agrostis lachnantha* and *Arundo donax.*

2.2.3 *Eragrostis tef -Enneapogon cenchroides* Variant

This variant represents newly rehabilitated areas less than one year old and is characterised by Species Group H (Table 3.1). Two of the diagnostic grass species, *Enneapogon cenchroides* and *Eragrostis tef* which are both annual pioneers, originated from the seed mixture used to rehabilitate this area. The other two diagnostic species are the annual grass *Eleusine coracana* subsp. *africana* and the crop plant *Zea mays.* Other species with high cover-abundance values include the sedge *Cyperus esculentus* (Species Group L, Table 3.1) and the annual forbs *Amaranthus hybridus* (Species Group I, Table 3.1), *Tagetes minuta* and *Commelina benghalensis* (Species Group L, Table 3.1).

3 *Spergularia media* Community

This is a species poor community consisting only of the perennial forb *Spergularia media* (Species Group O, Table 3.1) and the annual forb *Chenopodium album* (Species Group I, Table 3.1) established on non-rehabilitated ash. This community is ultimately destroyed during rehabilitation and is replaced by species found in the seed mixtures and soil seed bank of the topsoil, as well as species able to migrate from nearby vegetation.

3.3.2 Ordination

The floristic relationship between communities is investigated by a stepwise ordination of results. Four ordinations were progressively conducted on the floristic data. Group numbers indicated in ordination diagrams are community numbers used in the text.

The **first step of ordination** included a scatter diagram of all 113 relevés indicating the floristic relationship of all communities described, and illustrates the presence of three groups in the ordination space (Figure 3.1). Relevés are separated in two groups along ordination axis 1 of Figure 3.1. The first group is compressed on the left side of ordination axis 1, and is characterised by sample plots located in the natural grassland (*Brachiaria serrata-Setaria sphacelata* Community (1)) and already rehabilitated areas (*Eragrostis curvula-Cynodon dactylon* Community (2)). The group at the right side of ordination axis 1 includes relevés which form part of the community which developed on non-rehabilitated areas (*Spergularia media* Community (3)). The *Eragrostis curvula-Cynodon dactylon* Community (2) (bottom of ordination axis 2), and *Brachiaria serrata-Setaria sphacelata* Community (1) (top of ordination axis 2) occur as separate groups along ordination axis 2 in Figure 3.1. The first step of ordination therefore clearly separates the three communities. Both ordination axes can be related to the quality of the topsoil to sustain vegetation, and the stage of development of the ecosystem these communities are occupying.

For the second ordination step the relevés of the *Spergularia media* Community (3) are excluded from the analysis. Figure 3.2 illustrates the scatter diagram of the **second ordination step**. The eigenvalue of ordination axis 1 (0.899) still indicates great differences in the samples of the communities along this axis. Three groups can be identified along ordination axis 1. The *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2) occurring in newly rehabilitated areas is situated at the left of ordination axis 1 and the *Brachiaria serrata-Setaria sphacelata* Community (1) occurring in the natural grassland is situated on the right side of ordination axis 1. The *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) which occur in older rehabilitated areas is situated in the middle between the *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2) and the *Brachiaria serrata-Setaria sphacelata* Community (1). Ordination axis 1, therefore, represents a successional gradient from pioneer (left side of ordination axis 1) to hypothetical climax vegetation (right side of ordination axis 1) (Figure 3.2). The community on the left side of ordination axis 1 is characterised by species such as *Eragrostis tef*, *Enneapogon cenchroides*, *Eleusine coracana* subsp. *africana* and the dominant occurrence of *Cyperus esculentus*. The community on the right is characterised by species such as *Brachiaria serrata*, *Heteropogon contortus*, *Setaria sphacelata* var. *torta* and *Tristachya leucothrix*.

The different variant and sub-variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) and *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2) cannot be distinguished in the second ordination step (Figure 3.2). In the **third step of ordination**, all the relevés of the *Brachiaria serrata-Setaria sphacelata* Community (1) are excluded (Figure 3.3) and only relevés from the *Eragrostis curvula-Cynodon dactylon* Community (2) characterising areas already rehabilitated are used. The scatter diagram of Figure 3.3 presents a wedge pattern with a large amount of variation along ordination axis 2, particularly the right side of ordination axis 1. Ordination axis 1 also shows a gradient that can be attributed to differences in community development and the ecological condition of the rehabilitated ash disposal sites. The left side of ordination axis 1 represents the *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2), which has a poor rehabilitated condition typical of rehabilitated sites or those sites which were disturbed by the dumping of domestic waste (Figure 3.3). Secondary disturbances like those resulted in the development of the *Portulaca oleracea-Bidens formosa* Variant (2.2.1) of the *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2). The *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1), which represents old rehabilitated areas, that is of a higher rehabilitated quality (better condition) occur at the right side of ordination axis 1. The *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) is also in a more advanced stage of community development. The quality/condition of rehabilitation in this case means higher cover-abundance values for perennial grasses and absence of annual forbs and grasses typical of pioneer vegetation. The gradient along ordination axis 1 may also, therefore, be considered a successional gradient from pioneer communities at the left to climax communities on the right.

Variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1.1, 2.1.2 and 2.1.3) are not clearly distinguishable from the ordination diagram. The second ordination axis also indicates that a large amount of variation exists in the species composition of the variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) (Figure 3.3). The sub-communities form relatively distinctive groups, indicating that sub-communities are dissimilar regarding their vegetation composition.

For the **fourth ordination step** of ordination all the relevés representing the *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2) is excluded, in other words the relevés present on the left of ordination axis 1 of Figure 3.3. Only the relevés of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1), which represent the older rehabilitated sites are used in the fourth ordination step. No distinct groups divide the different vegetation groups that characterise older rehabilitated areas (Figure 3.4). The *Lepidium bonariense-Eragrostis trichophora* (2.1.3) Variant, however, occurs at the bottom of ordination axis 2, and the *Chamaecrista biensis* Variant (2.1.1) and *Lespedeza cuneata-Hyparrhenia hirta* Variant (2.1.2) occur at the top of ordination axis 2 (Figure 3.4). The *Chamaecrista biensis* Variant (2.1.1) and *Lespedeza cuneata-Hyparrhenia hirta* Variant (2.1.2) grade into each other along ordination axis 1, as indicated by the shared species (Species Groups J, K and L, Table 3.1) between these two variants (Figure 3.4). Nearly similar eigenvalues between ordination axis 1 and 2 indicate that the same amount of variation that exist between the variants (ordination axis 2) also exist in the variants (ordination axis 2). No definite environmental gradients can be linked with the variations that exist along the two axes. Ecological interpretation of the data will be conducted by direct gradient analysis in Chapter 8 using the CANOCO computer program (Ter Braak, 1987-1992).

The variants are therefore relatively homogenous in vegetation composition. Differentiation between variants is only possible along ordination axis 2 and the ordination is, therefore, not able to indicate differences based on the floristic composition on a variant level.

Table 3.4 indicates that the different steps of the ordination are able to explain progressively the variation in the data because a reduction in the sum of all unconstrained eigenvalues from 11.166 in the first ordination step to 5.610 in the fourth ordination step exists. The sum of all unconstrained eigenvalues of the fourth step of ordination, however, indicates that a large amount of variation remain unexplained due to the large size of the sum of unconstrained eigenvalues.

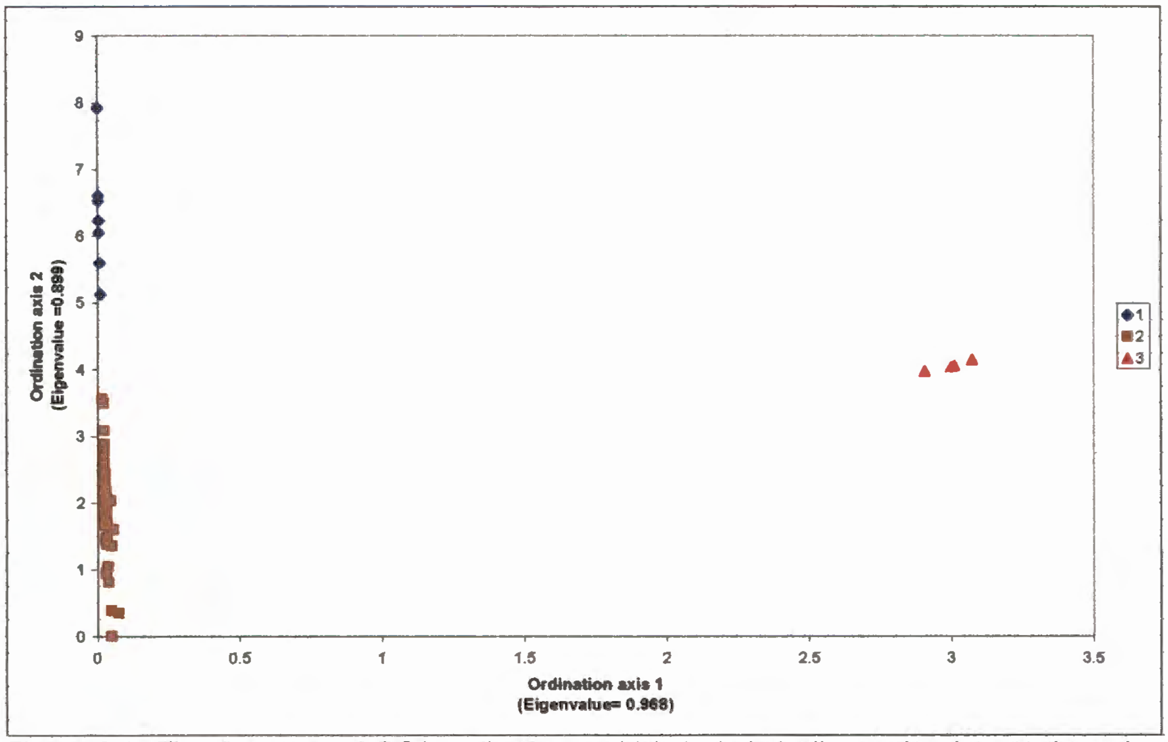

Figure 3.1: The first step of DCA ordinations, which included all sample plots at the ash disposal areas at Hendrina Power Station and an adjacent natural grassland (symbols according to community numbers on right of figure-see text).

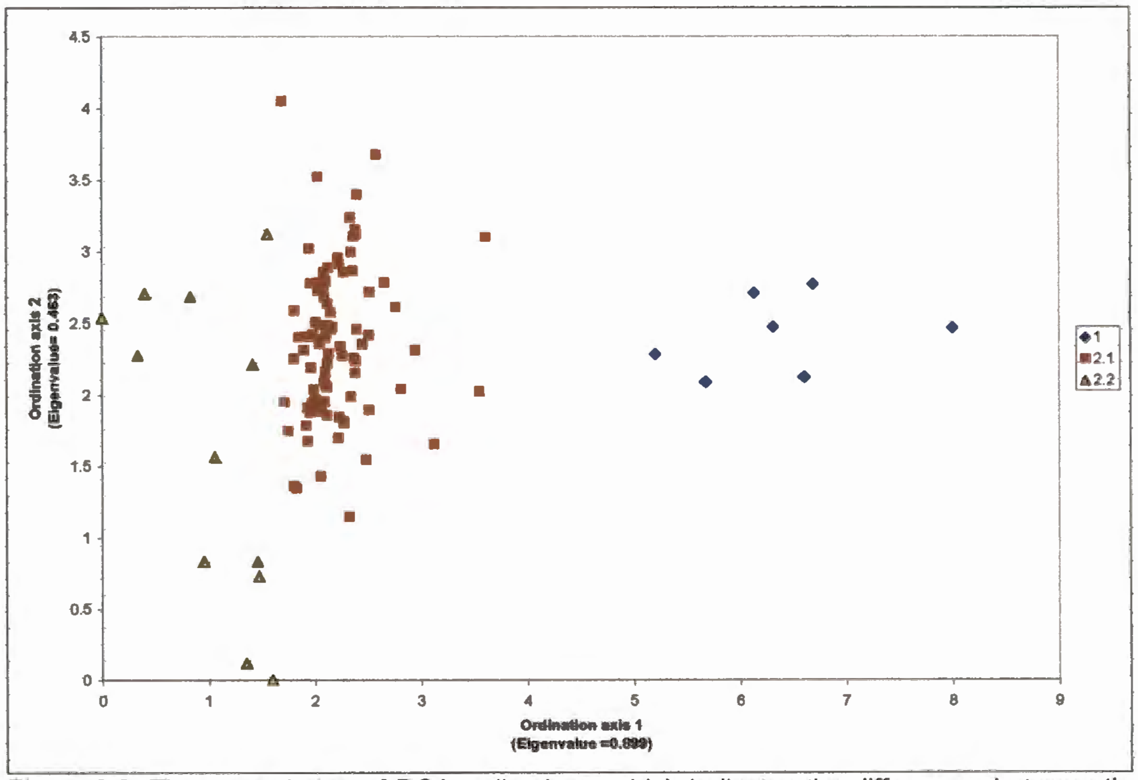

Figure 3.2: The second step of DCA ordinations, which indicates the differences between the adjacent natural grassland (right side of ordination) and all rehabilitated areas (left side of ordination) on ash disposal areas at Hendrina Power Station (symbols according to community numbers on right of figure-see text).

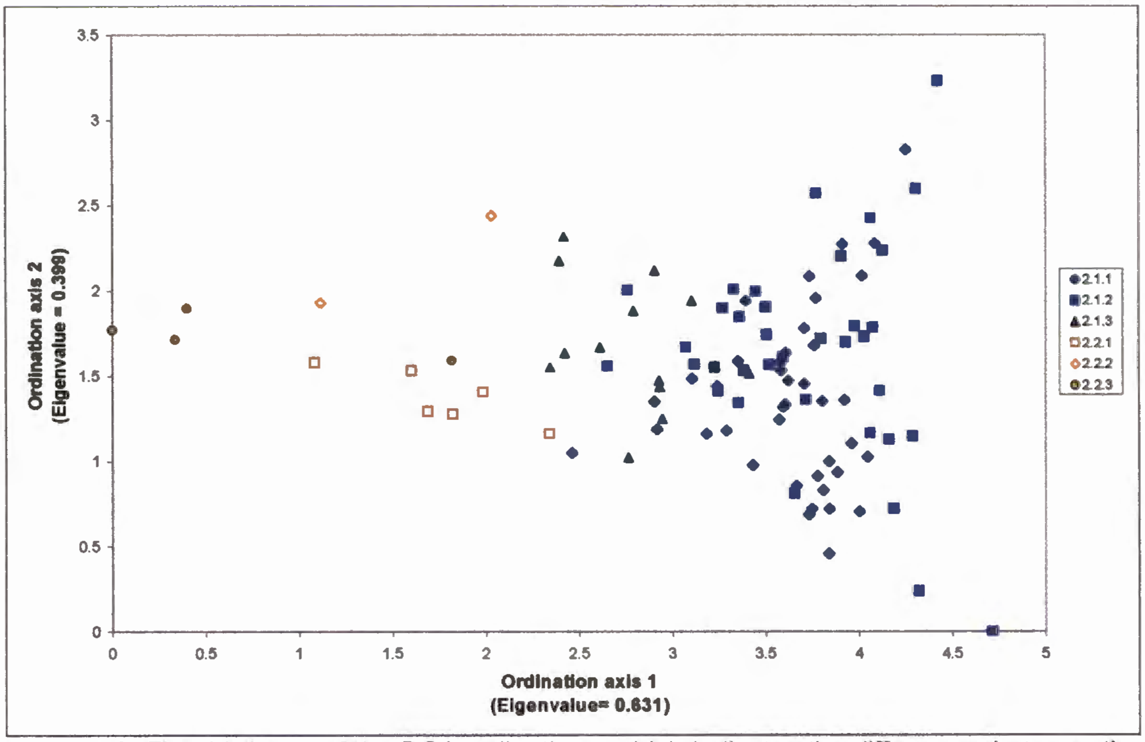

Figure 3.3: The third step of the DCA ordinations, which indicates the differences between the vegetation of rehabilitated ash disposal areas at Hendrina Power Station (symbols according to community numbers on right of figure-see text).

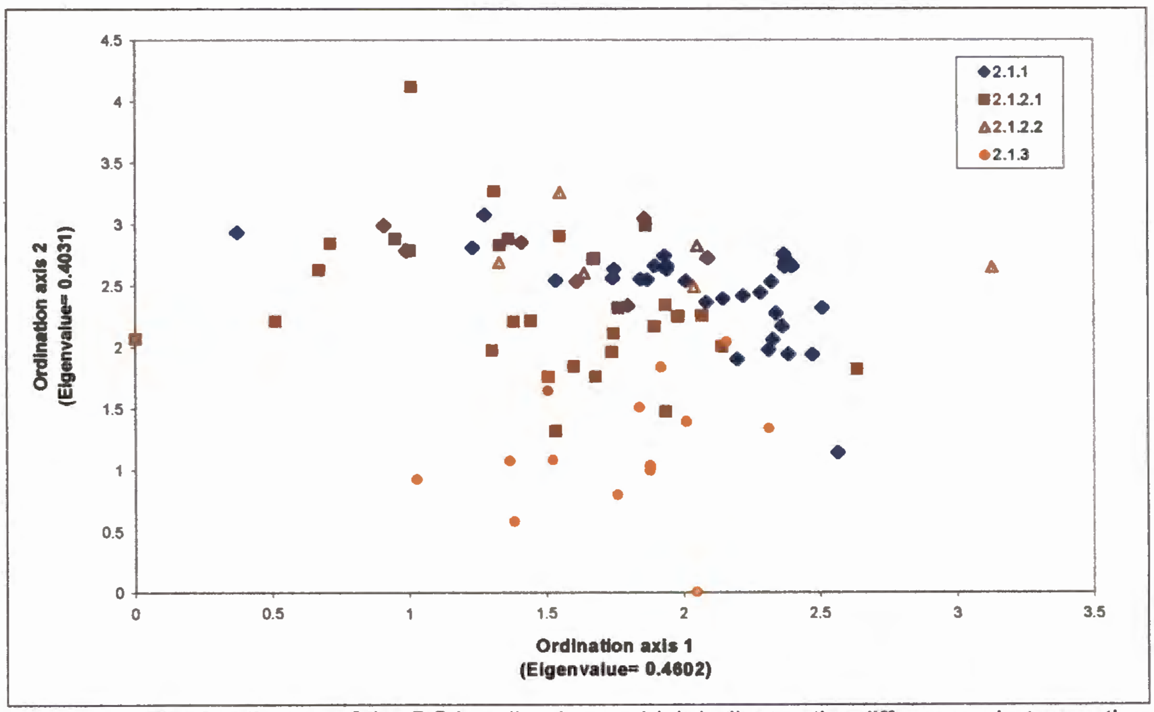

Figure 3.4: The fourth step of the DCA ordinations, which indicates the differences between the vegetation of old rehabilitated areas on ash disposal sites at Hendrina Power Station (symbols according to community numbers on right of figure-see text).

If the magnitudes of the eigenvalues of the first two axes are considered then it can also be deduced that the gradients of ordination axis 1 and 2 are still of importance because both eigenvalues are higher than 0.3 (Ter Braak & Verdonschot, 1995).

Table 3.4: Sum of all unconstrained eigenvalues for the ordination of all steps conducted

Ordination step	First ordination axis eigenvalue	Second ordination axis eigenvalue	Sum of all unconstrained eigenvalues
First	0.968	0.899	11.166
Second	0.899	0.463	10.001
Third	0.631	0.399	7.334
Fourth	0.460	0.403	5.610

3.3.3 Species Diversity

Species diversity between the natural grassland areas (*Brachiaria serrata-Setaria sphacelata* Community (1)), rehabilitated areas (*Eragrostis curvula-Cynodon dactylon* Community (2)), and the non-rehabilitated ash disposal site (*Spergularia media* Community (3)) was clearly different. The *Spergularia media* Community (3), on unrehabilitated areas, was not included in the statistical analysis because it caused a large amount of heteroscedasticity in the data set. In Table 3.5 the species richness, evenness and Shannon diversity values are compared statistically on community, sub-community and variant level. No statistically significant results exist between communities, sub-communities or variants for evenness values, but statistically significant differences in species richness and Shannon Diversity Index values exist and will be discussed further.

Table 3.5: Average and standard deviation values (italics) for Shannon Diversity Index values, evenness and species richness between communities, sub-communities and variants on ash disposal sites at Hendrina Power Station

Community structure			Shannon Index		Evenness		Species Richness	
1			2.152	*0.347*	0.667	*0.09*	25.2	*3.701*
2			1.447	*0.382*	0.603	*0.135*	11.288	*3.048*
	2.1		1.444	*0.382*	0.606	*0.135*	11.119	*3.057*
		2.1.1	1.268	*0.36*	0.574	*0.143*	9.233	*2.096*
		2.1.2	1.567	*0.346*	0.636	*0.119*	12	*2.887*
		2.1.3	1.631	*0.342*	0.627	*0.136*	14	*2.412*
	2.2		1.476	*0.408*	0.574	*0.146*	13.167	*2.401*

Table 3.6: Alpha values for t-tests and ANOVA tests of Species Richness (transformed) and Shannon Index values on community, sub-community and variant level

	Species Richness		Evenness		Shannon Index	
	t/f-statistic	P-value	t/f-statistic	P-value	t/f-statistic	P-value
Community (t)	8.090(t)	0.000	1.037	0.303	4.015	0.000
Sub-community (t)	-1.652	0.103	0.564	0.575	-0.190	0.8497
Variant	18.647	0.000	1.589	0.212	7.019	0.002

(t) t-statistic of student t-test for independent variables

3.3.3.1 Community level

Alpha diversity at a community level is significant for both species richness and Shannon diversity values (Table 3.6). The average species richness and Shannon Diversity Index values are statistically significantly higher for the *Brachiaria serrata-Setaria sphacelata* Community (1) (average species richness: 25.2 (Table 3.5); average Shannon Diversity Index: 2.152 (Table 3.5)) than for the *Eragrostis curvula-Cynodon dactylon* Community (2) (average species richness: 11.3; average Shannon Diversity Index: 1.4) (Figure 3.5.1 and 3.5.2 and Table 3.6).

3.3.3.2 Sub-community level

No statistical significantly differences in alpha diversity exist between the different sub-communities (Table 3.5). The species richness of the *Amaranthus hybridus–Cyperus esculentus* Sub-community (2.2) are slightly higher (average: 13.2) than the species richness of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) (average: 11.1) (Table 3.5). The average Shannon Diversity Indices of both sub-communities are approximately 1.4 (Table 3.5).

3.3.3.3 Variant level

The *Eragrostis tef-Enneapogon cenchroides* Variant (2.2.3) and *Panicum maximum-Digitaria eriantha* Variant (2.2.2) were not included in the statistical analysis, due to insufficient sample sizes. The ANOVA test for species richness and Shannon Index values are both statistically significant between variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) (Table 3.5). Comparison of the species richness and Shannon Index values of the different variants indicate that only the *Chamaecrista biensis* Variant (2.1.1) had a statistically significant lower species richness (average: 9.2) and Shannon Index (average: 1.3) compared to the other two variants (all average species richness values> 11; Shannon Index> 1.5) (Figures 3.6.1 and 3.6.2 and Table 3.5).

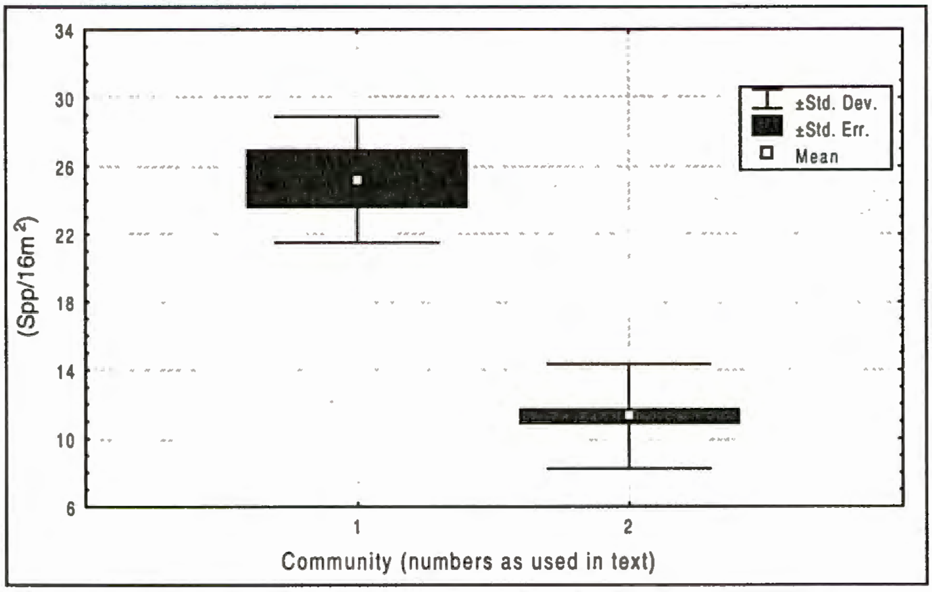

Figure 3.5.1: Differences in species richness between the *Brachiaria serrata-Setaria sphacelata* Community (1) and the *Eragrostis curvula-Cynodon dactylon* Community (2) at Hendrina Power Station.

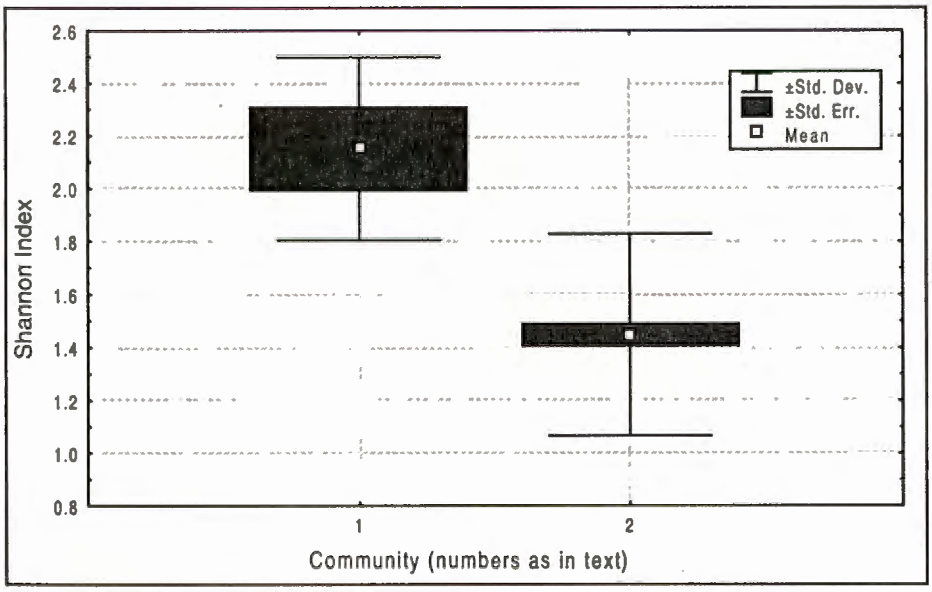

Figure 3.5.2: Differences in Shannon diversity index values for between the *Brachiaria serrata-Setaria sphacelata* Community (1) and the *Eragrostis curvula-Cynodon dactylon* Community (2) at Hendrina Power Station.

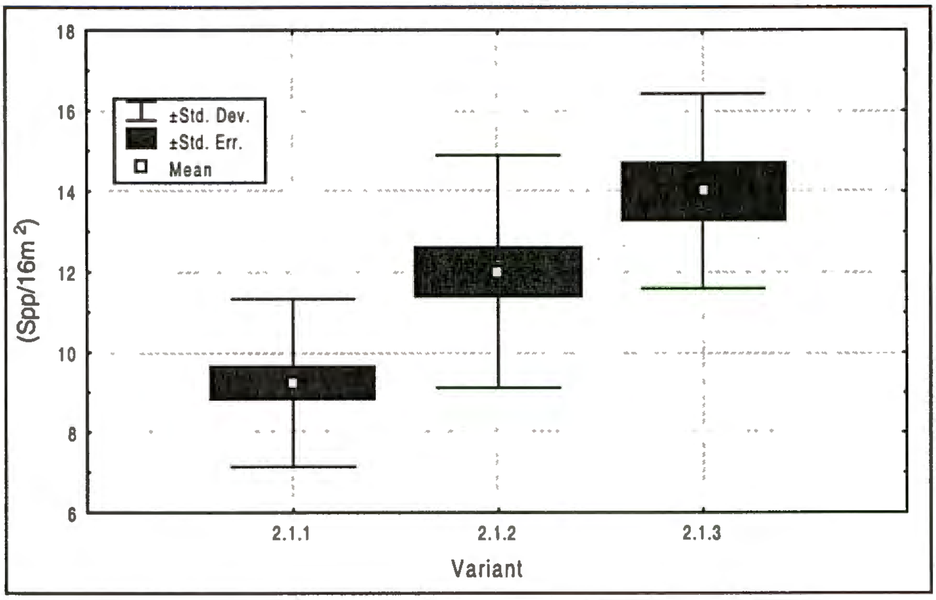

Figure 3.6.1: Differences in species richness between different variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) on ash disposal sites at Hendrina Power Station.

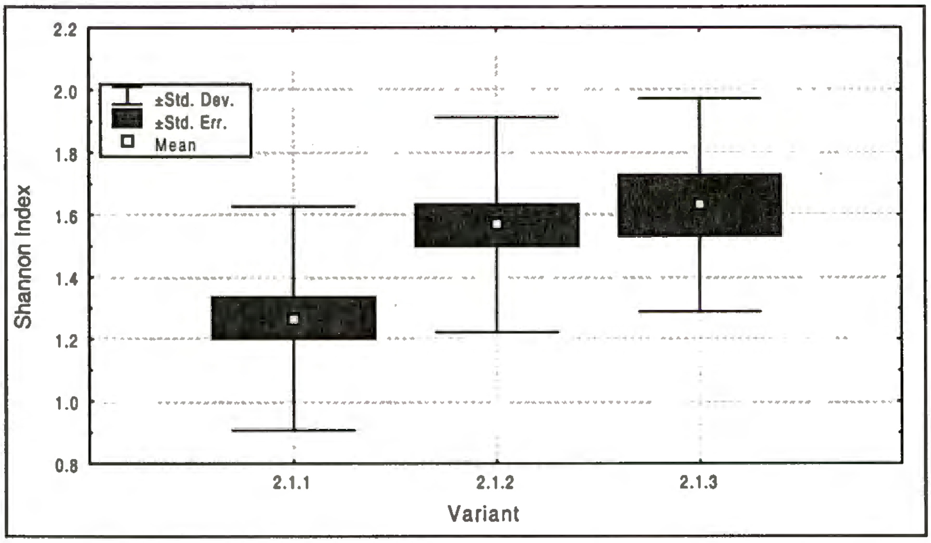

Figure 3.6.2: Differences in Shannon Index values between variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) on ash disposal sites at Hendrina Power Station.

3.4 CONCLUSIONS

The phytosociological analysis shows that the adjacent natural grassland has little in common with respect to species composition with the rehabilitated areas. Sub-communities on the ash disposal sites are related to the dynamics of the rehabilitated vegetation and, therefore, represent certain successional stages. The vegetation of old rehabilitated sites are homogenous in species composition and are dominated by the grasses *Eragrostis* spp. (*Eragrostis curvula, Eragrostis trichophora* and *Eragrostis chloromelas*), *Hyparrhenia hirta Pennisetum clandestinum* and *Cynodon dactylon.* Roux (1969) indicates that *Cynodon dactylon, Eragrostis* spp. and *Hyparrhenia hirta* can all be related to succession of old fields. Species associated with the rehabilitated areas are therefore similar to vegetation found on abandoned old fields on the South African Highveld. Variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) are strongly related to certain treatments and the ability of species to establish themselves on a particular habitat. An example of a treatment specific vegetation type is the *Lespedeza cuneata-Hyparrhenia hirta* Variant (2.1.2), which only occurred on slopes of ash disposal areas rehabilitated during 1994 (descriptions of treatments are provided in Chapter 2.) Many of the species occurring on this grid are not common to the Hendrina area, for example *Lespedeza cuneata* and the *Acacia* spp. These species were brought in through the *Cynodon* sods collected in Natal (M.D. Michael, pers. com.)[2]. The *Acacia mearnsii* Woodland (2.1.2.2) one of the sub-variants of the *Lespedeza cuneata-Hyparrhenia hirta* Variant (2.1.2) can also be associated with the use of topsoil which contained seeds of this species. Anthropogenic influences (disturbance and age after rehabilitation) can be regarded as the most important distinguishing factors between sub-communities of rehabilitated areas.

The phytosociological study indicates that permanent survey grids (see Chapter 2) occur mostly in the variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1). Permanent grids can be grouped into three homogeneous groups. Grids 10, 11 and 12 (plateaus) belong to the *Chamaecrista* Variant (2.1.1). Grids on all the slopes of ash disposal site 1 and 3 are related to the *Vigna vexillata-Cynodon dactylon* Sub-variant (2.1.2). Grid 1 on the plateau of ash disposal site 1 is associated with the *Lepidium bonariensis-Eragrostis trichophora* Variant (2.1.3). The only grids that differs from one vegetation type to another are the middle transects of grids 7(7/2), which changed from the *Eragrostis tef-Enneapogon cenchroides* Variant (2.2.3) (*Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2)) to the *Lespedeza cuneata-Hyparrhenia hirta* Variant (2.1.2) of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1).

Vegetation classification of rehabilitated sites (variant level) was difficult due to their artificial nature and the homogenous occurrence of dominant species. Mosaics in the vegetation, which

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are difficult to interpret, also occur in places. The ecological interpretation of results is also difficult as indicated in Figure 3.4. A definite gradient exists along ordination axis 1, but no environmental effect can be found to explain the gradient (Figure 3.4). The effect of competition among large tuft grasses is not investigated in this thesis and should be investigated further in other studies.

Some of the grids are problematic for further analyses. Grids 7 and 8 do not form a homogenous unit like the other grids, but are divided into three different stages of rehabilitation and each transect therefore occurs as part of different communities. Due to the non-uniformity and insufficient sample replicas of grids 7 and 8, these grids will mostly be left out of any statistical analysis. This is unfortunate because transects along these grids show the most change. The monitoring system used is also too large for the *Portulaca oleracea- Bidens formosa* Variant (2.2.1). The small extent of those areas may also render the monitoring unnecessary.

Ecological stability cannot always be related to diversity because ecological stability is ultimately dependent on environmental stability (Kent & Coker, 1994). Diversity did also not increase from new to old rehabilitated but decreased, probably due to out-competition of annuals by perennial grass species. Species richness was more significant than Shannon Index values. The low diversity of rehabilitated sites can be explained by the small species pool on rehabilitated sites, high competitiveness of dominant species and habitat restrictions posed by the ash disposal sites.

The effect of environmental factors, especially factors relating to the growth medium, will be investigated by direct gradient analysis with the application of CCA (Canonical Correspondence Analysis) and RDA (Redundancy Analysis) ordination techniques (Ter Braak, 1987-1992) (Chapter 8). A phytosociological approach proved to be a useful basis to describe the overall vegetation of the ash disposal sites.

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Chapter 4 A FLORISTIC COMPARISON BETWEEN VEGETATION ON REHABILITATED ASH DISPOSAL SITES AND AN ADJACENT NATURAL GRASSLAND*

Abstract: A list of all species collected during the three year period is provided together with their life form spectra. The floristic composition of the ash disposal area at Hendrina Power Station is also compared with the floristic composition of an adjacent natural grassland. A total of 278 species were found during the study of which 151 species occurred on the ash disposal sites and 163 species were found in the natural grassland. Of all the species, 35 occurred in both areas of which most were annual pioneer species. The species composition and life form spectra of the two areas were considerably different. Therophytes were, for example, more abundant on the ash disposal areas. The reconstruction of an ecosystem on ash disposal sites with a species composition similar to that of the natural grassland will probably require far more financial inputs and habitat amelioration than presently applied.

CONTENTS

* Submitted for publication to the *South African Journal of Botany*

4.1 INTRODUCTION

An important component of any ecosystem is the species that exist in that system. Derelict land is characterised by distinct floras due to the habitat differences which exist in such areas (Bradshaw, 1983) and the colonisation by uncommon species (Bradshaw & Chadwick, 1980) with different life form compositions. Due to present rehabilitation practices only a small number of species establish on rehabilitated areas which therefore leads to an ecosystem of low diversity (Roberts *et al.*, 1981). Floras of derelict land are however seldom studied and are therefore relatively unknown. The floristic composition of these sites may however give important information on the ecological and environmental conditions that persists on derelict land. Species of certain families are normally associated with specific soil conditions and can be used as indicators of such conditions (Bradshaw & Chadwick, 1980).

The life form spectra of species were used by Down (1973) to determine successional patterns and to describe the vegetation on colliery waste. Down (1973) used life form spectra because basic floristic methods were found to be of limited value since the high variability of early colonisers and ruderal species during early successional stages. The plant community structure on reclaimed non-ferrous metal sites were also investigated by Vangronsveld *et al.* (1996) by comparing the life form spectra and species composition between treated and untreated sites Down (1973). The description of communities based on floristic composition was also found to be difficult in the phytosociological study (Chapter 3) because of the artificial nature of communities and the stochastic colonisation patterns of annual forbs.

The aim of this study is to compare the adjacent natural grassland with the ash disposal sites in terms of their floristic composition, γ-diversity and life form spectra. A further aim of the study is to provide a list of all species collected in these two areas during the three-year survey period. Results may give some insight into the floristic characteristics of derelict areas such as ash disposal areas.

4.2 MATERIALS AND METHODS

Table 4.1 presents a summary of most represented families found on ash disposal areas and the natural grassland including the number of genera that is represented by each family. Table 4.2 lists the families that are found in the one area but that are absent in the other area. An annotated list of all species found and positively identified during the study period is provided in Table 4.3. Information on the life forms of the species according to Raunkiaer (1934), habitat type (natural grassland/ash disposal area) and exotic or indigenous status are included. The species, which were used in the seed mixture of the rehabilitation treatments, are also indicated.

Species names conform to those listed in Arnold & De Wet (1993) except where otherwise indicated.

The percentage similarity between the total floristic composition of the vegetation of the natural grassland and ash disposal areas was also calculated with Sørensens Coefficient of Similarity (Kent & Coker, 1994).

4.3 RESULTS

A total of 278 species were collected on the ash disposal areas and the adjacent natural grassland during the study period (Table 4.1). Ninety-eight species belonged to the Monocotyledonae of which most are from the family Poaceae (68 species). The remainder of the species (180) belong to the Dicotyledonae. The Dicotyledonae families that are the best represented are Asteraceae (56 species) and Fabaceae (30 species) of which most species belong to the subfamily Papilionoideae.

4.3.1 Difference in γ-diversity (overall) of ash disposal areas and the natural grassland studied

The Sørensens Index indicates a 22.6 % similarity between the two areas. Thirty-five species occur in both areas including the forbs *Tagetes minuta, Schkuhria pinnata, Pseudognaphalium undulatum, Pseudognaphalium luteo-album, Conyza bonariensis, Conyza podocephala, Nidorella anomala, Lobelia flaccida, Wahlenbergia undulata, Kohautia amatymbica, Verbena bonariensis, Walafrida densiflora, Sebaea grandis, Hibiscus microcarpus, Sida dregei, Euphorbia striata, Pelargonium luridum, Zornia milneana, Tephrosia capensis, Chamaecrista biensis, Delosperma herbeum, Commelina africana, Bulbostylis humilis* and *Kyllinga erecta.* Grasses which were found in both areas are *Cynodon dactylon, Eragrostis plana, Eragrostis curvula, Eragrostis chloromelas, Eragrostis capensis, Sporobolus africana, Setaria sphacelata* var. *torta, Themeda triandra, Heteropogon contortus, Cymbopogon excavatus* and *Hyparrhenia hirta.* A total of 151 species was collected on the ash disposal sites and 163 species in the natural grassland.

4.3.2 Difference in the life form spectra between ash disposal areas and the natural grassland

Figure 4.1 indicates the difference in life form composition according to Raunkiaer (1934). The most represented life form in all the areas is the hemicryptophytes (Figure 4.1). Many of the forbs with perennial rootstocks belong to the proto-hemicryptophytes, which is characterised by the elongated aerial shoots and the largest leaves in the middle portion of the shoots. Many of the species that have a hemicryptophytic life form occur in the natural grassland. Good examples are the species *Gnidia caffra, Acalypha angustata, Schistostephium crataegifolium* and most of the species of the family Fabaceae. All perennial species of the Poaceae and most perennial species of the Asteraceae (*Hypochaeris radicata, Berkheya setifera, Helichrysum nudifolium* and *Senecio coronatus*), however, have a rosette life form. A hemicryptophytic life form with leaves in a rosette at the base of the plant is an important survival strategy of plant species in the study area because of the large number of species with this type of strategy.

The major difference in life form spectra between natural grasslands and the ash disposal areas is the large number of therophytes on the ash disposal areas. Species with a therophyte life form, on the ash disposal sites, are similar to the number of hemicryptophytes on these sites. Examples of species which are therophytes are the species from the Asteraceae family, for example *Bidens bipinnata*, *Schkuhria pinnata* and *Conyza bonariensis;* species from the Chenopodiaceae, for example *Chenopodium album* and from the Poaceae family, for example *Eleusine coracana* subsp. *africana*, *Eragrostis tef* and *Setaria pallide-fusca*. The second most important life form in the natural grassland is species with a cryptophytic life form. The species with a cryptophytic life form are, however, considerably less than the number of species with a hemicryptophytic life form.

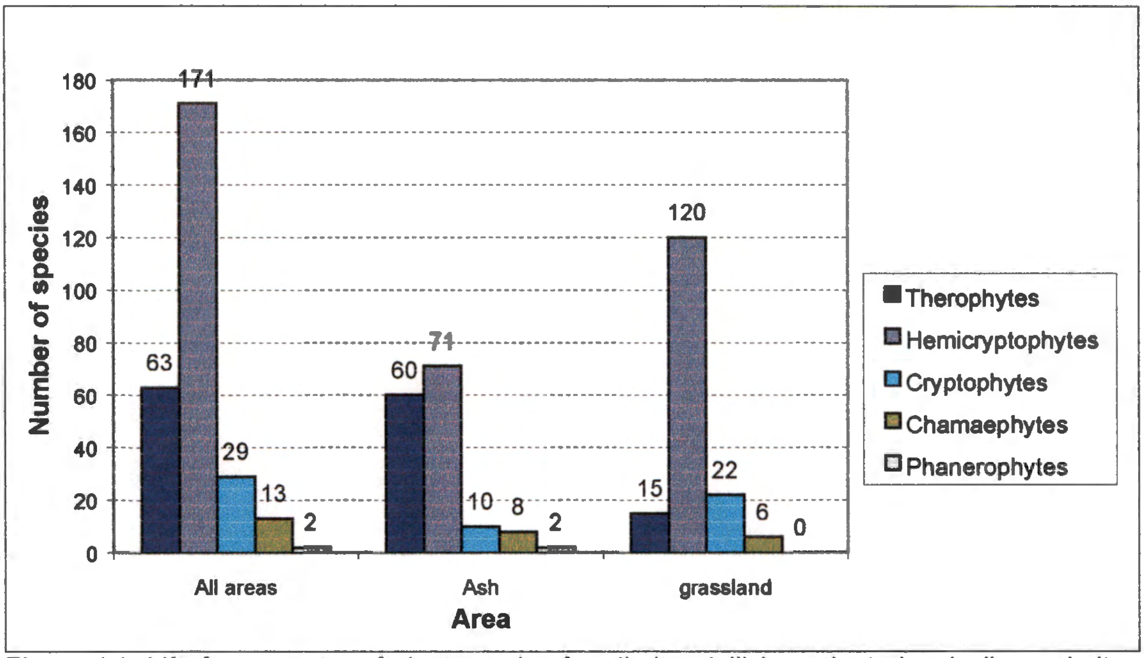

Figure 4.1: Life form spectra of plant species for all sites (all) investigated, ash disposal sites (ash) and an adjacent natural grassland (grassland) at Hendrina Power Station.

4.3.3 Comparison of families occurring on ash disposal sites and the natural grassland

The families Poaceae, Asteraceae and Fabaceae (Papilionoideae) are the most represented families according to the number of genera in both the natural grassland and the ash disposal sites. These three families also contain the most species in comparison to the other families. The family Poaceae is represented by a total of 44 species on the ash disposal sites and 34 species in the natural grassland. Thirty species that occurred on ash disposal areas, and 34 species from the natural grassland belong to the family Asteraceae. The families which are represented by a smaller number of genera are, however, considerably different between the two areas. Families that are represented in both areas are for example the Cyperaceae and Malvaceae (Table 4.1). Families that are present in only one of either the natural grasslands or the ash disposal sites are listed in Table 4.2. Although a total of 12 species, from the family Liliaceae, were found in the natural grassland, species from this family was absent on the ash disposal sites (Table 4.2). Families with species typically found in saline and ruderal conditions (for example Chenopodiaceae, Amaranthaceae, Aizoaceae and Brassicaceae) were not found in the natural grassland (Table 4.2).

Table 4.1: Families with two or more genera occurring on rehabilitated ash disposal sites or the natural grassland at Hendrina Power Station and the number of genera represented

Families	Ash disposal sites	Natural grasslands
Poaceae	31	24
Asteraceae	19	18
Fabaceae (subfamily: Papilionoideae)	9	11
Cyperaceae	3	3
Malvaceae	2	2
Rubiaceae	1	5
Euphorbiaceae	1	3
Asclepiadaceae	1	3
Geraniaceae	1	2
Convolvulaceae	1	2
Gentianaceae	1	2
Lobeliaceae	1	2
Scrophulariaceae	4	
Amaranthaceae	3	
Solanaceae	3	
Polygonaceae	2	
Chenopodiaceae	2	
Brassicaceae	2	
Onagraceae	2	
Liliaceae		8
Acanthaceae		4
Apiaceae		2
Lamiaceae		2

Table 4.2: Families that were found in the one study area, but did not occur in the other area.

Families only found on the ash disposal sites	Families only found in natural grassland
Cannaceae	Juncaceae
Polygonaceae	Liliaceae
Chenopodiaceae	Orchidaceae
Amaranthaceae	Santalaceae
Nyctaginaceae	Illecebraceae
Aizoaceae	Caryophyllaceae
Portulacaceae	Crassulaceae
Brassicaceae	Rhamnaceae
Capparaceae	Sterculiaceae
Polygalaceae	Thymelaeaceae
Tilliaceae	Apiaceae
Onagraceae	Periplocaceae
Solanaceae	Acanthaceae
Cucurbitaceae	Lamiaceae
Schrophulariaceae	Plantaginaceae
	Dipsacaceae

4.4 CONCLUSIONS

Although both areas studied have only a few perennial grass species, which occur frequently, a large number of other species which occur less frequently, occur on the ash disposal sites. An important characteristic of the vegetation of both areas is the large number of species that belong to the families Poaceae, Asteraceae and Fabaceae.

The two areas are, however, floristically totally different. The species that occurred in both areas are opportunistic annual species with a therophytic life form. The number of hemicryptophytic grasses and particularly hemicryptophytic forbs are low in both areas. Although alpha diversity for the two areas is found to be dissimilar, the gamma diversity is very similar. It must be noted that the surface area of the ash disposal sites is considerably larger than that of the natural area studied. Seven more species occur in the natural grassland than on the ash disposal areas. Major differences in the survival strategy of species exist in the two areas. Larger amounts of species on the ash disposal areas have an annual life cycle (therophytes) and therefore survive in the form of seeds during harsh conditions, while most of the species in the natural grassland are perennial. The shoots of these perennial plants die back to ground level during the unfavourable season so that the lower part of the plant is protected by the soil and withered leaves (Raunkiaer, 1934).

To make the floristic composition of the ash disposal areas more similar to the floristic composition of the natural grasslands it will be necessary to find species adapted to both areas. Higher seed input of the grass species *Eragrostis plana*, *Setaria sphacelata* var. *torta*, *Heteropogon contortus*, *Themeda triandra* and *Brachiaria serrata* would probably have to be made. The adaptability of these species to survive the adverse growth conditions on ash disposal areas is, however, not well known. Results from surveys conducted on ash disposal areas on which seeds of *Heteropogon contortus* and *Themeda triandra* were used together with other grass species were not promising.

An analysis of the floristic composition of disturbed areas may provide valuable information regarding the identification of species to be used in restoration and rehabilitation strategies. The identification of benchmarks and experimental controls to evaluate the quality may be greatly improved if the total floristic compositions of the two areas are compared beforehand. This is not done in our study and it made the two areas relatively incomparable. The vegetation on ash disposal areas will probably never achieve the same floristic composition and life form characteristics that prevail in the natural grassland, due to the drastic environmental differences. Multivariate analysis between the natural grassland and rehabilitated ash disposal sites showed that the difference in the species composition between the two areas were substantial (Morgenthal *et al*, 1999). Other criteria than species composition may be a solution, as indicated by Down (1973), to determine the condition and rehabilitation success of rehabilitated vegetation. The number of annual species, which are typical of ruderal vegetation (Grime, 1979), may be a good indication of the successional stage of the vegetation. Therophytes may also be considered as r-selected species. The relation of r-selected to K-selected (Pianka, 1970) species may also be a good indicator of the successional stage in the vegetation. Therophytes, therefore r-selected species, are found to be more abundant on rehabilitated ash disposal sites than in the natural grassland.

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Table 4.3: Checklist of all species encountered on ash disposal areas (ash) and an adjacent natural grassland (grass) at Hendrina Power Station from 1997 to 1999.

	Species	Ash	Grass	Life form
MONOCOTYLEDONAE				
Poaceae				
9900170	***Urelytrum* Hack.**			
	U. agropyroides (Hack.) Hack. (409)		x	Hemicryp
9900280	***Elionurus* Kunth ex Willd.**			
	E. muticus (Spreng.) Kunth		x	Hemicryp
9900370	***Imperata* Cirillo**			
	I. cylindrica (L.) Raeusch.	x		Hemicryp
9900710	***Andropogon* L.**			
	A. eucomus Nees (396)	x		Hemicryp
	A. schirensis A.Rich.		x	Hemicryp
9900720	***Cymbopogon* Spreng.**			
	C. excavatus (Hochst.) Stapf ex Burtt Davy	x	x	Hemicryp
9900730	***Hyparrhenia* Fourn.**			
	H. hirta (L.) Stapf*	x	x	Hemicryp
	H. tamba (Steud.) Stapf	x		Hemicryp
9900780	***Trachypogon* Nees**			
	T. spicatus (L.f.) Kuntze [2] (253)		x	Hemicryp
9900800	***Heteropogon* Pers.**			
	H. contortus (L.) Roem. & Schult.)*	x	x	Hemicryp
9900810	***Diheteropogon* (Hack.) Stapf**			
	D. amplectens (Nees) Clayton		x	Hemicryp
9900830	***Themeda* Forssk.**			
	T. triandra Forssk.*	x	x	Hemicryp
9900890	***Digitaria* Haller**			
	D. eriantha Steud.*	x		Hemicryp
	D. monodactyla (Nees) Stapf		x	Hemicryp
	D. ternata (A. Rich.) Stapf [2] (295)		x	Hemicryp
	D. tricholaenoides Stapf (419)		x	Hemicryp
9900940	***Alloteropsis* Presl**			
	A. semialata (R. Br.) Hitchc. subsp. *Semialata* (404)		x	Hemicryp
9901040	***Brachiaria* (Trin.) Griseb.**			
	B. serrata (Thunb.) Stapf		x	Hemicryp
9901070	***Paspalum* L.**			
	P. dilatatum Poir.	x		Hemicryp
	P. scrobiculatum L. [2] (303)	x		Hemicryp
9901100	***Urochloa* Beauv.**			
	U. mosambicensis (Hack.) Dandy (343)	x		Cham
9901160	***Panicum* L.**			
	P . coloratum L. var. *coloratum* (426)	x		Ther
	P. maximum Jacq.	x		Hemicryp
	P. natalensis Hochst.		x	Hemicryp
9901280	***Setaria* Beauv.**			
	S pallide-fusca (Schumach.) Stapf & C.E. Hubb.	x		Ther
	S sphacelata (Schumach.) Moss var *torta* (Stapf) Clayton	x	x	Hemicryp
	Setaria sp. *cf nigrirostris* (Nees) Dur. & Schinz		x	Hemicryp
9901340	***Melinis* Beauv.**			
	M. repens (Willd.) Zizka subsp. *repens*	x		Ther
9901390	***Pennisetum* Rich**			
	P. clandestinum Chiov.#*	x		Hemicryp
9901400	***Cenchrus* L.**			
	C. ciliaris L.*	x		Hemicryp
9901740	***Tristachya* Nees**			
	T. leucothrix Nees		x	Hemicryp
9901950	***Avena* L.**			
	A. fatua L.# (397)	x		Ther
9901970	***Helictotrichon* Schult.**			
	H. turgidulum (Stapf) Schweick.[2] (293)		x	Hemicryp
9902110	***Cortaderia* Stapf.**			
	C. jubata (Lem.) Stapf#	x		Hemicryp

Table 4.3 (continued)

	Species	Ash	Grass	Life form
9902130	***Arundo* L.**			
	A. donax L.#	x		Cham
9902430	***Agrostis* L.**			
	A.eriantha Hack. var *eriantha* (398)	x		Hemicryp
	A. lachnantha Nees var. *lachnantha* ^{2} (296)	x		Hemicryp
9902460	***Calamagrostis* (Adanson)**			
	Calamagrostis sp.#^{2} (309)	x		Hemicryp
9902620	***Aristida* L.**			
	A. aequiglumis Hack. ^{2} (251)		x	Hemicryp
	A. congesta Roem. & Schult. subsp. *congesta*	x		Hemicryp
9902830	***Sporobolus* R. Br.**			
	S. africanus (Poir.) Robyns & Tournay	x	x	Hemicryp
9902860	***Eragrostis* Wolf**			
	E. barbinodis Hack.		x	Hemicryp
	E. capensis (Thunb.) Trin. (386)	x	x	Hemicryp
	E. chloromelas Steud.*	x	x	Hemicryp
	E. curvula (Schrad.) Nees*^{2} (256) (257)	x	x	Hemicryp
	E. echinochloidea Stapf* (382)	x		Hemicryp
	E. gummiflua Nees		x	Hemicryp
	E. lehmanniana Nees var. *lehmanniana**	x		Hemicryp
	E. nindensis Ficalho & Hiern		x	Hemicryp
	E. plana Nees	x	x	Hemicryp
	E. racemosa (Thunb.) Steud.		x	Hemicryp
	E. tef (Zucc.) Trotter#* (344)	x		Ther
	E. trichophora Coss. & T. Durand	x		Hemicryp
	Eragrostis sp. (294)	x		Hemicryp
9902940	***Microchloa* R. Br.**			
	M. caffra Nees		x	Hemicryp
9902960	***Cynodon* Rich.**			
	C. dactylon (L.) Pers.*	x	x	Cryp
9902980	***Harpochloa* Kunth**			
	H. falx (L.f.) Kunze (399)		x	Hemicryp
9903010	***Chloris* Swartz.**			
	C. gayana Kunth#*	x		Hemicryp
	C. virgata Sw.*	x		Ther
9903310	***Eleusine* Gaetn.**			
	E. coracana (L.) Gaertn. subsp. *africana* (Kenn.- O' Byrne) (371)	x		Ther
9903320	***Dactyloctenium* Willd.**			
	D. aegyptium (L.) Willd. (346)	x		Ther
9903340	***Pogonarthria* Stapf**			
	P. squarrosa (Roem. & Schult.) Pilg.*	x		Hemicryp
9903442	***Bewsia* Goossens**			
	B. biflora (Hack.) Gooss. (418) (315)		x	Hemicryp
9903500	***Triraphis* R. Br.**			
	T. andropogonoides (Steud.) Phill.		x	Hemicryp
9903530	***Trichoneura* Anderss.**			
	T. grandiglumis (Nees) Ekman *var. grandiglumis*		x	Hemicryp
9903570	***Enneapogon* Beauv.**			
	E. cenchroides (Roem. & Schult.) C. E. Hubb.*	x		Ther
9903710	***Fingerhuthia* Nees**			
	F. africana Lehm.*	x		Hemicryp
9904280	***Bromus* L.**			
	B. catharticus Vahl.# (353)	x		Ther
	***Zea* L.**			
	Z. mays L. #	x		Ther
Cyperaceae				
459000	***Cyperus* L.**			
	C. esculentus L. (419)	x		Cryp
	C. obtusiflorus Vahl var. *obtusiflorus* *(300)* (373)		x	Cryp
	C. usitatus Burch. var. *usitatus*^{2} (250)	x		Cryp
462000	***Kyllinga* Rottb.**			
	K. erecta Schumach. ^{2} (301)	x	x	Cryp
471010	***Bulbostylis* Kunth**			
	B. humilis (Kunth) C.B.Clarke^1 (410)	x	x	Ther

Table 4.3 (continued)

	Species	Ash	Grass	Life form
Commelinaceae				
896000	***Commelina* L.**			
	C. africana L. var. *africana*	x	x	Hemicryp
	C. benghalensis L.	x		Ther
Juncaceae				
936000	***Juncus* L.**			
	J. dregeanus Kunth [2] (302)		x	Hemicryp
Liliaceae				
989000	***Anthericum* L.**			
	A. calyptrocarpum Baker (364)		x	Cryp
	A. cooperi Baker (366)		x	Cryp
	A. fasciculatum Baker (365)		x	Cryp
1026000	***Aloe* L.**			
	A. ecklonis Sam-Dyck (390)		x	Hemicryp
1029010	***Chortolirion* A. Berger**[1]			
	C. angolense (Baker) A. Berger (389)		x	Cryp
1080000	***Urginea* Steinh.**			
	U. multisetosa Baker (319)		x	Cryp
1084000	***Dipcadi* Medik.**			
	D. marlothii Engl.		x	Cryp
	D viride (L.) Moench (374)		x	Cryp
1088000	***Eucomis* L' Hérit**			
	E. autumnalis (Mill.) Chitt.		x	Cryp
1089000	***Ornithogalum* L.**			
	O. tenuifolium Delaroche subsp. *tenuifolium* [2] (313)		x	Cryp
1090010	***Ledebouria* Roth.**			
	L. inquinata (C. A. Sm.) Jessop [2] (292)		x	Cryp
	L. ovatifolia (Baker) Jessop		x	Cryp
Amaryllidaceae				
1189000	***Crinum* L.**			
	C. bulbispermum (Burm. *f.*)	x		Cryp
Hypoxidaceae				
1230000	***Hypoxis* L.**			
	H. acuminata Baker		x	Cryp
	H. angustifolia Lam. var. *angustifolia* (318)		x	Cryp
	H. argentea Harv. ex Baker var. *argentea* (356)		x	Cryp
	H. rigidula Baker var. *rigidula* (332) (402)		x	Cryp
Iridaceae				
1311000	***Gladiolus* L.**			
	G. crassifolius Bak. (362)		x	Cryp
	Gladiolus sp.#	x		Cryp
Cannaceae				
1363000	***Canna* L.**			
	C. indica L..#	x		Cryp
Orchidaceae				
1422000	***Habenaria* Willd.**			
	H. epipactidea Richb. F. (378)		x	Cryp
DICOTYLEDONAE				
Santalaceae				
2118000	***Thesium* L.**			
	T. costatum A.W. Hill var. *paniculatum* N.E. Br. [2] (252)		x	Cham
Polygonaceae				
2195000	***Rumex* L.**			
	Rumex sp. *cf. lanceolatus* Thumb.	x		Cham
2201030	***Persicaria* Mill.**			
	P. lapathifolia (L.) S.F. Gray	x		Ther
Chenopodiaceae				
2223000	***Chenopodium* L.**			
	C. album L.# (381)	x		Ther
	C. multifidum L.# (387) (388)	x		Ther
2269000	***Salsola* L.**			
	S. kali L. (341)	x		Ther

Table 4.3 (continued)

	Species	Ash	Grass	Life form
Amaranthaceae				
2299000	***Amaranthus* L.**			
	A. hybridus L. # (377)	x		Ther
2330010	***Guilleminea* Kunth**			
	G. densa (Willd.) Moq.#	x		Hemicryp
2338000	***Gomphrena* L.**			
	G. celosioides Mart. #	x		Hemicryp
Nyctaginaceae				
2347000	***Mirabilis* L.**			
	M. jalapa L.#	x		Hemicryp
Aizoaceae				
2376000	***Limeum* L.**			
	L. pauciflorum Moq.	x		Hemicryp
	L. viscosum (Gay) Fenzl	x		Ther
Mesembryanthemaceae				
2405033	***Delosperma* N.E. Br.**			
	D. herbeum (N.E. Br.) N.E.Br. (338)	x	x	Cham
Portulacaceae				
2421000	***Portulaca* L.**			
	P.kermesina N.E. Br.	x		Ther
	P. oleracea L.	x		Ther
Caryophyllaceae				
2450000	***Spergularia* (Pers.) J. & C. Presl**			
	S. media (L.) C. Presl ex Griseb.# [2] (245)	x		Cham
Illecebraceae				
2467000	***Pollichia* Aiton**			
	P. campestris Aiton		x	Hemicryp
Caryophyllaceae				
2502000	***Dianthus* L.**			
	D. mooiensis F.N. Williams		x	Hemicryp
Brassicaceae				
2883000	***Lepidium* L.**			
	L. bonariense L.#	x		Ther
2917000	***Sisymbrium* L.**			
	S. thellungii O.E. Schulz (391)	x		Ther
Capparaceae				
3082000	***Cleome* L.**			
	C. monophyla L. (408)	x		Ther
Crassulaceae				
3168000	***Crassula* L.**			
	C. capitella Thunb.		x	Hemicryp
Fabaceae				
Mimosoidea				
3446000	***Acacia* Mill.**			
	A. meamsii De Willd#	x		Phan
	Acacia sp. *cf. gerrardii* Benth var. *gerrardii* (352)	x		Cham
3467000	***Elephantorrhiza* Benth.**			
	E. elephantina (Burch.) Skeels		x	Hemicryp
Caesalpiniodea				
3536010	***Chamaecrista* Moench**			
	C. biensis (Steyaert) Lock [2] (255)	x	x	Ther
Papilionoidea				
3657000	***Lotononis* (D.C.) Eckl. & Zeyh.**			
	L. calycina (E.Mey.) Benth. (320)		x	Ther
	L. foliosa Bolus		x	Hemicryp
3657010	***Pearsonia* Dummer**			
	P. cajanifolia (Harv.) Polhill subsp. *cajanifolia* [2] (244)		x	Hemicryp
3665000	***Melolobium* Eckl. & Zeyh.**			
	M. burchellii N.E. Br. [2] (240)		x	Hemicryp
	M. wilmsii Harms [2] (237)		x	Hemicryp

Table 4.3 (continued)

	Species	Ash	Grass	Life form
3669000	***Crotalaria* L.**			
	C. shinzii Baker f.[2] (297)	x		Ther
3673000	***Argyrolobium* Eckl. & Zeyh.**			
	A. lotoides Harv.[2] (233)		x	Hemicryp
3689000	***Melilotis* Mill.**			
	M. alba Desr. # (355)	x		Ther
3702000	***Indigofera* L.**			
	I. atrata N.E. Br. [2] (238)		x	Hemicryp
	I. filipes Benth. ex Harv.[2] (232)	x		Hemicryp
	I. hilaris Eckl & Zeyh. [2] (239)	x		Hemicryp
	I. torulosa E. Mey var. *angustiloba* (Baker f.) J.B. Gillett [2] (235)		x	Hemicryp
3718000	***Tephrosia* Pers.**			
	T. capensis (Jacq.) Pers. var. *capensis* [2] (230) (241) (242)	x	x	Hemicryp
	T. elongata E. Mey. var. *elongata* [2] (254)		x	Hemicryp
	T. polystachya E. Mey. var. *latifolia* Harv. [2] (231)	x		Hemicryp
3802000	***Stylosanthes* Sw.**			
	S. fruticosa (Retz.) Alston [2] (236)	x		Hemicryp
3804000	***Zornia* J. F. Gmel.**			
	Z. milneana Mohlenbr. (336)	x	x	Hemicryp
3820000	***Lespedeza* Michx**			
	L. cuneata (Dum. Cours.) G. Don# [2] (234)	x		Hemicryp
3897000	***Rhynchosia* Lour.**			
	R. minina (L.) DC. var. *prostrata* (Harv.) Meikle [2] (310)	x		Hemicryp
	R. totta (Thunb.) D.C. var. *totta* (314)		x	Hemicryp
2898000	***Eriosema* (DC.) G. Don**			
	E. burkei Benth. (414)		x	Hemicryp
	E. salignum E. Mey. (407)		x	Hemicryp
3905000	***Vigna* Savi**			
	V. oblongifolia A. Rich. var. *parviflora* (Baker) Verdc. [2] (291)		x	Hemicryp
	V. unguiculata (L.) Walp. subsp. *stenophylla (*Harv.) Maréchal *et al.* [2] (308)	x		Hemicryp
	V. vexillata (L.) A. Rich. var. *vexillata* (324)	x		Hemicryp
3910000	***Dolichos* L.**			
	D. sericeus E. Mey. subsp. *sericeus* [2] (311)		x	Hemicryp
Geraniaceae				
3925000	***Monsonia* L.**			
	M. attenuata Harv. (375)		x	Hemicryp
3928000	***Pelargonium* L'Hér**			
	P. luridum (Andr.) Sweet (337)	x	x	Cryp
	P. minimum (Cav.) Willd	x		Hemicryp
Oxalidaceae				
3936000	***Oxalis* L.**			
	O. depressa Eckl. & Zeyh. (392)	x		Cryp
	O. latifolia Humb., Bonpl. & Kunth #	x		Cryp
	O. obliquifolia Steud. ex Rich. (364)	x		Cryp
Polygalaceae				
4273000	***Polygala* L.**			
	P. hottentotta Presl	x		Hemicryp
Euphorbiaceae				
4407000	***Acalypha* L.**			
	A. angustata Sond. var *glabra* Sond. (425)		x	Hemicryp
4498000	***Euphorbia* L.**			
	E. clavaroides Boiss. var. *truncata* (N.E. Br.) White, Dyer & Sloane		x	Hemicryp
	E .striata Thunb. var. *striata* (395)	x	x	Hemicryp
4498000	***Chamaesyce* S. F. Gray**			
	C. inaequilatera (Sond.) Sojak		x	Ther
Rhamnaceae				
4861000	***Ziziphus* Mill.**			
	Z. zeyheriana Sond.		x	Cham
Tiliaceae				
4953000	***Corchorus* L.**			
	C. confusus Wild	x		Hemicryp

Table 4.3 (continued)

	Species	Ash	Grass	Life form
Malvaceae				
4998000	***Sida* L.**			
	S. dregei Burtt Davy	x	x	Cham
5013000	***Hibiscus* L.**			
	H.aethiopicus L. var *ovatus* Harv.		x	Hemicryp
	H. microcarpus Garcke (361)	x	x	Ther
	H. trionum L.	x		Ther
Sterculiaceae				
5056000	***Hermannia* L**			
	H. depressa N.E. Br.		x	Hemicryp
	H. transvaalensis Schinz. (383)		x	Hemicryp
Tamaricaceae				
5239000	***Tamarix* L.**			
	Tamarix ramosissima Ledeb. #	x		Phan
Thymelaeceae				
5435000	***Gnidia* L**			
	G. caffra (Meisn.) Gilg (339)		x	Hemicryp
	G. kraussiana Meisn. var *kraussiana* (340)		x	Hemicryp
Onagraceae				
5795000	***Epilobium* L.**			
	E. salignum Hausskn (405)	x		Hemicryp
5804000	***Oenothera* L.**			
	O. indecora Cambess. subsp. *bonariensis* W. Dietr.# (334)	x		Ther
	O. laciniata Hill# (379) (327)	x		Ther
	O. tetraptera Cav.#	x		Ther
Apiaceae				
6004010	***Ciclospermum* Lag.**			
	C. leptophyllum (Pers.) Eichler# (325)		x	Ther
6116000	***Peucedanum* L.**			
	P. magalismontanum Sond. (411)		x	Hemicryp
Gentianaceae				
6481000	***Sebaea* Soland. Ex R. Br.**			
	S. grandis (E. Mey.) Steud. (359)	x	x	Ther
	S. leiostyla Gilg (347)		x	Hemicryp
6503000	***Chironia* L.**			
	C. purpurascens (E. Mey.) Benth. *f.* subsp. *humilis* (Gilg) I. Verd. (329)		x	Hemicryp
Periplocaceae				
6747000	***Raphionacme* Harv.**			
	R. hirsuta (E. Mey.) R.A. Dyer ex E. Phillips (350)		x	Hemicryp
Asclepiadaceae				
6778010	***Aspidoglossum* E. Mey.**			
	A. biflorum E. Mey. [2] (299)		x	Hemicryp
6787010	***Pachycarpus* E. Mey.**			
	Pachycarpus sp.		x	Hemicryp
6791000	***Asclepias* L.**			
	A.stellifera Schltr. (335)		x	Hemicryp
	A. fruticosa L.	x		Cham
Convolvulaceae				
7003000	***Ipomoea* L.**			
	I. bathycolpos Hallier f. var. *bathycolpos*		x	Hemicryp
	I. crassipes Hook. (361)		x	Hemicryp
	I. ommaneyi Rendle (421)		x	Hemicryp
	I. purpurea (L.) Roth #	x		Hemicryp
7008010	***Turbina* Rafin.**			
	T. oblongata (E. Mey. ex Choisy) A. Meeuse (358)		x	Hemicryp
Verbenaceae				
7138000	***Verbena* L.**			
	V. bonariensis L.#	x	x	Hemicryp
	V. tenuisecta Briq.#	x		Hemicryp
Lamiaceae				
7236000	***Acrotome* Benth**			
	A hispida Benth. (333)		x	Hemicryp
7366010	***Becium* Lindl.**			
	B. obovatum (E. Mey. ex Benth) N. E. Br. subsp. *obovatum* var *obovatum (349)*		x	Hemicryp

Table 4.3 (continued)

	Species	Ash	Grass	Life form
Solanaceae				
7401000	***Physalis* L.**			
	P. viscosa L.#	x		Ther
7407000	***Solanum* L.**			
	S. nigrum L.# (330)	x		Ther
7415000	***Datura* L.**			
	D. stramonium L.#	x		Ther
Scrophulariaceae				
7460000	***Verbascum* L.**			
	Verbascum sp. *cf. tapsus* L. (316) #	x		Ther
7476000	***Nemesia* Vent.**			
	N. fruticans (Thunb.) Benth. (326)	x		Ther
7519000	**Sutera Roth**			
	Sutera sp *cf. caerulea* (L.f.) Hiern (368)	x		Hemicryp
Selaginaceae				
7568010	***Walafrida* E. Mey.**			
	W. densiflora (Rolfe) Rolfe	x	x	Hemicryp
Scrophulariaceae				
7597010	***Alectra* Thunb.**			
	A. sessiliflora (Vahl) Kuntze[2] (258)	x		Hemicryp
7625000	***Striga* Lour.**			
	S. bilabiata (Thunb.) Kuntze (412)		x	Hemicryp
	S. elegans Benth.		x	Hemicryp
Acanathaceae				
7941000	***Chaetacanthus* Nees**			
	C. costatus Nees		x	Hemicryp
7972000	***Crabbea* Harv.**			
	C. acaulis N.E. Br.		x	Hemicryp
	C. angustifolia Nees (348)		x	Hemicryp
7980000	***Blepharis* Juss.**			
	B. innocua C.B. Clarke var. *innocua* [2] (249)		x	Hemicryp
8094000	***Justicia* L.**			
	J. anagalloides (Nees) T. Anderson[2] (307)		x	Hemicryp
Plantaginaceae				
8116000	***Plantago* L.**			
	P. virginica L.# (321)		x	Ther
Rubiaceae				
8136000	***Kohautia* Cham. Schlechtd.**			
	K. amatymbica Eckl.& Zeyh.	x	x	Hemicryp
8348000	***Pentanisia* Harv.**			
	P. angustifolia (Hochst.) Hochst. (403)		x	Hemicryp
8351020	***Pygmaeothamnus* Robyns**			
	P. zeyheri (Sond.) Robyns var. *rogersii* Robyns		x	Hemicryp
8438000	***Anthospermum* L.**			
	A. rigidum Eckl. & Zeyh. subsp. *pumilum* (Sond.) Puff (317)		x	Hemicryp
8464000	***Richardia* L.**			
	R. brasiliensis Gomes #		x	Hemicryp
Cucurbitaceae				
8599000	***Cucumis* L.**			
	C. zeyheri Sond. (345)	x		Hemicryp
Dipsacaceae				
8546000	***Scabiosa* L.**			
	S. columbaria L. (428)		x	Hemicryp
Campanulaceae				
8668000	***Wahlenbergia* Schrad & Roth**			
	W. undulata (L.F.) A. D.C. (360)	x	x	Hemicryp
Lobeliaceae				
8694000	***Lobelia* L.**			
	L. flaccida (Presl) A. D.C. subsp. *flaccida* [2] (248)	x	x	Ther
8695000	***Monopsis* Salisb.**			
	M. deciplens (Sond.) Thulin (323)		x	Hemicryp

Table 4.3 (continued)

	Species	Ash	Grass	Life form
Asteraceae				
8751000	***Vernonia* Schreb.**			
	V. galpinii Klatt (304)		x	Hemicryp
	V. oligocephala (DC.) Sch. Bip. ex Walp.		x	Hemicryp
8900000	***Aster* L.**			
	A. squamatus (spreng.) Hieron.# (312)	x		Ther
8919000	***Felicia* Cass.**			
	Felicia sp. *cf. fascicularis* D.C.		x	Cham
	F. muricata (Thunb.) Nees	x		Cham
8925000	***Nidorella* Cass.**			
	N. anomala Steetz.	x	x	Ther
8926000	***Conyza* Less.**			
	C. bonariensis (L.) Cronquist#	x	x	Ther
	C. canadensis (L.) Cronquist#	x		Ther
	C. podocephala DC.	x	x	Hemicryp
8992000	***Gnaphalium* L.**			
	G. pensylvanicum Willd.# (357)	x		Ther
8992050	***Pseudognaphalium* Kirp.**			
	P. luteo-album (D.C.) Hilliard & B.L.Burtt	x	x	Ther
	P. undulatum (L.) Hilliard & B.L. Burtt	x	x	Ther
9006000	***Helichrysum* Mill.**			
	H. aureonitens Sch. Bip. (424)		x	Hemicryp
	H. caespititium (DC.) Harv. (384)	x		Hemicryp
	H. callicomum Harv. [2] (259) (322)	x	x	Hemicryp
	H. cephaloideum DC.		x	Hemicryp
	H. coriaceum Harv. (422) (394)		x	Hemicryp
	H. nudifolium (L.) Less. (415)		x	Hemicryp
	H. oreuphium Klatt		x	Hemicryp
	H. rugulosum Less.		x	Hemicryp
9037000	***Stoebe* L.**			
	S. vulgaris Levyns		x	Cham
9130000	***Acanthospermum* Schrank**			
	A. glabratum (D.C.) Wild #	x		Ther
9237000	***Bidens* L.**			
	B. bipinnata L.#	x		Ther
	B. formosa (Bonato) Sch. Bip. #	x		Ther
	B. pilosa L.#	x		Ther
9282000	***Flaveria* Juss.**			
	F. bidentis (L.) Kuntze#	x		Ther
9291000	***Schkuhria* Roth**			
	S. pinnata (Lam.) Cabrera#	x	x	Ther
9311000	***Tagetes* L.**			
	T. minuta L.#	x	x	Ther
9356000	***Schistostephium* Less.**			
	S. crataegifolium (D.C.) Fenzl ex Harv.		x	Hemicryp
9411000	***Senecio* L.**			
	S affinis DC. (417) (416)		x	Hemicryp
	S. asperulus DC. [2] (298)	x		Hemicryp
	S. consanguineus DC. (370)	x		Ther
	S. coronatus (Thunb.) Harv. (367)		x	Hemicryp
	S. erubescens Aiton var *crepidifolius* DC. (393)	x		Hemicryp
	S. harveianus MacOwan (423)	x		Hemicryp
	S. hieracioides DC. (376)		x	Hemicryp
	S. oxyriifolius D.C.		x	Hemicryp
	S. polyodon DC.var *polyodon* (385)	x		Hemicryp
9417000	***Euryops* Cass.**			
	E. transvaalensis Klatt (305) (372)		x	Hemicryp
9425010	***Castalis* Cass.**			
	C. spectabilis (Schltr.) T. Norl. (427)		x	Hemicryp
9432030	***Haplocarpha* Less**			
	H. lyrata Harv. (369)		x	Hemicryp

Table 4.3 (continued)

	Species	Ash	Grass	Life form
9434000	***Gazania* Gaertn.**			
	G. krebsiana Less. subsp. *serrulata* (DC.) Rössl.		x	Hemicryp
9438000	***Berkheya* Ehrh.**			
	B. setifera DC. (400)		x	Hemicryp
	B. zeyheri (Sond. & Harv.) Oliv. Hiem (401) (413)		x	Hemicryp
9462000	***Cirsium* Mill. *emend.* Scop**			
	C. vulgare (Savi) Ten.# (342)	x		Ther
9501000	***Dicoma* Cass.**			
	D. gerrardii Harv. ex F.C.Wilson		x	Hemicryp
	D. zeyheri Sond. subsp. *Zeyheri* (331)		x	Hemicryp
9528000	***Gerbera* L.**			
	G. galpinii Klatt [2] (243)		x	Hemicryp
	G. piloselloides (L.) Cass		x	Hemicryp
	G. viridifolia (DC.) Sch. Bip. subsp. *natalensis* (Sch. Bip.) H.V.Hansen (354)		x	Hemicryp
9572000	***Hypochoeris* L.**			
	H. radicata L.# (406)	x		Hemicryp
9592000	***Taraxacum* Weber *ex* Wiggers**			
	T. officinale Weber *sens. lat.* #	x		Hemicryp
9579000	***Tragopogon* L.**			
	T. dubius Scop# (420)	x		Ther
9595000	***Sonchus* L.**			
	Sonchus sp. (380)	x		Ther
	Sonchus sp. *cf. asper* (L.) Hill subsp. *asper#* (351)	x		Ther
	S. oleraceus L.#	x		Ther
9596000	***Lactuca* L.**			
	L. capensis Thunb. (328)	x		Hemicryp

Exotic species #
Species used in rehabilitation *
1: According to Retief & Herman (1997)
2: Identified by the National Botanical Institute, Pretoria

Life forms according to Ranklaer (1934)

Cham:	Chamaephytes
Cryp:	Cryptophytes
Hemicryp:	Hemicryptophytes
Phan:	Phanerophytes
Ther:	Therophytes

Numbers in brackets are collectors numbers for Morgenthal, T.L. housed in the A.P. Goossens (PUC) Herbarium

Chapter 5 SPATIAL HETEROGENEITY IN THE VEGETATION COMPOSITION OF REHABILITATED ASH DISPOSAL SITES*

Abstract: Vegetation of disturbed areas consists of a mosaic of successional patterns relating to time and condition of abandonment. The aim of this study is to determine the spatial heterogeneity between survey grids, and how the community structure of ash disposal sites with different site conditions, rehabilitation ages and abandonment characteristics changes in relation to each other. The hypothesis tested in this study is that heterogeneity and therefore community structure between sites will remain constant.

The unweighted pair-group average cluster (UPGMA) analysis and the Detrended Correspondence Analysis (DCA) ordination technique are used to determine the changes in spatial heterogeneity of grids over three years.

The newly rehabilitated area, revegetated less than one year, illustrates the greatest changes. This area illustrates convergence to older rehabilitated sites, but remain a separate group over the three years. Shifts in the cluster positions, indicating community change, are also observed for grids on older rehabilitated areas. Many sites of older rehabilitated areas that are grouped together at the onset of the study remained associated with each other. Although changes in the community structure occur, these are not drastic because the linkage distances between the third and fourth division level remained small. The eigenvalues between ordinations of consecutive years also remained relatively similar indicating little change in heterogeneity of the vegetation. Changes in the community structure are due to increases in importance value of *Hyparrhenia hirta* and decreases in importance value of *Eragrostis curvula* and *Pennisetum clandestinum*. The stochastic nature of annual forb populations is probably another reason for changes in community structure. The hypothesis of this study cannot be rejected because although change in community structure occurred it did not influence heterogeneity of the vegetation on old rehabilitated sites.

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* Submitted for publication in *Landscape and Urban Planning*

CONTENTS

5.1 INTRODUCTION

Initial site conditions may have important effects on the vegetation development and species composition of revegetated areas. Changes in the structure of plant communities can, be influenced by the presence or absence of certain species or abandonment characteristics (soil characteristics, year and season of abandonment and previous crop) during earlier succession, according to Egler (1954) and Myster & Picket (1990). Vegetation of a rehabilitated area would, therefore, also consist of a mosaic of successional patterns related to time and conditions of abandonment as found in old-field succession (Barbour *et al.*, 1987 and Glenn-Lewin & Van der Maarel, 1992). The study of spatial patterns is therefore important, to understand changes in community structure (Glen-Lewin & Van der Maarel, 1992).

Miller *et al.* (1995) illustrated the importance of scale in spatial heterogeneity. In their study on the spatial dynamics of dune vegetation Yarranton & Morrison (1974) indicated that vegetation changed from a colonisation stage to a persistent stage. For the study of grassland dynamics, Austin (1980) used a transition matrix and numerical classification to determine statistically the probability of a sample remaining in the same community.

The aim of the present study is to investigate the spatial heterogeneity of vegetation on ash disposal areas regarding its species composition and community structure.

The hypothesis tested in this study is that heterogeneity and therefore community structure between sites will remain constant. The magnitude of the DCA ordination eigenvalues is used as an indication of the heterogeneity between sites and is compared between years to determine if heterogeneity remains constant. Cluster analyses and ordination diagrams of consecutive years are compared to detect changes in the community structure of rehabilitated sites and to describe these changes.

This study differs from the phytosociological study (Chapter 3) in that this study is conducted on quantitative data on a smaller scale over a period of three years. This study is also important to determine the existence of stable states in the vegetation.

No attempt is made to explain specific groupings or to relate environmental factors to any of the ordination axes subjectively. This will be investigated in Chapter 8 of the study, where the CANOCO program will be used to directly relate environmental variables to species occurrences. This approach ensures that the relationship between species occurrences and environmental factors is valid statistically and verified objectively.

5.2 MATERIALS AND METHODS

5.2.1 Data sampling

Survey data of ten survey grids (grids 1, 2, 3, 4, 7, 8, 9, 10, 11 and 12 of which only the middle transects were included of grids 7 and 8, located on newly rehabilitated areas), were used for this study. Survey grids are characterised by different ages after rehabilitation and rehabilitation treatments (see Chapter 2 for description of survey grids). Grids 5 and 6 were excluded because surveys on these grids were abandoned shortly after initiation of the monitoring program due to a shortage of survey time. The total number of sample plots for every year consisted of 28 sampling plots. Surveys of these plots extended over a period of three years (March 1997-February 1999) and included frequency, basal cover and density surveys. The descending point method was used to obtain frequency and basal cover data. Approximately 120 points were surveyed along each transect. At each point the nearest plant within a radius of 30 cm was noted. If no plant occurred within this radius, the point was noted as bare ground. Additionally, basal hits were also noted to obtain the basal cover of each species. Density surveys were conducted in five quadrats of 1 m^2 along each transect. The five quadrats are summed to give an indication of the densities of species over the entire transect. These surveys were repeated each year during the growing season (January-March) from 1997 to 1999.

5.2.2 Data analysis

Data were analysed with multivariate data analysis techniques, using the importance values for each species over each transect. Data sets were analysed separately. Multivariate analysis is a meaningful approach for the study of plant community dynamics, because multi-species data are summarised to give a better indication of the relationship between sample plots (Austin, 1980 and Austin *et al.* 1981).

The average importance values of grids of every year were used to classify grids into homogeneous clusters. The unweighted pair-group average clustering analysis (UPGMA) technique, calculated from Square Euclidean Distances (SED) as coefficient was employed to determine how grids were related to each other for every year from 1997 until 1999. STATISTICA-for Windows (1995) was used for the calculation of the SED matrices and the construction of a dendrogram from the unweighted pair-group average cluster analysis. The unweighted pair-group average cluster analysis (UPGMA), together with the centroid clustering technique, are some of the most frequently used techniques for hierarchical classification (Magurran, 1988 and Gaugh, 1982). The unweighted pair-group average cluster analysis was employed due to the ease of computation and construction of the dendrogram by the STATISTICA computer program. Thatcher (1979) also used this cluster technique to determine the relationship between different plant communities on gold slime dams in the Witwatersrand.

DCA ordination was applied thereafter to organise data for further interpretation of the three data sets of each year. Ordination can be regarded as a next logical step after classification. Classification procedures only attempt to group similar grids and also to explain how these groups (clusters) are hierarchically related in a dichotomous arrangement. Ordination explains the variation in the data set by organising grids and species on a two-dimensional graph. The result of an ordination is the arrangement of species and samples in a low-dimensional space so that samples with similar species are in proximity of each other and sample plots with dissimilar species far apart (Gauch, 1982).

DCA-ordination technique (Hill, 1979b) from the CANOCO computer program (Ter Braak, 1987-1992) was employed and was run on the given default values of the program. Data from the 1997, 1998 and 1999 summer season, consisting of 28 sampling transects from the ten grids, were analysed separately. Samples were grouped together in the scatter diagram of the DCA ordination of samples based on the clusters indicated on the third division level in the dendrogram of each year.

5.3 RESULTS

5.3.1 Spatial heterogeneity of grids during 1997

Figure 5.1 illustrates the hierarchical classification of sampling plots during the 1997 season. Grids are first divided into newly rehabilitated (one year after rehabilitation commencement) (G8/2 & G7/2) and older rehabilitated areas (> 3 years after rehabilitation commencement). According to the cluster diagram (Figure 5.1) newly rehabilitated areas are relatively heterogeneous in species composition. The older rehabilitated areas are further sub-divided into three different groups with SED values larger than 2. Transect G7/3 from grid 7 is first separated from the remaining grids and then grids G9, G2 and G1 are separated from the other grids (Figure 5.1). The remaining grids are sub-divided again into two different groups with SED larger than 1. The clusters of Grids G10 and G11 are separated from the cluster of grids G8/3, G12, G4 and G3.

The following species were dominant in the different clusters during 1997:

a) *Cyperus esculentus, Pennisetum clandestinum, Eragrostis tef* and *Enneapogon cenchroides* (G8/2 and G7/2).
b) *Hyparrhenia hirta* and *Bidens formosa (*G7/3).
c) *Eragrostis curvula, Cynodon dactylon* and *Hyparrhenia hirta* (G11, G10, G8/3, G12, G4 and G3).
d) *Pennisetum clandestinum, Eragrostis curvula* and *Hyparrhenia hirta* (G9, G2 and G1).

Similar results are portrayed by the DCA ordination of the 28 sampling transects from the ten grids, and a degree of conformity is visible. The cluster groups from the first three divisions are also evident in DCA sample ordination (Figure 5.2). Transects 7/2 and 8/2 (newly rehabilitated areas) occur as outliers to the left on ordination axis 1 (Group A). The remaining grids are situated in close proximity to each other. Grid G1 occurs nearest to the newly rehabilitated transects (G7/2 & G8/2). The rest of the clusters indicated in Figure 5.1 are grouped together in the ordination diagram. Group B (Grids G1, G2, and G9) occurs to the left of ordination axis 1 and Group C (G10, G11, G12, G3, G4 and G8/3) is situated to the right of ordination axis 1. Transects G7/3 and G8/3 are however disjuncted from the rest of the grids and occur on opposite poles of ordination axis 2. Although both transects G7/3 and G8/3 occur as outliers in the ordination diagram, only G7/3 is grouped on its own in Figure 5.1. The DCA ordination (Figure 5.2) and cluster analysis (Figure 5.1) therefore differ in their interpretation of transect G8/3.

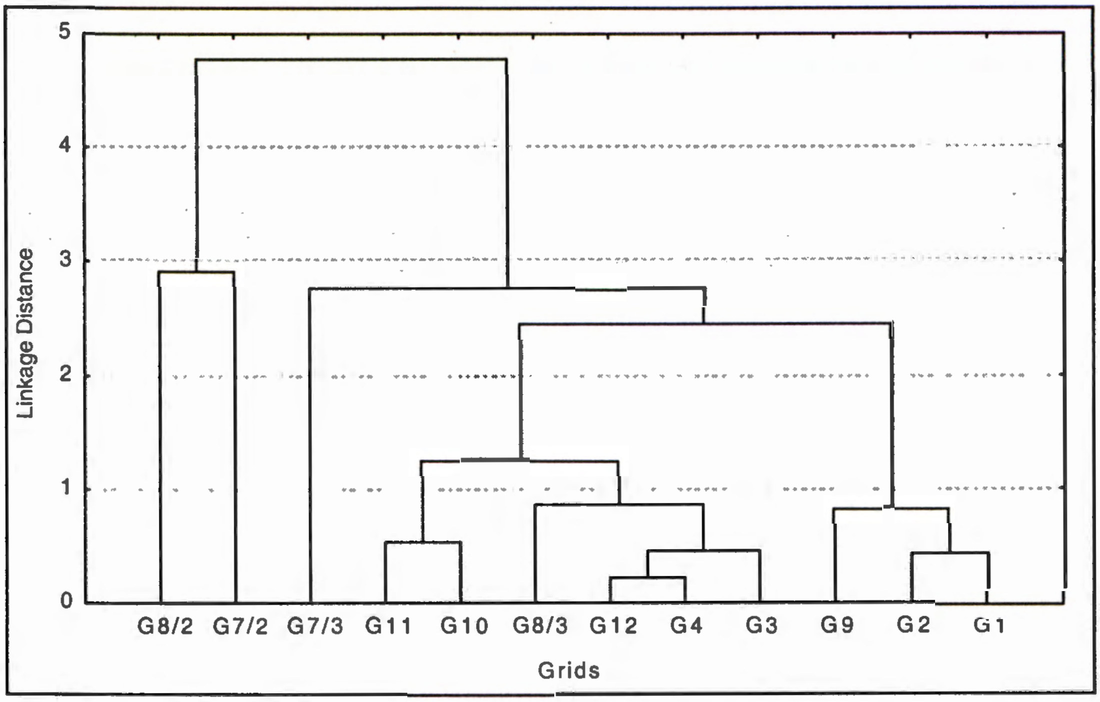

Figure 5.1: Dendrogram of an unweighted pair-group average clustering analysis with Square Euclidean distances as linkage distance, illustrating differences between grids on rehabilitated ash disposal sites at Hendrina Power Station during the 1997 season.

The species ordination illustrates a wedge effect in the data (Figure 5.3). Four species groups can be separated, which are little associated with clusters indicated in Figure 5.1. Species in Group 1 (Figure 5.3) are related to the transect 7/2 and 8/2 (Group A, Figure 5.2) on newly rehabilitated areas. Group 1 (Figure 5.3) consists of the annuals *Enneapogon cenchroides* (Enna cen), *Eragrostis tef* (Erag tef), *Eleusine coracana* subsp. *africana* (Eleu cor), *Chloris virgata* (Chlo vir), *Commelina benghalensis* (Comm ben) and *Amaranthus hybridus* (Amar hyb). The second species group (Group 2) represents species from the remainder of the grids, except for species from transects G7/3 and G8/3. By comparing the location of the groups, indicating the clusters, in the sampling ordination (Figure 5.2) with the species ordination (Figure 5.3) the following can be inferred. Group B (G1, G2 and G9) (Figure 5.2) has high importance values of *Pennisetum clandestinum* and *Tagetes minuta* (Group 2, Figure 5.3). Group C (G3, G4, G8/3, G10, G11 and G12) (Figure 5.2) is less associated with the species *Pennisetum clandestinum* and, more associated with *Eragrostis curvula*, *Cynodon dactylon* and, in the case of G9, G10 and G11, also with *Hyparrhenia hirta* (Group 2, Figure 5.3).

The species composition of the grids at the bottom of the ordination axis 2 (Figure 5.2) is dominated by *Eragrostis curvula* (Erag cur), and sampling girds situated at the top (Figure 5.2) are dominated by *Hyparrhenia hirta* (Hypa hir). The gradient along ordination axis 2 in this group is of particular interest because it indicates the differences between rehabilitated grassland dominated by either *Eragrostis curvula* or by *Hyparrhenia hirta*. Species associated with *Eragrostis curvula* were *Eragrostis plana* (Erag plana), *Imperata cylindrica* (Impe cyl), *Verbena bonariensis* (Verb bon), *Rhynchosia* spp. (Rhyn spp.) *and Lespedeza cuneata* (Lesp cun) (Figure 5.3). Species which were associated with *Hyparrhenia hirta* included *Heteropogon contortus* (Hete con), *Chloris gayana* (Chlo gay), *Setaria pallide-fusca* (Seta pal) and *Pogonarthria squarrosa* (Pogo squ) (Figure 5.3).

Species in Group 3 (Figure 5.3) are associated with Group D in the sample ordination (Figure 5.2). Species occurring in this species group are *Melinis repens* (Meli rep), *Bidens formosa* (Bide for), *Flaveria bidentis* (Flav bid) and *Hyparrhenia tamba* (Hypa tam). Transect G7/3 is dominated by an almost pure stand of *Hyparrhenia hirta*.

Species group 4 (Figure 5.3), situated at the bottom right-hand side of ordination axis 1, represents species from grid G8/3 (Figure 5.2) and is characterised by the low occurrence of *Hyparrhenia hirta* (Group 2, Figure 5.3). Moist soil conditions are typical in this grid, resulting in a high cover of mosses (not included in species ordination). Species associated with G8/3 includes *Conyza* spp. (Cony spp), *Asclepias fruticosa* (Ascl fru), *Cirsium vulgare* (Cirs vul) and *Hypochaeris radicata* (Hypo rad). *Eragrostis curvula* is the dominant species along this grid.

5.3.2 Spatial heterogeneity of grids during 1998

A reduction in heterogeneity from the 1997 season to the 1998 season from more than 4 square Euclidean Distances (SED) (Figure 5.1) to less than 4 SED (Figure 5.4) is evident on the dendrogram drawn from the average importance values of the 1998 data set (Figure 5.4). The division between newly rehabilitated and older rehabilitated grids does not exist any more in the dendrogram of the 1998 data (Figure 5.4). Transect G7/3 is still an outlier from the remaining grids, which are mainly represented by two other clusters with a SED of more than 2.5. The first of these two clusters form two smaller clusters with G11, G10 and G9 in one group and G8/3, G12, G4 and G3 in another group. The second cluster incorporates two smaller clusters; the first includes the transects 8/2 and 7/2 from the newly rehabilitated areas and the second, grids G2 and G1.

The following species were dominant in the different clusters during 1998:

a) *Hyparrhenia hirta* and *Conyza bonariensis* (G7/3).
b) *Eragrostis curvula, Hyparrhenia hirta* and *Cynodon dactylon* (G11, G10 and G9).
c) *Eragrostis curvula, Conyza bonariensis* and *Cynodon dactylon* (G8/3, G12, G4 and G3).
d) *Pennisetum clandestinum, Cyperus esculentus* and *Eragrostis curvula* (G8/2, G7/2).
e) *Pennisetum clandestinum, Hyparrhenia hirta* and *Eragrostis curvula* (G2 and G1).

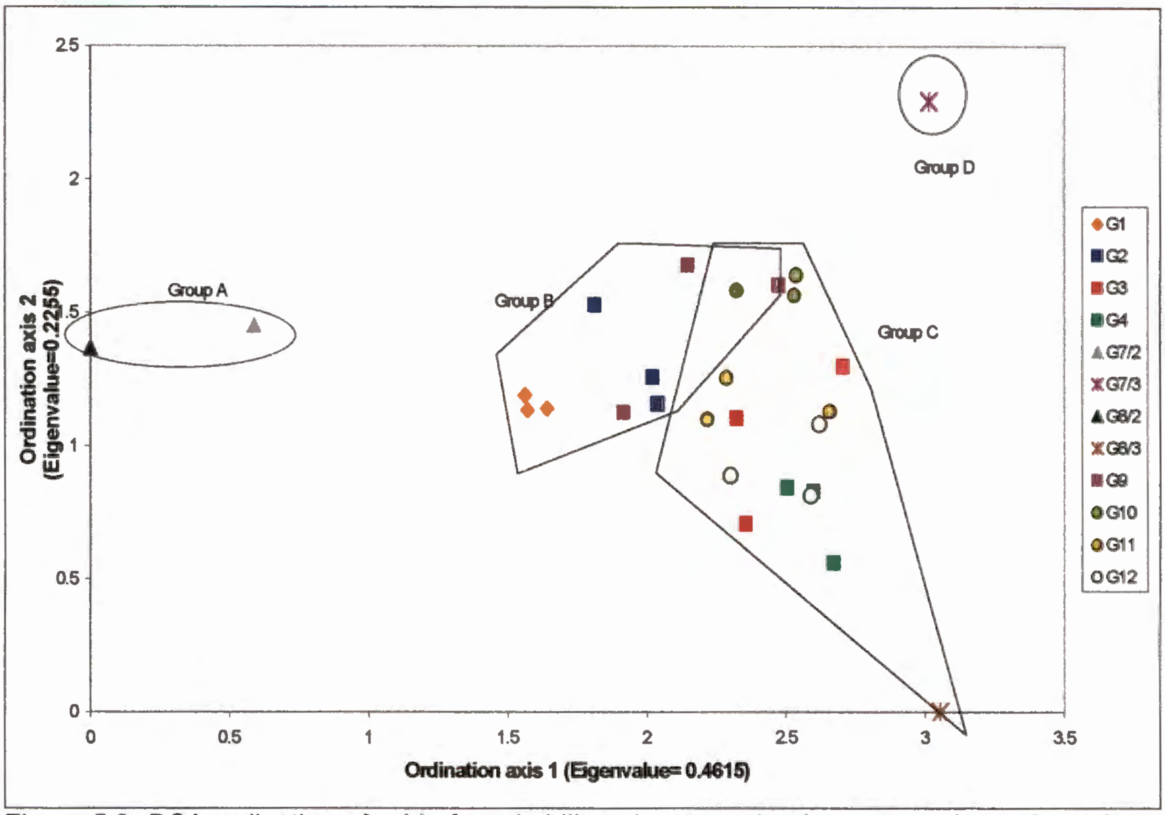

Figure 5.2: DCA ordination of grids for rehabilitated areas using important values of species during the 1997 season at Hendrina Power Station.

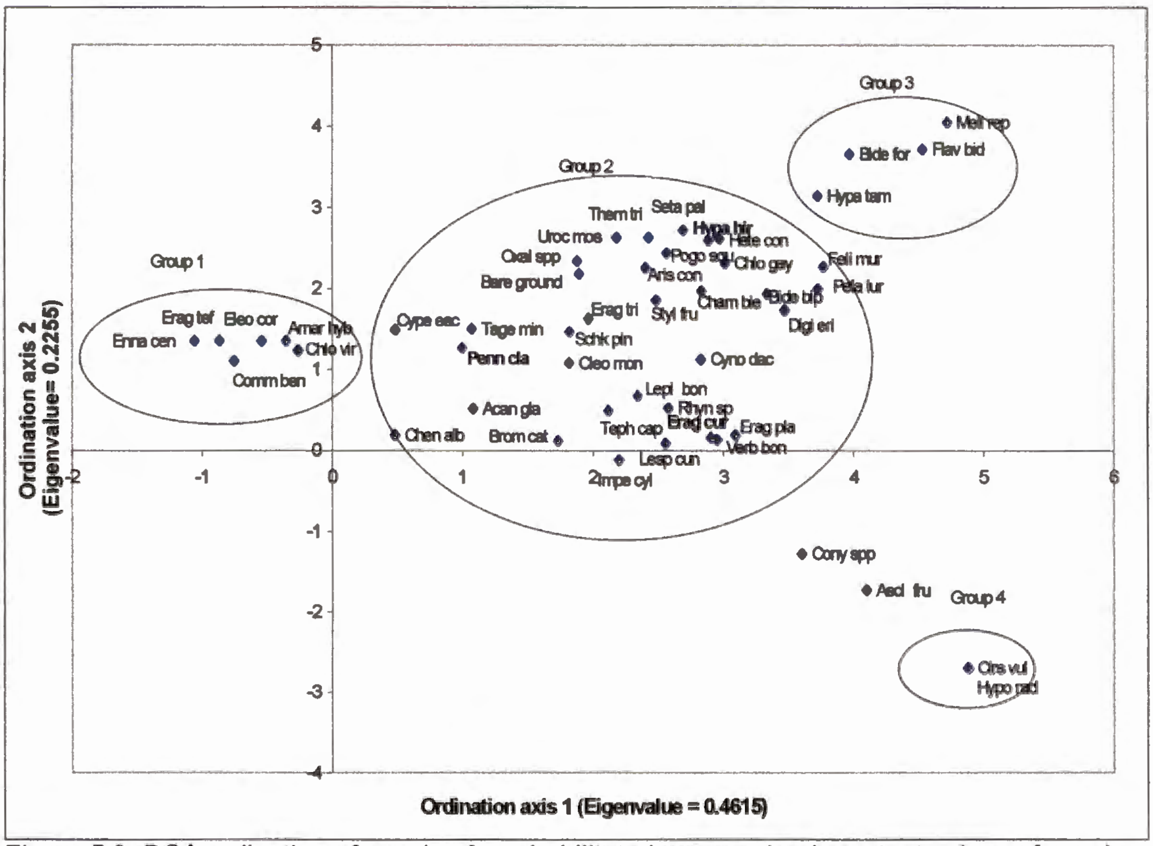

Figure 5.3: DCA ordination of species for rehabilitated areas using important values of species during the 1997 season at Hendrina Power Station

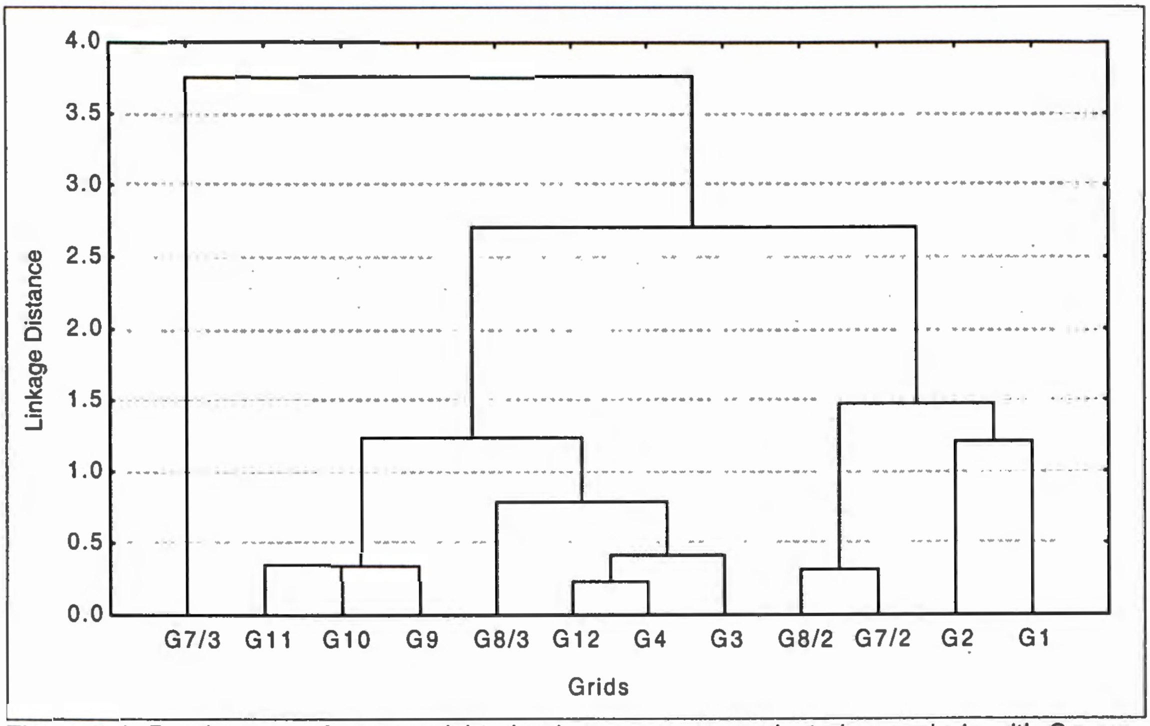

Figure 5.4: Dendrogram of an unweighted pair-group average clustering analysis with Square Euclidean distances as linkage distance, illustrating differences between grids on rehabilitated ash disposal sites at Hendrina Power Station during the 1998 season,

The positions of the different clusters are indicated in the DCA ordination of grids (Figure 5.5). Figure 5.5 illustrates considerable changes in the positions of the grid in the DCA sample ordination from 1997 (Figure 5.2) to 1998. Main differences in the orientation of grids in the ordination diagram are the position of transects G7/2 and G8/2 in relation to the other grids in the diagram (Figure 5.5). As already indicated, clusters are also separated further in the ordination diagram in 1998 than in 1997 and are associated better in the ordination scatter diagram (Figure 5.5). Little overlap in the cluster groups in the ordination diagram also exists.

The gradient along ordination axis 1 from newly rehabilitated to older rehabilitated areas, as observed in 1997 (Figure 5.2), is not so explicit any more. In 1998, transects G7/2 and G8/2 (two year old rehabilitated areas) occur together with G1 and G2 on the left side of ordination axis 1 (Group A) (Figure 5.5). This is in accordance with the dendrogram (Figure 5.4).

Most of the remaining grids are situated in the middle of ordination axis 1, while G8/3 occurs as an outlier on the right side of ordination axis 1 (Figure 5.5). Transect G7/3 occurs as an outlier at the bottom of ordination axis 2 (Group D- Figure 5.5) as well as in the unweighted pair-group average cluster analysis (Figure 5.4). Group B indicates that the cluster of Grids G9, G10 and G11 is situated to the middle of the first ordination axis (Figure 5.5). Grids G12, G4, G3 and G8/3, which form a separate cluster in Figure 5.4, are situated to the right along ordination axis 1 (Group C) (Figure 5.5).

Figure 5.6 represents the distribution diagram of the DCA ordination of species during 1998. If Figure 5.5 (sample ordination) and Figure 5.6 (species ordination) are compared, certain observations about species distribution patterns can be made. The species *Amaranthus hybridus* (Amar hyb), *Bromus catharticus* (Brom cat), *Commelina benghalensis* (Comm ben), *Chenopodium album* (Chan alb) and *Pogonarthria squarrosa* (Pogo squ), which is indicated by Group 1 (Figure 5.6), can be associated with the transects occurring on newly rehabilitated areas (G7/2 & G8/2) (Figure 5.5). The newly rehabilitated sites are separated from grid 1 at the bottom of ordination axis 2 (located on unsown areas of ash disposal site 1) (Figure 5.5), based on the occurrence of these species in Group 1 and the low occurrence species in Group 2. Species in Group 2 include *Sebaea grandis* (Sebe gra), *Eragrostis trichophora* (Erag tri), *Acanthospermum glabratum* (Acan gla), *Bidens formosa* (Bide for) and *Pennisetum clandestinum* (Penn cla) (Figure 5.6).

Ordination axis 1 (Figure 5.6) probably represents a gradient in the importance values of the species *Pennisetum clandestinum* (Penn cla), *Tagetes minuta* (Tage min), *Eragrostis trichophora* (Erag tri) and *Bidens formosa* (Bide for), which decreases from left to right along ordination axis 1. *Eragrostis curvula* (Erag cur) (Group 5, Figure 5.6) and *Conyza bonariensis* (Cony bon) (Group 6, Figure 5.6), however, increase in importance values from left to right along ordination axis 1 (Figure 5.6). The grass *Eragrostis curvula,* therefore, dominates the vegetation at grids G12, G4, G3 and G8/3 (Group C, Figure 5.5). Figures 5.5 and 5.6 further illustrates that *Chamaecrista biensis* (Cham bie), *Eragrostis chloromelas* (Erag chl), bare ground, *Themeda triandra* (Them tri), *Eragrostis echinochloidea* (Erag ech), *Agrostis eriantha* (Agro eri) and *Digitaria eriantha* (Digi eri) (Group 3, Figure 5.6) are associated with grids G10, G11 (Group B, Figure 5.5) and G12 (Group C, Figure 5.5).

The positions of the outliers G7/3 and G8/3 are due to the absence of most of the species occurring in the centre of the ordinal space. A number of species is also associated with transect G8/3 including *Pseudognaphalium luteo-album* (Pseu lut), *Verbena bonariensis* (Verb bon), *Cirsium vulgare* (Cirs vul), *Sonchus oleraceus* (Sonc ole), *Agrostis lachnantha* (Agro lac) and *Epilobium salignum* (Epil sal) (Group 4, Figure 5.6). Most of these species are associated with this sampling transect due to higher moisture conditions (on most of the occasions during surveys these areas were characterised by wet conditions and high moss coverage).

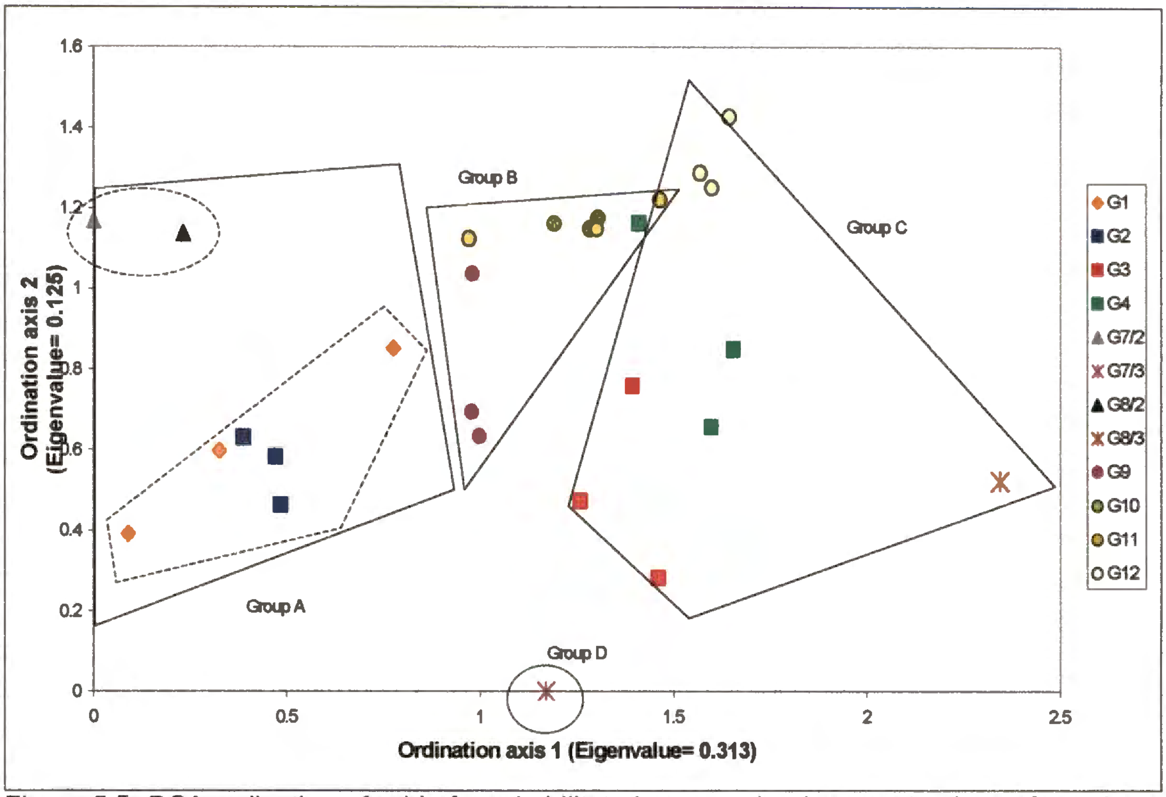

Figure 5.5: DCA ordination of grids for rehabilitated areas using important values of species during the 1998 season at Hendrina Power Station.

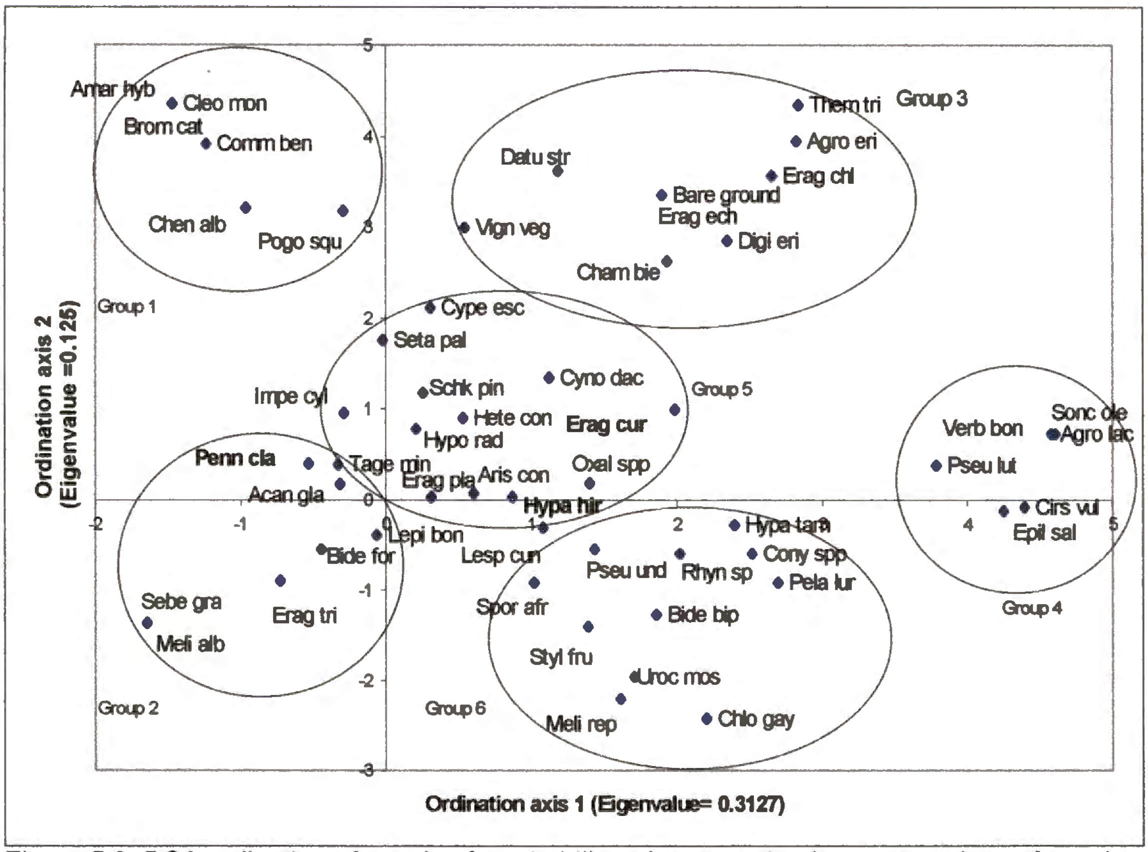

Figure 5.6: DCA ordination of species for rehabilitated areas using important values of species during the 1998 season at Hendrina Power Station.

Group D (Figure 5.5) can be associated with species of Group 6 (Figure 5.6); namely *Melinis repens* (Meli rep), *Chloris gayana (Chlo gay)* and *Urochloa mosambicensis* (Uroc mos) and the absence or lower occurrence of species in Group 3 (Figure 5.6). Group D (Figure 5.5) is also dominated by the species *Hyparrhenia hirta* (Hypar hir). Grids 2 and partially grid 4 of Group C are associated with species of Group 6 (Figure 5.6). Species in Group 6 includes *Hyparrhenia tamba* (Hypa tam), *Conyza* spp (Cony spp), *Pelargonium luridum* (Pela lur*), Stylosanthes fruticosa* (Styl fru), *Sporobolus africana* (Spor afr), *Bidens bipinnata* (Bide bip), *Lespedeza cuneata* (Lesp cun) and *Rhynchosia* sp. (Rhyn sp).

Species in Group 5 (Figure 5.6), which include *Heteropogon contortus* (Hete con), *Cynodon dactylon* (Cyno dac), *Arsitida congesta* (Aris con), *Eragrostis plana* (Erag plana) and *Hypochaeris radicata* (Hypo rad) are associated with grids in Group B, especially grid 9 (Figure 5.5). Species in Group 5 may also have a common occurrence throughout the grids for example *Eragrostis curvula* (Erag cur), *Hyparrhenia hirta* (Hypa hir) and *Cynodon dactylon* (Cyno dac*).*

5.3.3 Spatial heterogeneity of grids during 1999

The dendrogram from the unweighted pair-group average cluster analysis of importance values from 1999 (Figure 5.7) is similar to the dendrogram of importance values of 1998 (Figure 5.4). Transect G7/3 is again an outlier from the rest of the survey grids. Transects G8/2 and G7/2, occurring on newly rehabilitated areas, have shifted in their position from the 1998 to the 1999 dendrogram. These two transects from grids G7 and G8 now occur together with G12, G8/3 and G4 in a separate cluster. This cluster however splits to separate the two transects (G7/2 & G8/2), which occurs on newly rehabilitated areas, from G12, G8/3 and G4 on a SED of 1,321. Grids G11, G10, G9, G3, G2 and G1 form a separate cluster on a SED of 2.022 at the second division of the clustering procedure. Grid G1, however, is included in a separate cluster on a SED of 1.62.

The following species were dominant in the different clusters during 1999:

a) *Hyparrhenia hirta* and *Conyza bonariensis* (G7/3).
b) *Eragrostis curvula, Cyperus esculentus* and *Tagetes minuta* (G8/2 and G7/2).
c) *Eragrostis curvula, Cynodon dactylon* and *Chamaecrista biensis* (G12, G8/3 and G4).
d) *Hyparrhenia hirta, Eragrostis curvula* and *Chamaecrista biensis* (G11, G10, G9, G3 and G2).
e) *Pennisetum clandestinum, Eragrostis curvula* and *Chamaecrista biensis* (G1).

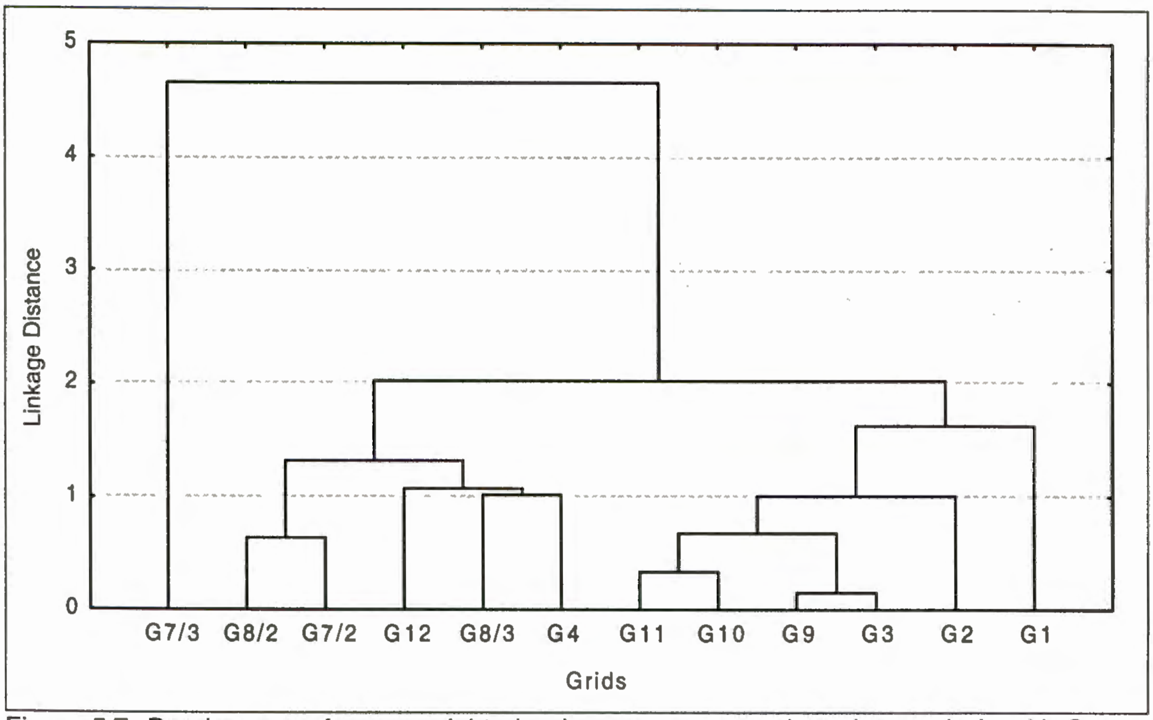

Figure 5.7: Dendrogram of an unweighted pair-group average clustering analysis with Square Euclidean distances as linkage distance, illustrating differences between grids on rehabilitated ash disposal sites at Hendrina Power Station during the 1999 season.

The position of clusters described in Figure 5.7 are indicated in the DCA ordination scatter diagram of grids (Figure 5. 8). Transects G7/3 and G8/3 are outliers in the ordination space. Although G7/3 occurs as a separate cluster, G8/3 is grouped together with G4 and G12 (Group D) in the cluster analysis (Figure 5.7). Grid 1, which is a separate cluster in Figure 5.7, is situated at the bottom left-hand side of the ordination diagram (Group B). Group C, indicating the cluster group of grids G2, G3, G9, G10 and G11, occurs to the left of ordination axis 1. Transects on newly rehabilitated sites (G7/2 and G8/2) (Group A) also occur at the bottom of ordination axis 2 together with Grid G1 (Group B). Group D, consisting of the grids G4, G12 and G8/3, occurs to the middle and right of ordination axis 1.

The species ordination (Figure 5.9) for the 1999 data indicates two groups of species. Group 1 represents species from the largest section of the sampling data and Group 2 represents species (*Calamagrostis* sp. (Cala spp), *Agrostis lachnantha* (Agro lac), *Cirsium vulgare* (Cirs vul), *Sonchus oleraceus* (Sonc ole), *Conyza bonariensis* (Cony bon), *Pseudognaphalium* spp. (Pseu spp), *Hyparrhenia tamba* (Hypar tam) *Verbena bonariensis* (Verb bon) and *Hypochaeris radicata (Hypo rad)*), of which mostly occur at G8/3. Ordination axis 1 of Figure 5.9 again represents a gradient in the importance values of *Pennisetum clandestinum* (Penn cla) and *Hyparrhenia hirta* (Hypa hir) which decreases from left to right, and *Eragrostis curvula,* which increases from left to right along ordination axis 1. Grids G10, G11 and transect G7/3 (Figure 5.8) are more associated with particularly *Hyparrhenia hirta* (Hypa hir) and also *Eragrostis echinochloidea* (Erag ech), *Nemesia fruticans* (Neme fru) and *Urochloa mosambicensis* (Uroc mos) (Figure 5.9). Comparison between the sample (Figure 5.8) and species (Figure 5.9) ordination indicates that the species *Acanthospermum glabratum* (Acan gla), *Paspalum scrobiculatum* (Pasp scr) and *Kyllinga erecta* (Kyll ere) are associated with grid G1. Transect G7/2 is associated with *Pogonarthria squarrosa* (Pogo squ), *Datura stramonium* (Datu str) and *Enneapogon cenchroides* (Enna cen), and transect G8/2 is associated with *Tragopogon dubius* (Trag dub). Figure 5.9 also indicates that *Hyparrhenia hirta* (Hypa hir) is more dominant to the top of ordination axis 2. The bottom of ordination axis 2 is associated more with vegetation consisting of annual species, especially *Tagetes minuta* (Tage min), *Bidens bipinnata* (Bide bip), *Senecio consanguineous* (Sene con) and *Bidens formosa* (Bide for) (Figure 5.9). Therefore vegetation of G7/3, G10 and G11 will have a higher occurrence of *Hyparrhenia hirta* than vegetation of G9, G1, G7/2 and G8/2 that will consist more of the annual species mentioned at the bottom of ordination axis 2 (Figure 5.8). It can be inferred from the relationship between *Hyparrhenia hirta* and *Eragrostis curvula* in the ordination space of Figure 5.9 that these two species do not share a dominant position. Group D (Figure 5.8) (Grids G8/3, G12, G4) is also associated with higher occurrence of *Eragrostis curvula* (Erag cur) (Figure 5.9).

5.3.4 Eigenvalues

If the magnitude of the eigenvalues is used as a measure of the amount of heterogeneity in the data set, it can be inferred that, from 1997 to 1998, there was a reduction in heterogeneity in the vegetation on rehabilitated ash disposal sites (Table 5.1). The difference in the sum of eigenvalues can be explained by the convergence of the newly rehabilitated areas towards plant communities of an older rehabilitation age. From the 1998 season to the 1999 season, the heterogeneity of vegetation did not decrease again, but increased slightly. The species gradient along ordination axis 1 decreased from 1997 to 1998, and remained the same during 1999. A similar trend can be observed for the second ordination axis from 1997 to 1998. This could probably be due to an increase in annual species during the 1999 growth season, which can be derived from the distribution of species along ordination axis 2 (Figure 5.9).

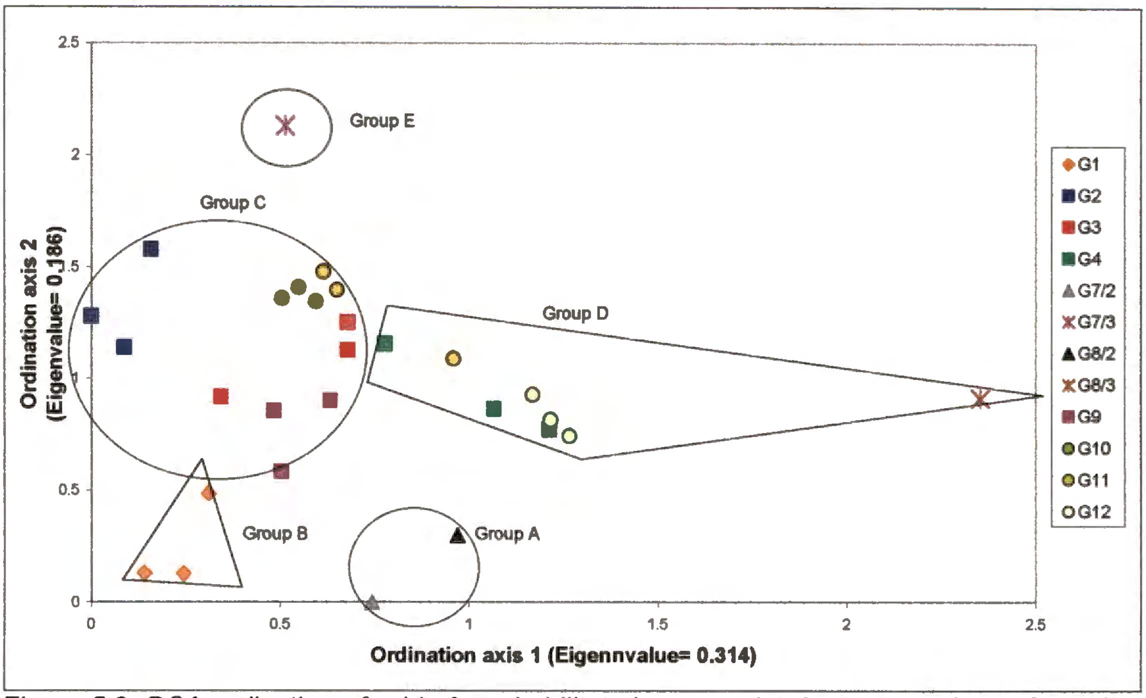

Figure 5.8: DCA ordination of grids for rehabilitated areas using important values of species during the 1999 season at Hendrina Power Station.

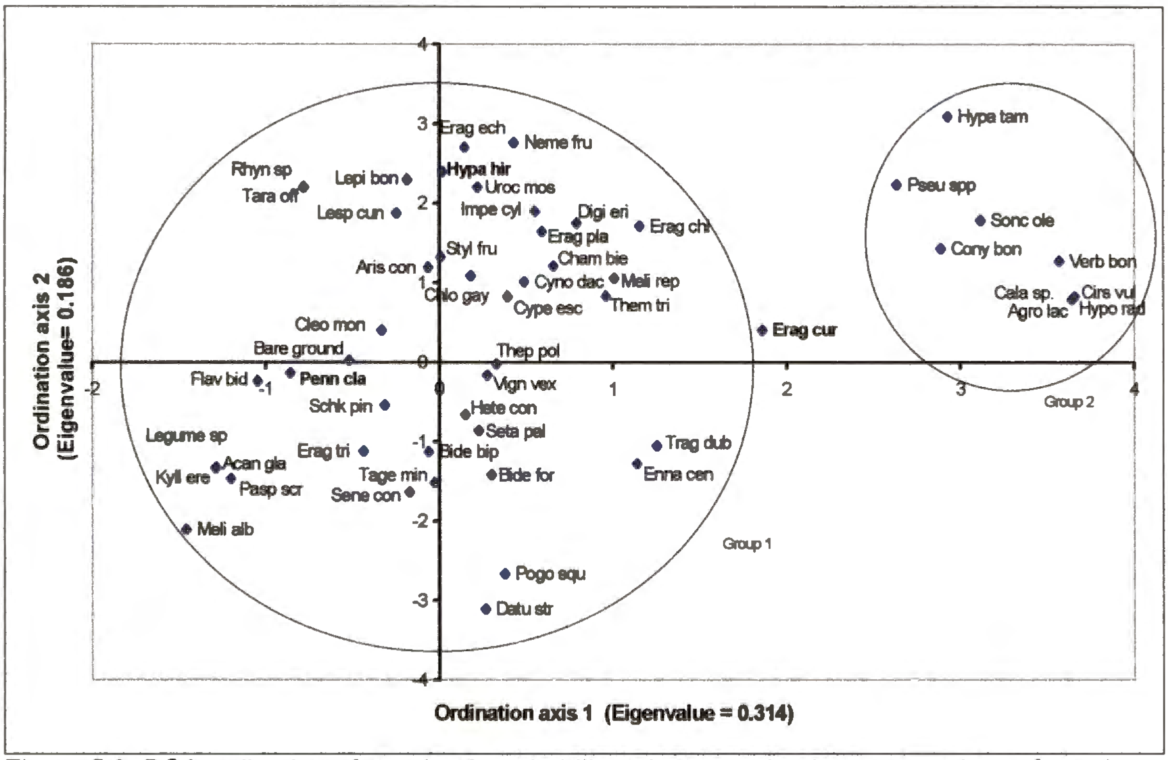

Figure 5.9: DCA ordination of species for rehabilitated areas using important values of species during the 1999 season at Hendrina Power Station.

Table 5.1:Ordination statistics, indicating the eigenvalues for the first four axes and the sum of all unconstrained eigenvalues of the DCA ordination with importance values from the 1997, 1998, and 1999 summer season on rehabilitated ash disposal sites at Hendrina Power Station

Ordination	1-axis	2-axis	3-axis	4-axis	Sum of all eigenvalues
1997	0.461	0.226	0.108	0.051	1.892
1998	0.313	0.125	0.082	0.035	1.347
1999	0.314	0.185	0.084	0.045	1.484

5.4 DISCUSSION AND CONCLUSIONS

Figure 5.10 illustrates the changes in the cluster properties for the first three division levels of rehabilitated ash disposal sites at Hendrina Power Station. The most important change in the community structure is the closer association of the newly rehabilitated area with older rehabilitated areas. Figure 5.10 indicates that the newly rehabilitated area (G7/2 and G8/2) became more similar in community structure to the older rehabilitated areas during 1997-1998 but remains a separate community. These tendencies can be observed in both the cluster analyses (Figure 5.10), and the sample ordinations (Figures 5.2, 5.5 and 5.8). The vegetation changes on the newly rehabilitated areas can be described as successional due to the change in species composition from mostly annual species to a state where perennials plays an increasing importance.

Another site that illustrated strong differences when compared to the remainder of the sites was transect G7/3, according to the cluster analysis (Figure 5.10). No convergence of this site with other vegetation could be observed. The reason for this dissimilarity indicated in the cluster analyses is the total dominance of *Hyparrhenia hirta* in the vegetation on this site.

Transect G8/3 was also totally dissimilar to other the grids. Cluster analyses, however, fail to indicate any major difference in the vegetation composition of this site in relation to other sites. This was probably not due to the dominance of a particular species but because this site was characterised by the presence of species not occurring or common in other sites, for example *Calamagrostis* sp., *Sonchus oleraceus*, *Pseudognaphalium* spp. *Cirsium vulgare* and *Verbena bonariensis*. The reason for these differences in the vegetation composition on transect 8/3 was probably the occurrence of wet conditions along the bottom of the slopes on which this site was situated.

According to the cluster analyses, the rest of sites were relative homogenous in their vegetation composition. The cluster analyses grouped these grids (G1, G2, G3, G4, G8/3, G9, G10, G11 and G12) together, based on the similarity of the dominant species. The heterogeneity between sites described by the cluster analyses were therefore based on differences and changes in the composition of dominant species, which included the grasses *Eragrostis curvula*, *Hyparrhenia hirta*, *Cynodon dactylon* and *Pennisetum clandestinum,* and the forbs *Conyza bonariensis* and *Chamaecrista biensis*. Communities from the cluster analyses (Figure 5.10), therefore, are not related to differences in the initial rehabilitation treatment as observed in the phytosociological study (Chapter 3).

Changes in the spatial heterogeneity of old rehabilitated sites were due to changes in the importance values of dominant species in the vegetation of sites G2, G3 and G9. Although grids G10 and G11, and grids G4, G8/3 and G12 diverged to form separate clusters during 1998, differences could already be observed between these grids in 1997, but only at a lower level in the cluster diagram (Figure 5.1). Both grids G2 and G3 showed changes in their community structure that could have been caused by fires which swept through these grids during the 1997-1998 period. Changes in community structure on older rehabilitated sites may therefore be related to regular fire occurrences. G9 and G2 changed from a cluster group in which the dominant species was *Pennisetum clandestinum,* to a cluster in which the dominant species was *Hyparrhenia hirta*. Site G3 was part of a cluster group in which the dominant species were *Eragrostis curvula* and *Cynodon dactylon,* but changed during 1998-1999 to a cluster in which the vegetation was dominated by *Hyparrhenia hirta*.

Heterogeneity in the data remained the same on older rehabilitated areas and therefore it can be concluded that vegetation is not becoming more homogeneous in species composition and therefore the hypothesis that heterogeneity in the data will be constant cannot be rejected. Community development on rehabilitated ash disposal sites also follows a pattern, as proposed by Yarranton & Morrison (1974), from colonisation stage to a persistent stage. The community structure on old rehabilitated sites however did not remain the same, in spite of the similar heterogeneity between years, because of changes in the abundance of dominant and co-dominant species. The heterogeneity in the data can be linked to past revegetation practices such as the use of *Pennisetum clandestinum*. The dominant occurrence of *Hyparrhenia hirta* cannot be explained by the revegetation practices. As proposed by Egler (1954) and Myster & Picket (1990) the initial inputs (quality of the topsoil, post rehabilitation practices, which is totally unknown and revegetation practices) determined the vegetation composition. The only visible convergence is between the newly rehabilitated sites and old rehabilitated sites due to the community development in the newly rehabilitated sites. Changes in the community structure on old rehabilitated areas did not influence the heterogeneity in the data and therefore cannot be described as significant.

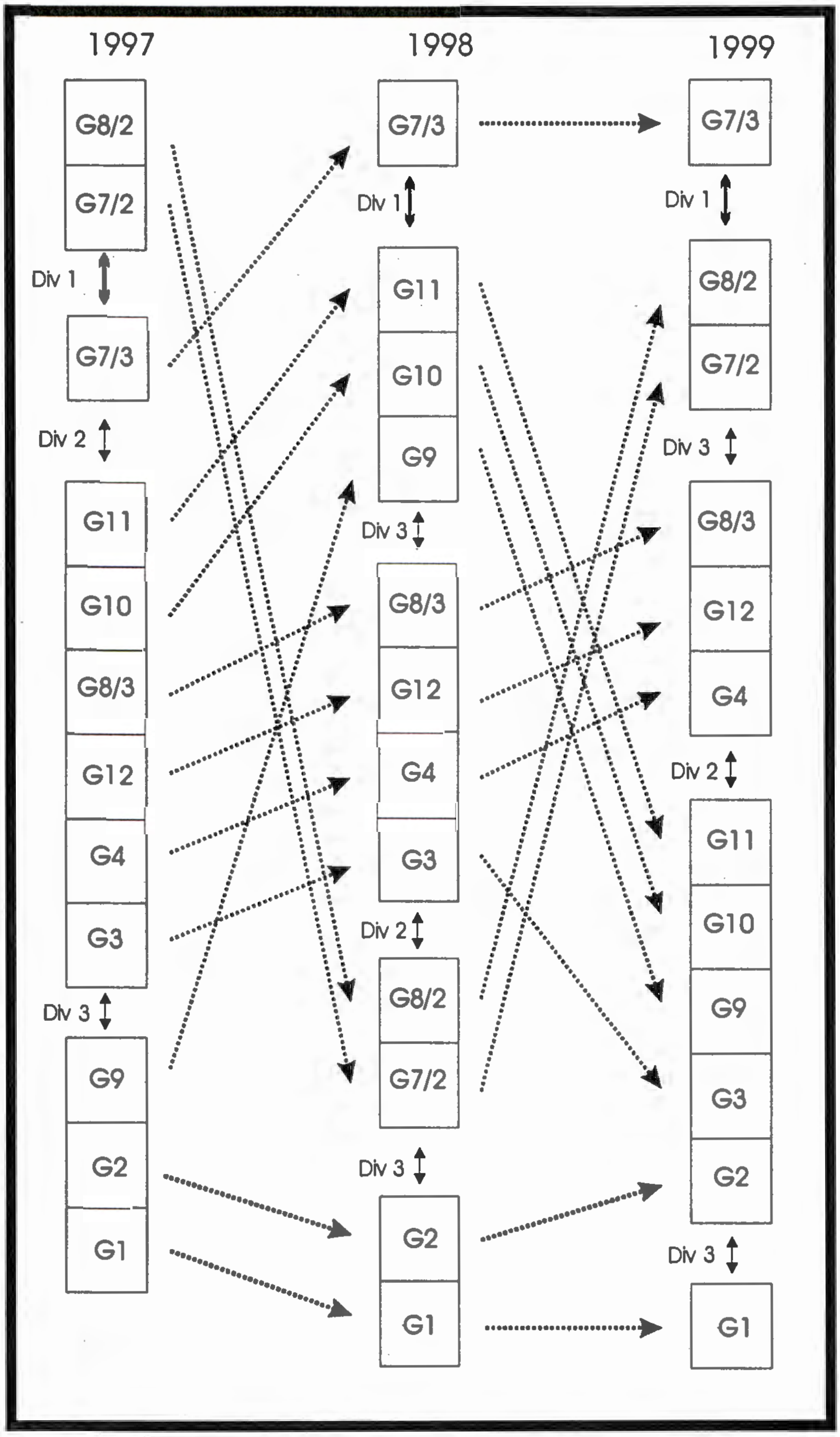

Figure 5.10: Changes in the cluster properties for the first three division levels of the dendrogram from 1997 to 1999 (Arrows indicate the shifts in the location of the grids in the dendrograms. Div1: Division 1; Div2: Division 2; Div 3: Division 3).

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Chapter 6 TRAJECTORIES OF VEGETATION CHANGE AND COMMUNITY DEVELOPMENT ON REHABILITATED ASH DISPOSAL SITES*

Abstract: Stable states in the vegetation composition are characterised by a lack of change in species composition. Changes in species composition are, therefore, investigated on eight sites characterised by differences in rehabilitation age, treatment and topography over a period of three years. Results may also indicate trajectories of change. Importance values are analysed with RDA and PCA ordination techniques. Changes in species abundances are also correlated with temporal changes. The Monte Carlo Permutation tests are significant for four of the survey areas tested. These changes over time can be attributed to an increase in importance values of *Chamaecrista biensis* and *Hyparrhenia hirta* and a decrease in the importance values of *Pennisetum clandestinum* and *Eragrostis curvula*. Importance values of *Eragrostis curvula* decreased on most of the sites that were regularly burned. Except for grid 11, no degradation in the grass sward was recorded. Most grids indicate a unidirectional change towards a *Hyparrhenia hirta* dominant grassland. Cyclic changes in annual forbs were evident for the annuals *Conyza bonariensis* and *Chamaecrista biensis*. Although the abundance values of specific species change, no drastic changes in the species composition are observed. Investigations on the affect of slope position on species composition indicate that slopes influence species composition on areas not transversed by any road.

* Submitted for publication in *Landscape and Urban Planning*

CONTENTS

6.1 INTRODUCTION

One of the major questions asked about rehabilitated sites is the stability of these systems. According to Barbour *et al.* (1987), a stable ecosystem can be defined as an ecosystem with lack of change in vegetation composition and the dominance of long lived species. Changes, which occur in a stable ecosystem, appear as random minor fluctuations around a long term mean. An ecosystem would be stable if no large-scale changes in biomass and species composition occur.

Interesting hypotheses around the concept of community development have been developed from studies in old fields. Myster and Picket (1990) proved that the presence or absence of certain species or abandonment characteristics during earlier succession might influence the trajectory of change and the rate of change. In the present study, types of treatment and types of topsoil used could be related to abandonment characteristics. Peet (1992) speculated that niche breadth should decrease during succession, and the beta diversity measured in compositional change should increase. The Clementsian model of succession (Barbour *et al.*, 1987), however, predicted otherwise. This model proposed that succession is a process of convergence to one stable state and would therefore result in a decrease of the compositional gradient. Succession is also believed to be unidirectional, and change in community composition follows a unidirectional pattern in old fields studies (Lepš, 1987). Tanslley 1935 and Whalley 1994 proposes that succession can follow a multidirectional pattern that may result in the divergence of different pioneer communities.

To describe the changes that occurred on the rehabilitated ash disposal sites each survey grid is regarded as an ecological unit. Ecological units are characterised by differences in treatments, age of rehabilitation, topography and environmental conditions.

The aim of this paper is to evaluate the community dynamics of each ecological unit, or grids by testing three hypotheses with the use of multivariate ordination technique and Canonical Analysis in the form of RDA's.

The first hypothesis tests the significance of change by determining the significance of the temporal gradient with the Monte Carlo permutation test and states that no significant relationship exists between change in species composition and time and changes can therefore be described as stochastic.

The second hypothesis test unidirectionality of change and states that if changes are statistically significant over time these changes will be similar among different sites.

A further aim is to investigate the influence of slope position on the species thereby testing the hypothesis that topography does not influence plant community development.

6.2 MATERIALS AND METHODS

6.2.1 Data sampling

Survey data of eight survey grids (grids 1, 2, 3, 4, 9, 10, 11 and 12), consisting of three transects each, were used for this study (see Chapter 2, Table 2.4 for information regarding grids). Grids 7 and 8 were not investigated due to the occurrence of transects on areas rehabilitated during different periods as was indicated in Chapter 3. Surveys of these plots extended over a period of three years (March 1997-February 1999) and included frequency, basal cover and density surveys. The descending point method was used to obtain frequency and basal cover data. Approximately 120 points were surveyed along each transect. At each point the nearest plant within a radius of 30 cm was noted. If no plant occurred within this radius, the point was noted as bare ground. Additionally, basal hits were also noted to obtain the basal cover of each species. Density surveys were conducted in five quadrats of 1 m^2 along each transect. The five quadrats were summed to give an indication of the densities of species over the entire transect. These surveys were repeated each year during the growing season (January-March) from 1997 to 1999. The different treatments, fire frequency and topography of each grid is provided in Chapter 2, Figure 2.4. Records on the incidents of fire before the study is unknown because no official records were kept which areas were burned. Observation during the phytosociological survey of December 1996 indicated that incidents of fires occurred throughout the dump during the winter of 1996. According to management fire is a yearly occurrence on the rehabilitated areas. Grids 1, 2, 4, 10 and 11 were totally or partially burned during the winter of 1997 and grids 1, 2, 3, 4 and the natural grassland were burned during 1998. Only grids 7, 8, 9 and 12 experienced no fire during the survey period.

6.2.2 Data analysis

Data were analysed using the importance values for each species over each transect. Importance values are the sum of the relative frequency, relative basal cover and relative density for each species at each transect (Mueller-Dombois & Ellenberg, 1974). The importance values of the following species were combined in broader species groups: *Cyperus esculentus* and *Cyperus usitatus* were combined and are indicated as *Cyperus* spp. (Cype spp); *Pseudognaphalium undulatum* and *Pseudognaphalium luteo-album* were combined and are indicated as *Pseudognaphalium* spp. (Pseu spp); *Eragrostis trichophora* and *Eragrostis curvula* were combined and are indicated as *Eragrostis* spp. (Erag spp). Due to the difficulty of identifying seedlings and small tufts of *Eragrostis* spp. and *Pseudognaphalium* spp. these species were grouped together. Combining these species in broader species groups do not have any impact on the interpretation of the data because the species in the species groups represents a similar ecological status.

The PCA (Principal Component Analysis) and RDA (Redundancy Analysis)-ordination techniques, from the CANOCO computer program (Ter Braak, 1987-1992) were use for data analyses. RDA is a direct ordination technique, based on the principles of the PCA-ordination technique, where the species are constrained by a number of environmental factors. Because it is based on the PCA-ordination technique, it is a linear model (Ter Braak, 1994 and Verdonschot & Ter Braak, 1994). The PCA and RDA ordination techniques were considered for analyses of the data sets due to the short gradients and the homogeneity of each sample plot. Myster and Pickett (1990) and Myster and Pickett (1994) also found PCA (the unrestrained version of Redundancy Analysis-RDA) ordination more suited for studies of the effect of different abandonment characteristics on old fields.

Due to the different habitat types and rehabilitation treatments, each survey plot can be perceived as a single ecological unit. Other environmental factors (for example aspect differences, fire frequency differences and differences in rehabilitation) influencing species composition were therefore excluded and only two major factors remained, namely differences that exist between the three transects (spatial differences) and differences between the three years of surveys. Each sample plot was first analysed using the RDA ordination technique with annual change from 1997-1999 (year-gradient) and variation from transect 1 to transect 3 (transect–gradient) as variables. Spatial and chronological differences in each sample grid could, therefore, be assessed. All RDA and PCA ordinations were standardised and centred by species. The Monte Carlo Permutation test (Ter Braak & Prentice, 1988; Verdonschot & Ter Braak, 1994) was used to determine the statistical significances for each variable (by means of forward selection), the overall effect of the environmental variable, and the eigenvalue of the first canonical axis. In all cases a total of 99 permutations were used to test the results. Ordination of sample plots that were not significantly related to environmental variables were re-analysed using a PCA centred and standardised by species ordination norm, to determine how transects were related over time and space in a non-directional environment. Guidelines for the interpretation of RDA plots were followed according to Ter Braak & Prentice (1988) and Ter Braak (1994).

Abbreviations for transects used in ordination diagrams consisted of the grid number followed by the transect number and year. For example 1297 would indicate the 2nd transect of grid 1 during the 1997 survey, whereas 12397 would indicate the 3rd transect of grid 12 during 1997.

Change in the rank of importance of the most dominant species over the three-year period is also illustrated in whisker plots for each grid. Spearman's Rank Correlation was also employed to determine how selected species were linearly correlated with temporal change over the three-year survey period. Spearman's Rank Correlation was used because it does not assume normality and can therefore be used to test non-parametric data (Sokal & Rohlf, 1969). The impediment with non-parametric analysis methods is the lack of power to achieve the same level of statistical significance of parametric methods. Kent & Coker (1994) indicated, for example, that the Spearman's Rank Correlation, although frequently used for ecological data, is only 91% as powerful as the Pearson's Product Moment Correlation Coefficient. In cases where the changes over the three transects showed statistically significant results, the changes in importance values for transects were also compared.

6.3 RESULTS

Results from the RDA ordination indicated that statistically significant directional change from 1997 to 1999 only occurred on grids 2, 10, 11 and 12 (Table 6.1). The only significant gradient between transect 1 to transect 3 is at grid 3, and was probably due to the effect of slope.
It is, however, surprising that only grid 3 of the four grids occurring on the slopes (grid 2, 3, 4 & 9) shows a statistically significant gradient from the top of the slope (transect 1) to the bottom (transect 3) (see Chapter 2, Figure 2.6).

Table 6.1: Statistics of RDA ordination of each grid over time and space, of rehabilitated ash disposal sites at the Hendrina Power Station

Grid	Years (97-99)	Transects	P-value First axis	P-value Overall test	1st axis eigenvalue	2nd axis eigenvalue
	% Variance explained					
(1)1	15	16	0.52	0.18	0.157	0.149
(2)2	25*	20	0.02	0.01	0.264	0.187
(3)3	14	27**	0.01	0.02	0.275	0.135
(4)4	13	19	0.39	0.20	0.189	0.136
(5)9	15	16	0.36	0.15	0.174	0.137
(6)10	28**	12	0.02*	0.02	0.277	0.122
(7)11	23**	12	0.05	0.08	0.234	0.118
(8)12	20*	16	0.28	0.07	0.211	0.150

*,**, Significant at P≤0.1, P≤0.05

6.3.1 Vegetation change on grid 1

The RDA ordination indicates that no statistically significant changes occurred, according to the Monte Carlo test (P=0.34), in the species composition over the three year period. Most of the variation in the data could be attributed to changes in the abundances of *Schkuhria pinnata* (Schk pin), *Chamaecrista biensis* (Cham bie), *Pennisetum clandestinum* (Penn cla) and *Hyparrhenia hirta* (Hypa hir). Although the RDA ordination is not statistically significant the PCA ordination (Figure 6.1) illustrates variation between years because of cyclic changes in annual species. Differences between the three transects during the first year were due to *Aristida congesta* (Aris con), which was associated with transect 1 (1197), *Verbena bonariense* (Verb bon) and *Hypochaeris radicata* (Hypo rad), which were associated with transect 2 (1297). During 1997 transect 3 (1397) was characterised by the species *Hyparrhenia hirta* (Hypa hir) and bare ground. These species probably did not occur or were less abundant on the other two transects. The PCA ordination diagram indicates increases in the annual species *Lepidium bonariense* (Lepi bon), *Bidens bipinnata* (Bidens bip), *Pseudognaphalium* spp. (Pseu spp) and

Conyza bonariense (Cony bon) on transect 2 (1298) during 1998. *Eragrostis plana* (Erag pla), *Setaria pallide-fusca* (Seta pal) and *Bidens formosa* (Bidens for) were also more prominently associated with transect 1 (1198) during 1998. Transect 3 (1398) also illustrated increases in the annual forbs *Tagetes minuta* (Tage min) and *Schkuhria pinnata* (Schk pin) during 1998. Changes in vegetation composition during 1999 (transects 1199, 1299 and 1399) could be linked to increases in the forbs *Chamaecrista biensis* (Cham bie) and *Paspalum scrobiculatum* (Pasp scr), as well as *Hyparrhenia hirta* (Hypa hir). Changes in the species composition between 1998 and 1999 were therefore considerable according to Figure 6.1 because of positional shifts of transects from right to left in the PCA ordination diagram (Figure 6.1). Changes in vegetation of grid 1 can partially be ascribed to stochastic events of annual forb species. Another factors that could have played a role are regular burning of the area and effects from covering of the area with topsoil during 1995.

Figure 6.2 indicates the average change in importance values for species on grid 1, during the three-year period. The importance value of *Pennisetum clandestinum* (Penn cla) declined statistically significantly (Table 6.3) during the three years of the study. Figure 6.2 indicates, however, that most of the decline in importance values took place during the first year of surveying. The population of *Eragrostis* spp. (Erag spp) however showed an increase in importance value from 1997-1998, followed by a stabilisation of the species occurrence during the next year (1998-1999). *Chamaecrista biensis* (Cham bie) and *Hyparrhenia hirta* (Hypa hir) showed a continued increase in importance values during this period, and were strongly correlated ($R = 0.948$, $p \leq 0.01$) with the year-gradient (Table 6.3). *Pennisetum clandestinum* (Penn cla) and *Eragrostis* spp. (Erag spp) were the most dominant species during the duration of the study. *Conyza bonariensis* (Cony bon) and *Cynodon dactylon* (Cyno dac) illustrated a peak occurrence during 1998 (Figure 6.2). *Cyperus* spp. (Cype spp) decreased in the importance values during the study period (Figure 6.2).

6.3.2 Vegetation change on grid 2

The RDA tri-plot (Figure 6.3) illustrates the change in species composition over the three-year period (1997-1999). Ordination of species over time indicated statistically significant changes in species composition during the survey period. Both Figure 6.3 and Figure 6.4 that *Hyparrhenia hirta* (Hypa hir) and *Eragrostis plana* (Erag pla) increased during the three-year period, because they were positively correlated with the year-gradient. *Eragrostis* spp. (Erag spp) and *Pennisetum clandestinum* (Penn cla), however, decreased, because they were negatively correlated with the year-gradient. Other species that, according to Figure 6.3, were positively correlated with the year-gradient were *Hyparrhenia tamba* (Hypa tam), *Chamaecrista biensis* (Cham bie), *Cyperus* spp. (Cype spp) and *Lepidium bonariensis* (Lepi bon).

The Monte Carlo permutation test for the spatial gradient (transect-gradient) along the three transects is not significant (P=0.06), but contributes nearly half of the variation (20%) in the ordination diagram. Transect 1 (2197, 2198 and 2199) on top of the slope was characterised by the species *Cynodon dactylon* (Cyno dac) and *Stylosanthes fruticosa* (Styl fru). *Hyparrhenia tamba* (Hypa tam) was more abundant at the bottom transect (2399) of the slope. The effect of slopes on selected species is indicated by the correlation of species with this factor in Table 6.4. *Hyparrhenia tamba* (R=0.858) is statistically significantly positively correlated with the effect of slope, but *Cynodon dactylon* (R=-0.738) is statistically significantly negatively correlated with slope (Table 6.4).

Figure 6.4 also shows considerable change in the importance values of species during the period. Spearman's rank correlations (Table 6.3) indicate that *Pennisetum clandestinum* and *Eragrostis* spp. are significantly negatively correlated with the year-gradient. *Hyparrhenia hirta* and *Eragrostis plana,* however, show a significant increase in their importance values (significantly positively correlated) over the three-year period. At the start of the surveys, *Pennisetum clandestinum* (Penn cla) had the highest important value, with *Eragrostis* spp. (Erag spp) and *Hyparrhenia hirta* (Hypa hir) the second most important species (Figure 6.4). During the following years, *Hyparrhenia hirta* (Hypa hir), however, replaced *Pennisetum clandestinum* (Penn cla) as the most important species (Figure 6.4). *Eragrostis* spp. (Erag spp) decreased so significantly in importance to be ranked fifth during 1999. *Cyperus* spp. (Cype spp) (of which the importance increased during the first year of study and remained the same for the following year) and *Cynodon dactylon* (Cyno dac) (of which the population size stayed the same for the survey period) replaced *Eragrostis* spp. (Erag spp) as third and fourth most important species, respectively. The importance values of *Chamaecrista biensis* (Cham bie) increased during 1999 while *Lespedeza cuneata* (Lesp cun) and *Conyza* spp. (Cony spp) did not illustrate any changes in their importance values along grid 2 (Figure 6.4). A possible explanation for these drastic changes is the annual occurrence of fire which, from field observation, have a definite effect on the vitality of *Eragrostis* spp. *and Pennisetum clandestinum.*

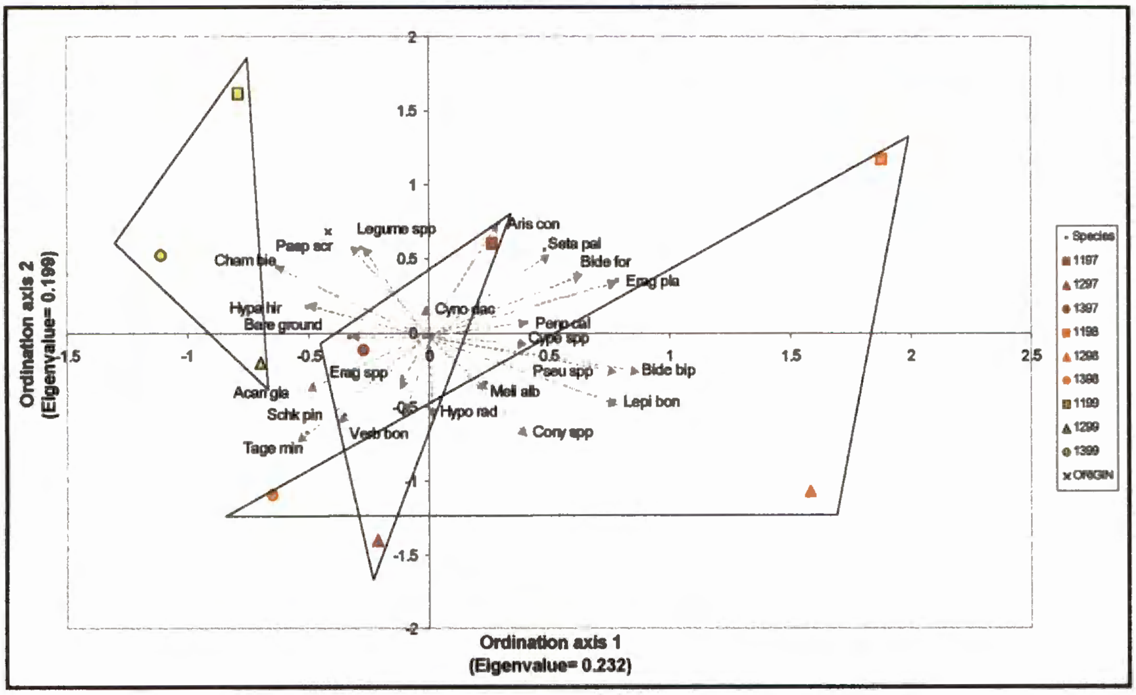

Figure 6.1: PCA ordination biplot of vegetation change over a three-year period on grid 1, situated on ash disposal site 1 at Hendrina Power Station.

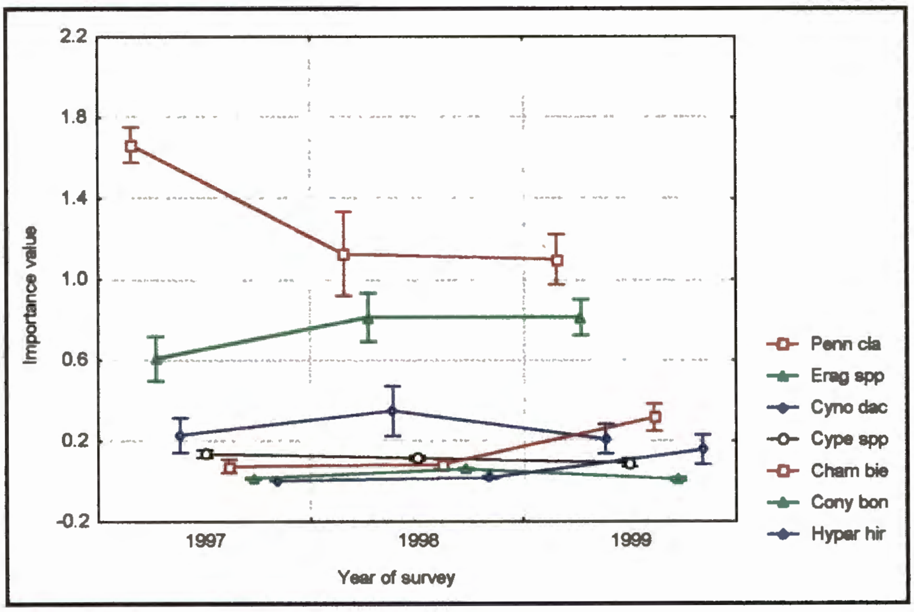

Figure 6.2: Change in importance values of selected species over a three-year period on grid 1, situated on ash disposal site 1 at Hendrina Power Station. Points indicate the average value and the whiskers the standard error deviation from the average.

6.3.3 Vegetation change on grid 3

The RDA ordination (Figure 6.5) indicates that most of the species are situated around a spatial gradient along the three transects of survey plot 3. The statistically significant correlation of vegetation with the spatial gradient can be attributed to the occurrence of a slope along grid 3.

According to Figure 6.5, species which are more associated with transect 1 on top of the slope are the species *Stylosanthes fruticosa* (Styl fru), *Eragrostis plana* (Erag pla), *Chamaecrista biensis* (Cham bie), *Chloris gayana* (Chl gay) and *Cynodon dactylon* (Cyno dac). The spatial gradient (transect-gradient) also indicates a decrease of *Hyparrhenia hirta* (Hypa hir) and an increase of the stoloniferous grass, *Pennisetum clandestinum* (Penn cla), and the large tuft forming grass, *Hyparrhenia tamba* (Hypa tam), from transect 1 to transect 3 down the slope. The only species that are correlated with the year-gradient (time gradient) are *Eragrostis* spp. (Erag spp) and *Melinis repens (Meli rep). Eragrostis* spp. (Erag spp) is negatively correlated with the year-gradient and *Melinis repens* (Meli rep) is positively correlated. The other species that illustrate increases in importance values during the study period are *Hyparrhenia hirta* (Hypa hir) and *Aristida congesta* (Aris con).

Similar patterns in species composition are indicated by Figure 6.6.1, which illustrate the change in importance values over the three transects. *Cynodon dactylon* (Cyno dac) do not show a linear decreases in its importance value down the slope but only decreases between transect 2 and 3. Analysis with Spearman Rank Correlation indicates that the importance values of *Pennisetum clandestinum, Chloris gayana, Bidens bipinnata, Chamaecrista biensis* and *Stylosanthes fruticosa* decrease statistically significantly linearly down the slope from transect 1 to 3 (Table 6.4). *Chloris gayana* (Chlo gay) and *Stylosanthes fruticosa* (Styl fru) occur predominantly on the upper slope (along transect 1) of the area on which grid 3 is situated. *Lespedeza cuneata* (Lesp cun) has a higher importance value along transect 3, situated on the lower slope.

Figure 6.6.2 illustrates the change in importance values of the most dominant species over the three-year period. Although Figure 6.5 does not indicate directional change over the three-year period, a degree of change occurred during this period according to Figure 6.6.2. Statistically significant ($P< 0.01$) decreases in the importance of *Eragrostis* spp. (Erag spp) and an increase (not statistically significant) in *Hyparrhenia hirta* (Hypa hir) are observed. An increase in the importance of *Conyza* spp. (Cony spp) during the second year, with a sharp decrease during the third year, indicates the stochastic nature of this annual forb. Results from Figure 6.6.2 predict a change in the ranking of important species. *Hyparrhenia hirta* (Hypa hir) would probably replace *Eragrostis* spp. (Erag spp) as the most important species. Importance values of Cyperus spp. (Cype spp), and the legumes *Chamaecrista biensis* (Cham bie) and *Lespedeza cuneata* (Lesp cun) increased during the three-year period.

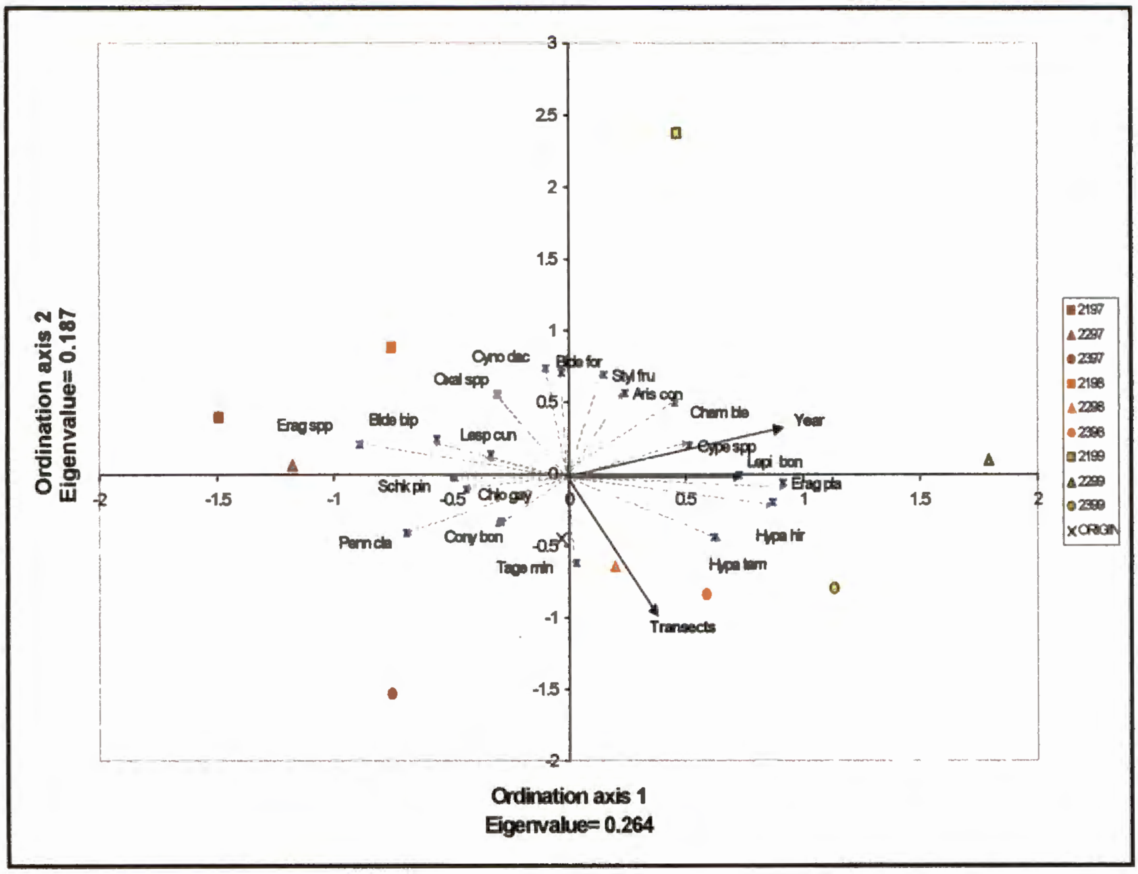

Figure 6.3: RDA ordination triplot of the change of vegetation over time (year-gradient) and space (transects-gradient) on grid 2, situated on ash disposal site 1 at Hendrina Power Station.

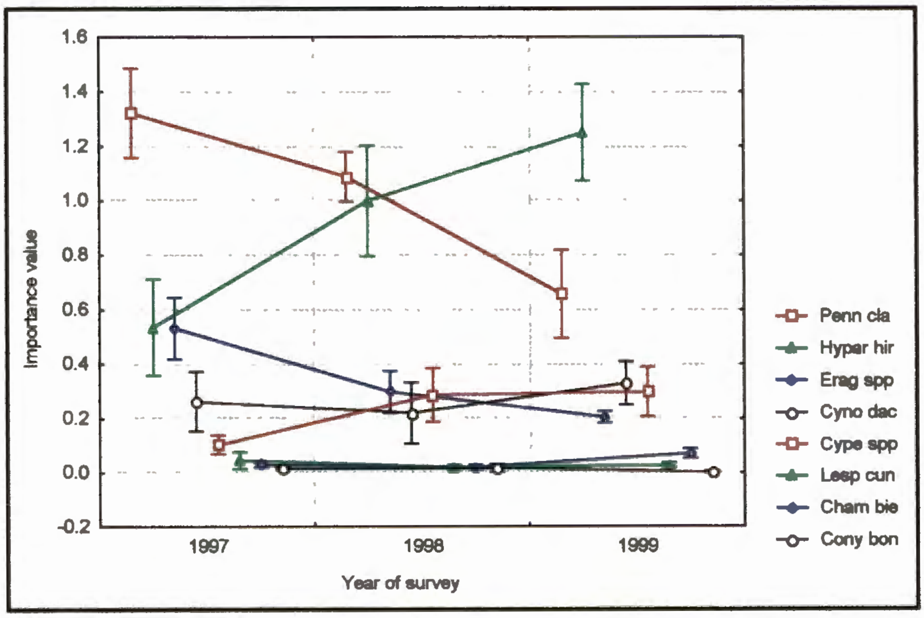

Figure 6.4: Change in importance values of selected species over a three-year period on grid 2, situated on ash disposal site 1 at Hendrina Power Station. Points indicate the average value and the whiskers the standard error deviation from the average.

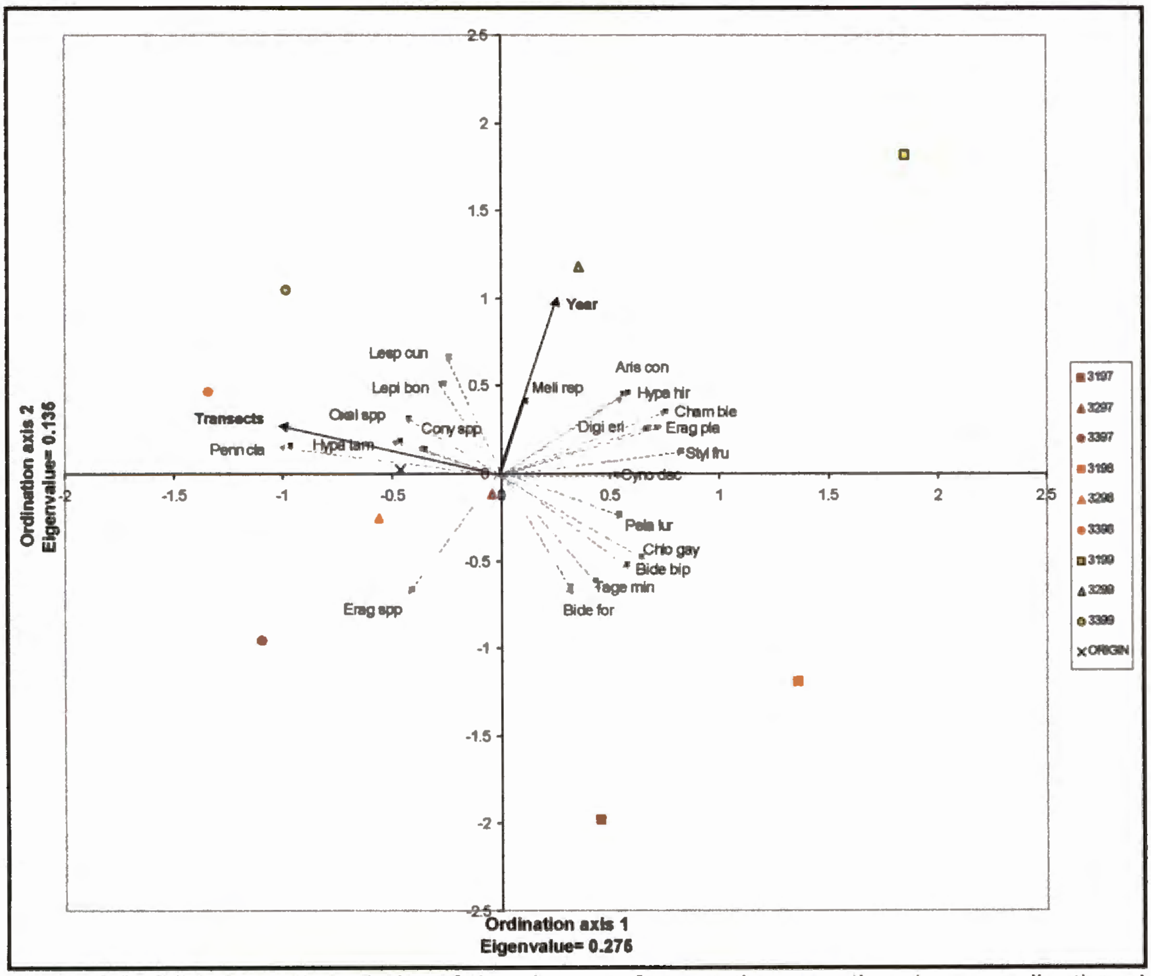

Figure 6.5: RDA ordination tri-plot of the change of vegetation over time (year-gradient) and space (transects-gradient) on grid 3, situated on ash disposal site 1 at Hendrina Power Station.

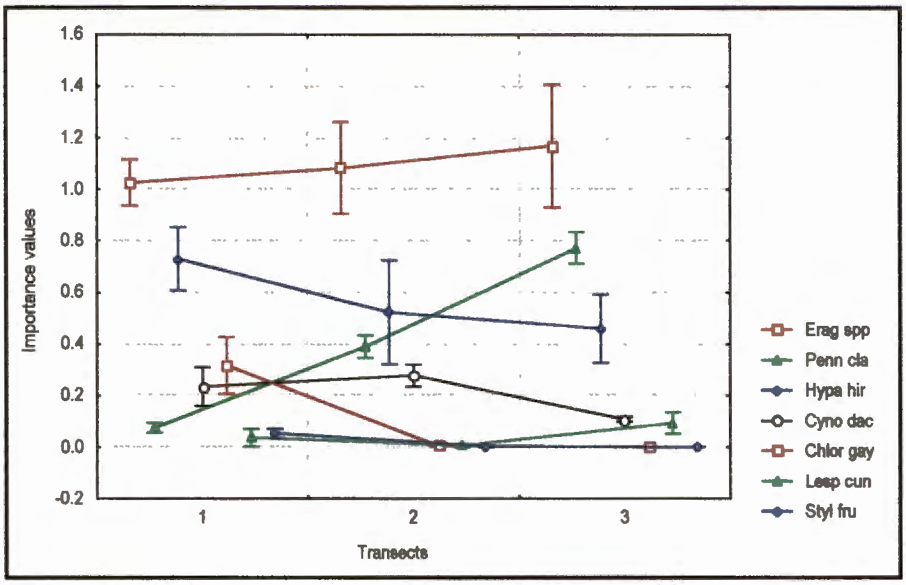

Figure 6.6.1: Change in importance values along the three transects.

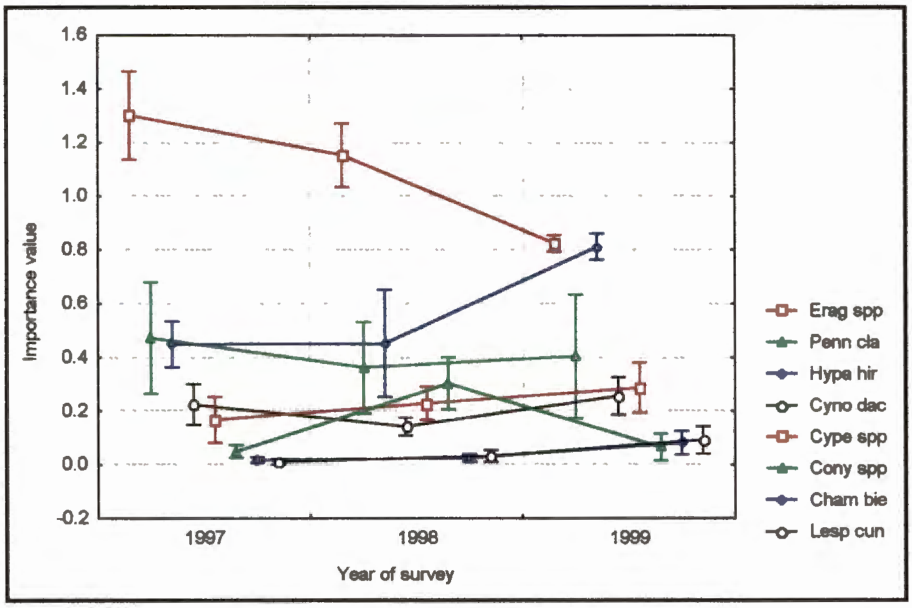

Figure 6.6.2: Change in importance values over a period of three years.

Figure 6.6: Change in importance values of selected species along the survey transects (Figure 6.6.1) and over a three-year period on grid 3 (Figure 6.6.2), situated on ash disposal site 1 at Hendrina Power Station. Points indicate the average value and the whiskers the standard error deviation from the average.

6.3.4 Vegetation change on grid 4

Forward selection and the application of the Monte Carlo permutation test with survey years (year-gradient) and transect (transect gradient) as environmental gradients, are, for both variables, not statistically significant (P> 0.05). The overall test with 199 permutations is also not significant (Table 6.1). The biplot of species together with samples of the PCA ordination (Figure 6.7) shows that little changes occurred during the first two years of surveys. Transects 1 (4199) and 2 (4299) changed dramatically during the last year (1999) of surveys. Results indicate a increase in the importance of the perennial grasses *Hyparrhenia hirta* (Hypa hir), *Digitaria eriantha* (Digi eri) and *Eragrostis plana* (Erag pla), the annual forbs *Lepidium bonariensis* (Lepi bon) and *Bidens formosa* (Bide for), and the perennial forb *Stylosanthes fruticosa* (Styl fru). Transect 3 (4399) does not, however, show this clear change, although a similar trajectory in the direction of transects 2 (4299) and 3 (4399) can be observed form the ordination diagram (Figure 6.7).

Figure 6.8 indicates the average importance values of the species on grid 4 for the three-year period. Tendencies observe in the ordination diagram are also perceived by the line graphs (Figure 6.8) for the species *Hyparrhenia hirta* (Hypa hir) and *Eragrostis plana* (Erag pla). *Cynodon dactylon* (Cyno dac) also increased in average importance values during the third year, which is not evident in the PCA ordination diagram of Figure 6.7. *Eragrostis* spp. (Erag spp) slightly decreased in importance during the three-year period. A similar pattern in the occurrence of *Conyza* spp. (Cony spp), as is found on other grids, is observed on grid 4. *Conyza* spp. (Cony spp) showed a marked increase during the second year (1998) but decreased in importance during the following year. *Eragrostis plana* (R=0.737) was the only species that statistically linearly increased during the three-year period (Table 6.3) (no statistically significant decreases in the species importance values were observed). The importance of *Lespedeza cuneata* (Lesp cun) remained the same, but the importance of *Pennisetum clandestinum* (Penn cla) decreased during the survey period.

The considerable change in species importance values during the last year of survey can possibly be related to fire occurrences on these transects during 1997 and 1998. The effect of slope was less important, due to a road traversing just above the second survey grid.

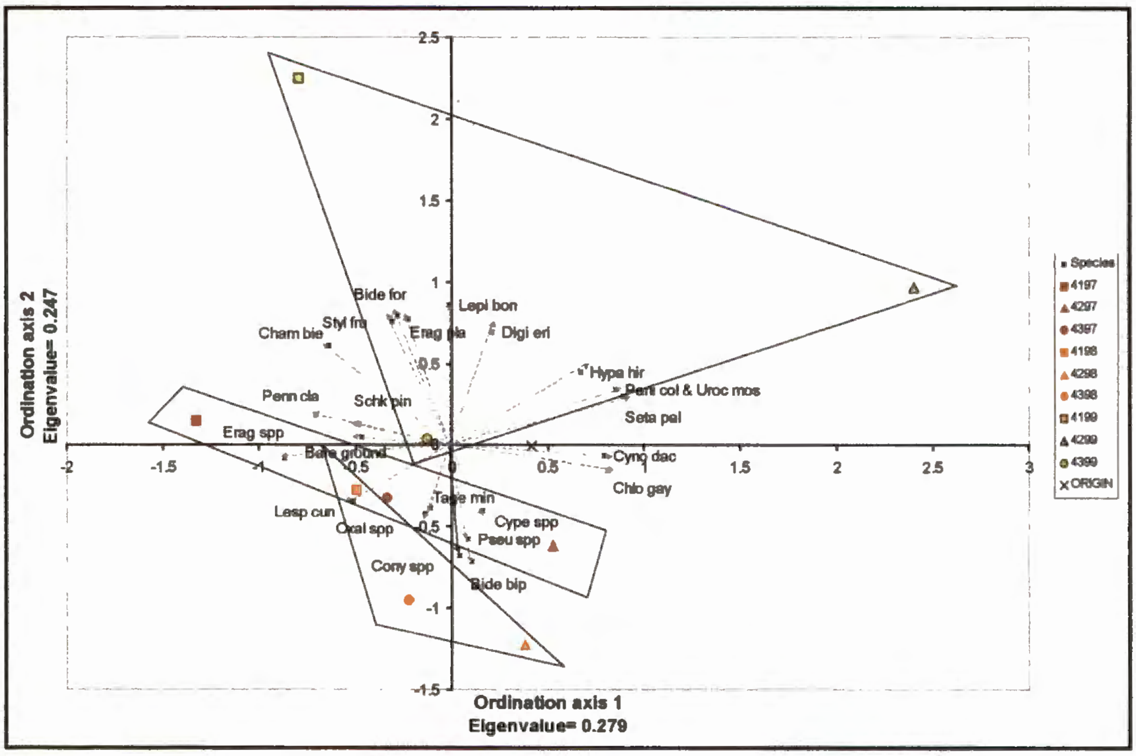

Figure 6.7: PCA ordination biplot of the three transects over the three-year period on grid 4 situated on the slope of ash disposal site 1 at Hendrina Power Station.

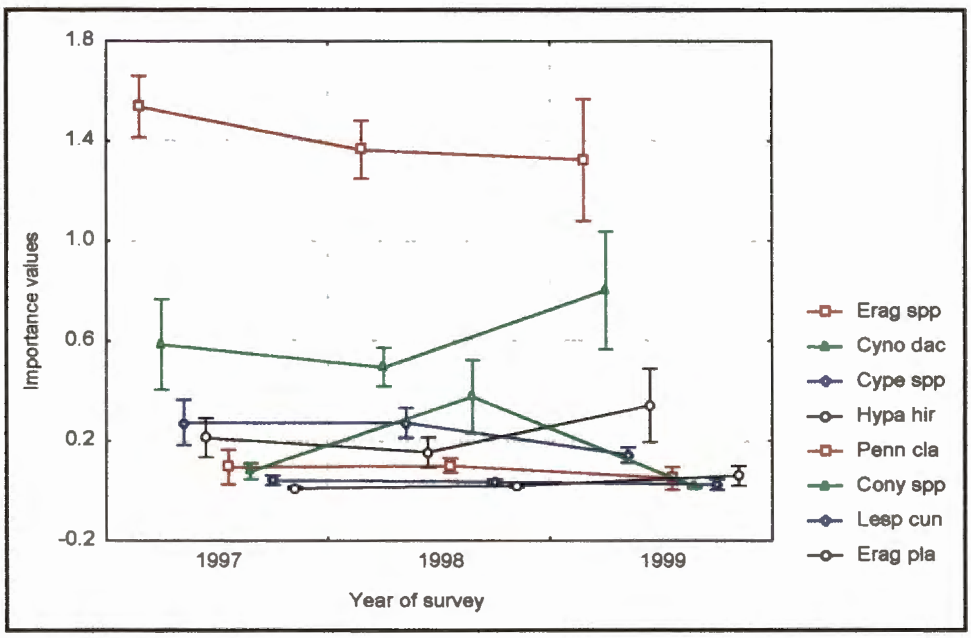

Figure 6.8: Change in the average importance values of selected species over a three-year period on grid 4, situated on the slope of ash disposal site 1 at Hendrina Power Station. Points indicate the average value and the whiskers the standard error deviation from the average.

6.3.5 Vegetation change on grid 9

No statistically significant changes in species importance values exist for the period 1997-1999 on grid 9 (Table 6.1). The gradient along the three transects (transect-gradient) is, according to the Mote Carlo permutation test, also not statistically significant.

Transects 1 (9197, 9198 and 9199) and 3 (9397, 9398 and 9399) illustrated large shifts in their position in the ordination space from 1998 to 1999. This shift can be attributed to the outbreaks of the annual forbs *Bidens pilosa* (Bide pil), *Bidens bipinnata* (Bide bip), *Schkuhria pinnata* (Schk pin) and *Tagetes minuta* (Tage min) along these transects (Figure 6.9). This increase in annual forbs can also be seen on Figure 6.10. Changes in the community composition during 1999 were therefore due to the stochastic nature of annual populations.

Figure 6.10 also indicates changes in the average importance values of species during the second year. *Eragrostis* spp. (Erag spp) and *Hyparrhenia hirta* (Hypa hir) replaced *Pennisetum clandestinum* (Penn cla) during 1997-1998 as the most important species. Both *Eragrostis* spp. (Erag spp) and *Hyparrhenia hirta* (Hypa hir) increased slightly in importance values over the survey period, which is contradictory to results found on other slopes in the area. In all of these grids *Eragrostis* spp. (Erag spp) decreased over the period of study. These contradictory results can be attributed to the absence of fire at grid 9.

6.3.6 Vegetation change on grid 10

According to Table 6.1 the gradient over the survey period from 1997 to 1999 is statistically significant but the gradient over the transects is not statistically significant. According to Figure 6.11 those changes over the survey period can be directly attributed to an increase in the importance values of the annual forbs *Chamaecrista biensis* (Cham bie) and *Tagetes minuta* (Tage min), and a decrease in the importance values of *Cyperus* spp. (Cype spp) and *Bidens formosa* (Bide for), as well as the perennial grass *Eragrostis* spp. (Erag spp). Figure 6.11 indicates that *Hyparrhenia hirta* (Hypa hir) is weakly correlated (Short vector) with changes over the survey periods (year) as well as the gradient over the different transects. This, therefore, indicates that the importance of *Hyparrhenia hirta* remained stable during the survey period.

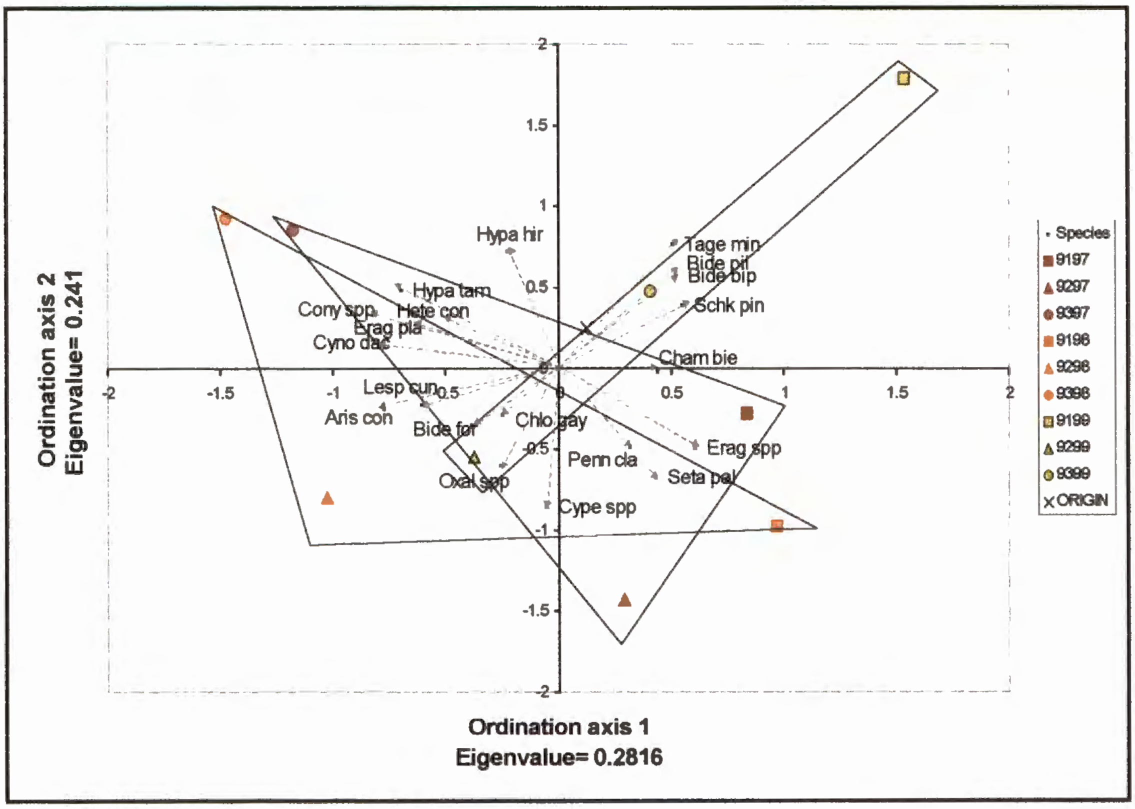

Figure 6.9: PCA ordination of three transects over a period of three years at grid 9, situated on ash disposal site 3 at Hendrina Power Station.

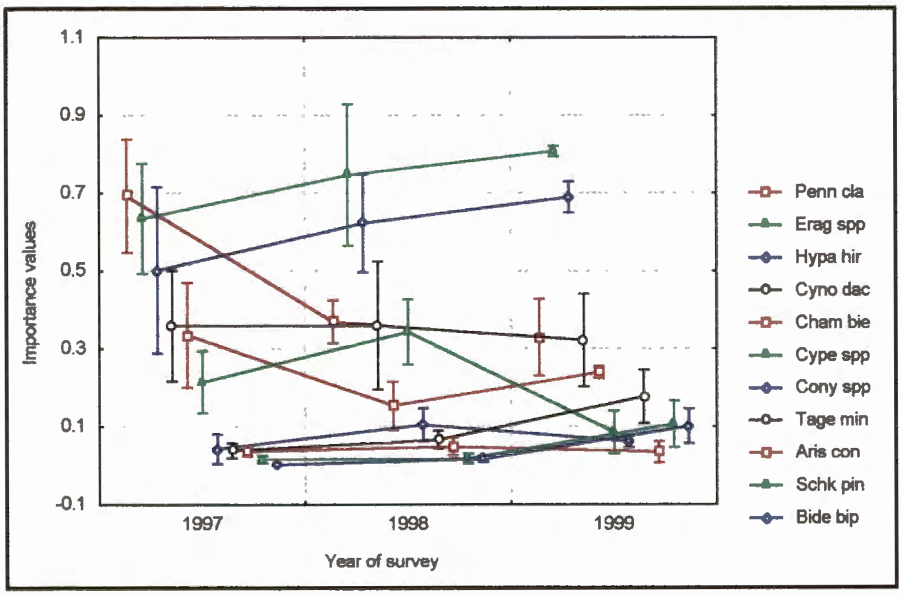

Figure 6.10: Change in species importance values over a three-year period on grid 9, situated on ash disposal site 3 at Hendrina Power Station. Points indicate the average values and the whiskers the standard error deviation from the average.

Figure 6.12 illustrates the change in importance values of species over the three-year period. *Hyparrhenia hirta* (Hypa hir) is indicated as the species with the highest importance value over the three years. It can, however, be observed that this species decreased in importance during 1998. To obtain an explanation for this occurrence, the relative frequency, relative basal cover and relative densities for this species are given in Table 6.2. Table 6.2 indicates a decrease in the relative basal cover of the species during 1998. This may be due to fire in the previous season. The change of *Hyparrhenia hirta* over all three years was, however, not statistically significant (Table 6.3).

Table 6.2: Population attributes of *Hyparrhenia hirta* at grid 10 over the past three years

Year	Relative frequency	Relative Basal Cover	Relative Density	Importance value
Average 1997	0.17	0.58	0.05	0.80
Average 1998	0.17	0.48	0.07	0.72
Average 1999	0.26	0.59	0.08	0.93

The decrease in the importance values of *Hyparrhenia hirta* (Hypa hir) was also accompanied by an increase in the importance values of *Eragrostis* spp. (Erag spp) and *Cynodon dactylon* (Cyno dac) during 1998 (Figure 6.12). During the following year *Eragrostis* spp. (Erag spp) and *Cynodon dactylon* (Cyno dac), however, sharply decreased, while the importance value of *Hyparrhenia hirta* (Hypa hir) increased. The importance values of *Cyperus* spp. (Cype spp) also sharply decreased over the three-year period. *Cyperus* spp. (Cype spp) had an importance of less than 0.2 (6%) in the community during the 1999 surveys. According to the Spearman's rank correlation (R=-0.843, P-values≤0.01) of *Cyperus* spp, the decrease in the species importance values was highly statistically significant (Table 6.3). The annual legume *Chamaecrista biensis* (Cham bie) also showed a statistically significant increase (R= 0.791, P-values≤0.05) during the three-year period. This increase was particularly evident during 1999. *Schkuhria pinnata* increased in importance from 1997 to 1999. Although *Eragrostis echinochloidea* is indicated by a long arrow in the RDA tri-plot, its importance value is very low according to Figure 6.12, therefore, the effect of species indicated by a long arrow must be considered carefully, because they may only occur in low abundances.

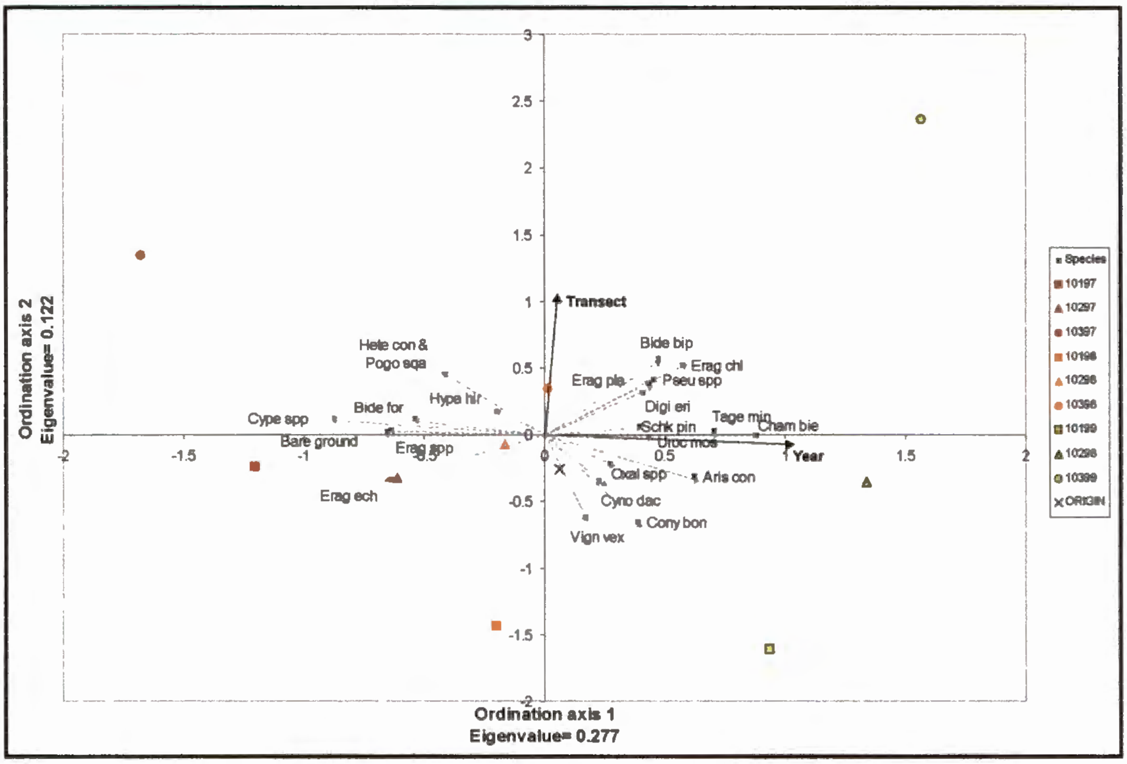

Figure 6.11: RDA ordination tri-plot of the change of vegetation over time (year-gradient) and space (transects-gradient) on grid 10, situated on ash disposal site 3 at Hendrina Power Station.

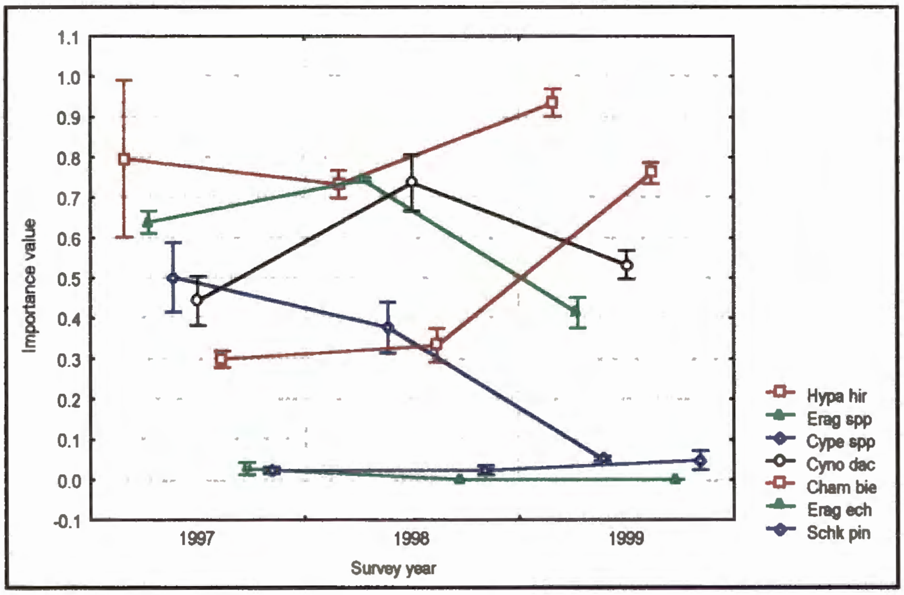

Figure 6.12: Change in the average importance values of selected species over a three-year period (1997-1999) of grid 10, situated on ash disposal site 3 at Hendrina Power Station. Points indicate the average values and the whiskers the standard error deviation from the average.

6.3.7 Vegetation change on grid 11

The RDA ordination (Figure 6.13) shows the statistically significant relationship between vegetation change and change over time. The wide distribution of transect points in the ordination space indicate that large differences between transects exist, but that differences are not directional from transect 1 to transect 3. The gradient over the three transects is also not significant during forward selection (Table 6.1). Directional change over time can be related to an increase in *Chamaecrista biensis* (Cham bie) and *Hyparrhenia hirta* (Hypa hir) and the decrease of *Cynodon dactylon* (Cyno dac) and *Cyperus* spp. (Cype spp) over this period (Figure 6.13). The percentage bare ground and the perennial grass *Themeda triandra* (Them tri) also increased during the survey period. The contribution of *Themeda triandra* to the vegetation composition at grid 11 was however small.

Eragrostis plana (Erag pla), *Aristida congesta* (Aris con), *Pseudognaphalium* spp. (Pseu spp) and *Conyza* spp. (Cony spp) were associated with transect 1 (11197, 11198 and 11199). Grid 11 is located on the plateau of ash disposal site 3. The plateau has a slight slope with transect 1 at the bottom of the slope (to the centre of the lagoon) and transect 3 on top of the slope on the dividing wall of the lagoon (Chapter 2, Figure 2.2). Transect 3 therefore traverse a drier and more compacted area, and is visually in a more degraded state than transect 1, situated at the centre of the lagoon area.

Figure 6.14 indicates the same patterns of species importance values over the three years. According to Table 6.3 a number of species show statistically significant correlations with the period of study. The annual species *Tagetes minuta* (Tage min) and *Schkuhria pinnata* (Schk pin) and the grass *Cynodon dactylon* (Cyno dac) decreased significantly during the 1997-1999 period, (Figure 6.14 and Table 6.3). *Hyparrhenia hirta* (Hypa hir) increased statistically significantly in its importance value during the 1997-1999 period (Table 6.3). During this period *Eragrostis* spp. (Erag spp) was replaced by *Hyparrhenia hirta* (Hypa hir) as the most important species, due to the sharp increase of *Hyparrhenia hirta* (Figure 6.14). The decrease in *Eragrostis* spp. was, however, not strongly correlated with the gradient over time from 1997 to 1999, and the linear correlation to the three year trend in time was not significant. This is probably due to the large variation in the importance value of the species (Figure 6.13). The importance value for *Conyza* spp. was the highest during 1998 (Figure 6.14).

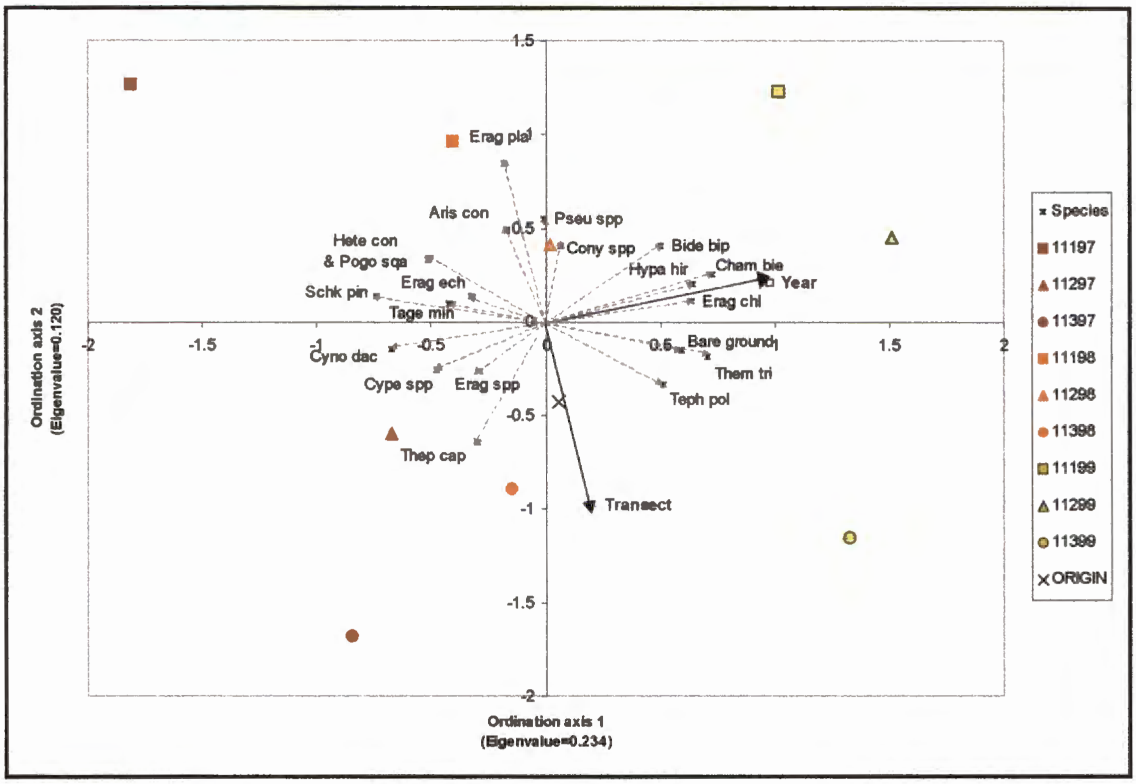

Figure 6.13: RDA ordination triplot of the change of vegetation over time (year-gradient) and space (transects-gradient) on grid 11, situated on ash disposal site 3 at Hendrina Power Station.

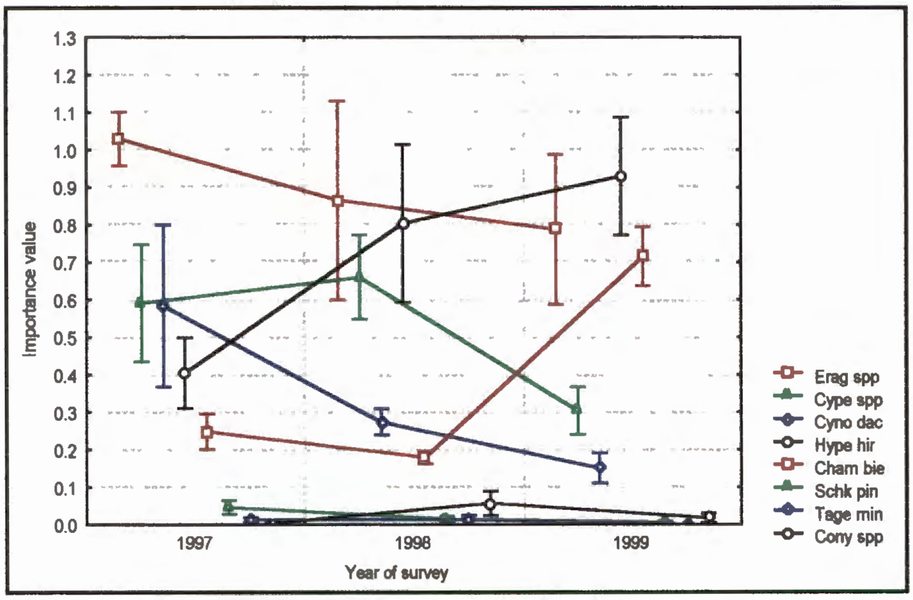

Figure 6.14: Change in average importance values over a three-year period on grid 11, situated on ash disposal site 3 at Hendrina Power Station. Points indicate the average values and the whiskers the standard error deviation from the average

6.3.8 Vegetation change on grid 12

Directional changes on grid 12 were associated with increases of especially the annual forb *Conyza* spp. (Cony spp) and the species *Chamaecrista biensis* (Cham bie), *Digitaria eriantha* (Digi eri) and *Aristida congesta* (Aris con) (Figure 6.15). During the survey period a decrease in the importance values of *Cyperus* spp. (Cype spp) and *Oxalis* spp. (Oxal spp) could be observed due to their negative correlation over time (year-gradient) (Figure 6.15). Important differences were also evident along the three transects. The importance values of *Hyparrhenia hirta* (Hypa hir) and *Cynodon dactylon* (Cyno dac) increased from transect 1 to transect 3. *Eragrostis chloromelas* (Erag chl) and *Eragrostis plana* (Erag pla) were, however, antagonistic to the occurrence of *Hyparrhenia hirta* (Hypa hir) and *Cynodon dactylon* (Cyno dac) and decreased from transect 1 (12197, 12198 and 12399) to transect 3 (12397, 12398 and 12399). The RDA ordination also indicates that significant differences existed over time (year-gradient) and space (transects-gradient) for *Pennisetum clandestinum* (Penn cla) and *Tagetes minuta (Tage min).* The sort vector of *Eragrostis* spp. (Erag spp.) in the RDA analysis (Figure 6.15) indicates that the importance of this species remained the same or showed a small decrease during the three-year period.

Figure 6.16 indicates *Eragrostis* spp. (Erag spp.) as the most important species. This species also remained the dominant grass during the three-year study. The contributions of other species were all below 0.6 (20% of total composition), except for *Chamaecrista biensis* (Cham bie) which showed a large increase in its importance values during 1999 (Figure 6.16). The effect of *Chamaecrista biensis* did not increased linearly over time, as could be interpreted by Figure 6.15, and did not relate statistically significantly to the three-year trend (Table 6.3). The importance of *Hyparrhenia hirta* (Hypa hir) was also very small (importance value less than 0.2 (6% of total composition)) and did not increase over time as was observed in most other grids. *Cyperus* spp. are negative correlated (R=-0.949, Table 6.3) with the three-year trend (year-gradient). According to Figure 6.16, the importance values of both *Tagetes minuta* (Tage min) and *Conyza* spp. (Cony spp) increased during 1997 to 1999.

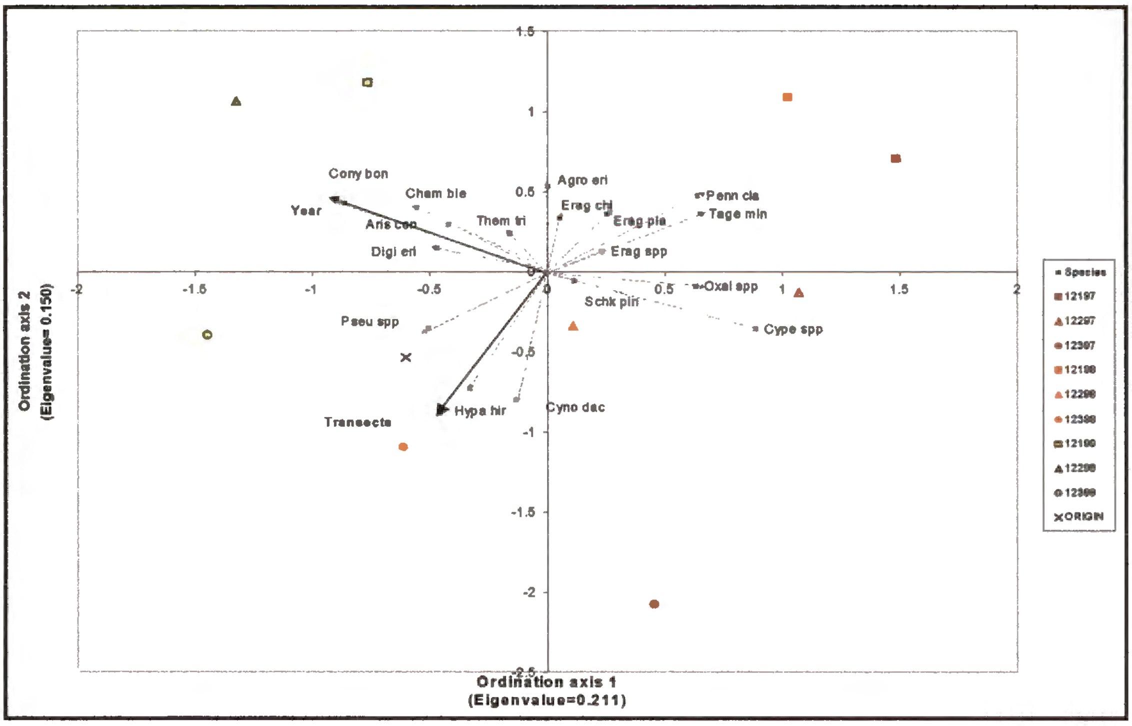

Figure 6.15: RDA ordination triplot of the change of vegetation over time (year-gradient) and space (transects-gradient) on grid 12, situated on ash disposal site 3 at Hendrina Power Station.

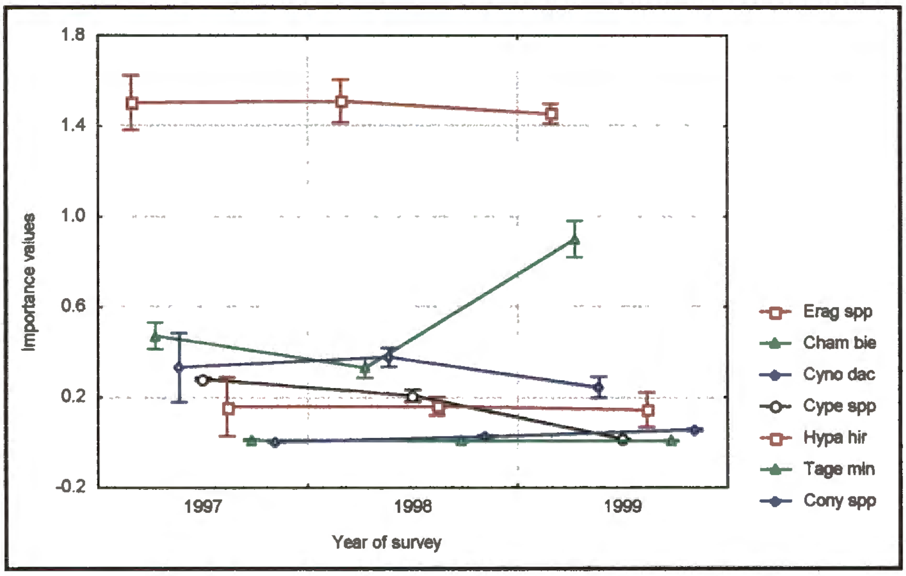

Figure 6.16: Change in the average importance values of selected species at grid 12, situated on ash disposal site 3 at Hendrina Power Station. Points indicate the average values and the whiskers the standard error deviation from the average

Table 6.3: Spearman rank correlation values for selected species importance values (only species with significant results shown) over a period of three years on rehabilitated ash disposal sites at Hendrina Power Station

	Grids							
Species	**1**	**2**	**3**	**4**	**9**	**10**	**11**	**12**
Pennisetum clandestinum	-0.685*	-0.791*	-0.158	-0.316	-0.632	/	/	-0.105
Eragrostis spp.	0.474	-0.791*	-0.843**	-0.263	0.263	-0.474	-0.211	-0.264
Cynodon dactylon	0.105	0.316	0.264	0.263	0.000	0.264	-0.843**	-0.211
Hyparrhenia hirta	0.948**	0.738*	0.632	0.053	0.105	-0.369	0.738*	0.158
Tagetes minuta	0.158	-0.531	-0.536	-0.211	0.738*	0.635	-0.693*	-0.344
Cyperus spp.	-0.632	0.632	0.422	-0.474	-0.422	-0.843**	-0.474	-0.949**
Schkuhria pinnata	-0.369	-0.231	0.345	0.058	0.422	0.368	-0.767*	/
Eragrostis plana	0.442	0.750*	0.590	0.737*	-0.369	/	/	-0.422
Chamaecrista biensis	0.791*	0.632	0.474	-0.132	/	0.791*	0.527	0.527

*, ** Significant correlations at p≤0.05; p ≤0.01 levels respectively

Table 6.4: The effect of a downward slope on selected species, tested with Spearman rank correlation on grids 2 and 3, situated on ash disposal site 1 at Hendrina Power Station

Species	Grid 2	Grid 3
Pennisetum clandestinum	0.053	0.949**
Chloris gayana	0.601	-0.820**
Bidens pinnata	-0.4330	-0.794*
Chamaecrista biensis	-0.264	-0.738*
Hyparrhenia tamba	0.858**	0.65**
Cynodon dactylon	-0.738**	-0.58
Stylosanthes fruticosa	0.635	-0.965**

*, ** Significant correlations at p≤0.05;p ≤0.01 levels respectively

6.4 DISCUSSION AND CONCLUSIONS

Directional changes in species composition on the ash dams are not consistent throughout. Only four grids or ecological units are statistically significantly related to a gradient of directional change over a three year period, namely grids 2, 10, 11 and 12 (Table 6.1). Most grids, however, displayed some sort of change in community structure because of changes in species abundances.

Increase in the importance values of *Hyparrhenia hirta* on most of the grids was observed, especially during the last year of the survey. The increase in *Hyparrhenia hirta* was on most grids also associated with a decrease in the population of *Eragrostis* spp. The stoloniferous grass *Pennisetum clandestinum* also decreased in importance values over time. This is especially true, where fire occurs annually, as in grids 1, 2 and 3. On areas where no regular fires occurs changes in species abundances are not as pronounces as areas regularly burned. On unburned areas *Eragrostis* spp. also does not show a collapse in importance values.

Stochastic fluctuations in the species populations of annuals were however also observed. *Conyza* spp. had a flourishing period during 1998 on most of the grids occurring on ash dam slopes. A drastic increase in the leguminous forb *Chamaecrista biensis* occurred during 1999 on all the surface grids.

Grids 2 and 3 on the slopes of the ash disposal sites illustrated a downward gradient in species composition (Table 6.1). Along grids 4 and 9, where a road divides the grid, the downward effect of slope was not prominent (Table 6.1). The effect of slope, therefore, plays an important role in species composition where it is not interrupted by a road or terrace step. This effect may be due to moisture differences, topsoil depth differences and the effect caused by the wash away of seeds down the slope. Plant invasion and colonisation from the adjacent area (catchment paddock) to the lower ash dam slope could also have effected the species composition between the upper and lower transects.

It can therefore be concluded that, although changes do not always occur at a statistically significant rate, changes in species do occur. Vegetation changes are, however, more related to species abundances than to changes in the total floristic composition.

Similar patterns in the change of certain species are observed between grids. Convergence towards *Hyparrhenia hirta* dominated grassland will probably occur in the areas where this pattern is observed, but differences between less abundant species will remain the same. An example of this is the exclusive occurrence of the two legumes *Stylosanthes fruticosa* and *Lespedeza cuneata* on the slopes. Five years after rehabilitation, these species have not yet colonised the plateaus of the disposal sites.

Further analysis on the basis of changes in diversity and rate of change will probably give more indication of the community dynamics of the ash dams over time. Available environmental variables will also be used to determine the causes of these changes over space and time. The three-year survey period is, however, too short to provide conclusive results. Inouye & Tilman (1988) studied the effect of different nitrogen applications on convergence and divergence of old fields for four years, and also indicated that longer survey periods give better results.

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Chapter 7 THE RATE OF COMMUNITY CHANGE AND DEVELOPMENT ON REHABILITATED ASH DISPOSAL SITES*

Abstract: Succession is synonymous with change in species composition and community structure whereas ecosystem stability is characterised by a lack of change and a decrease in rate of change. An increase in diversity may also be experienced, but no automatic relationship necessarily exists between diversity and stability. Low extinction rates and persistence of long-lived species adapted to the habitat also contribute to stability. Total stability is, however, never realistic due to fluctuations in species composition. The hypotheses regarding the decrease in rate of change and an increase in species diversity during succession are tested on rehabilitated ash disposal sites with the application of indices relating to similarity /dissimilarity and diversity indices. Rate of change on the older rehabilitated sites, over a period of three years, is found to be similar. Rate of change was initially high on newly rehabilitated ash disposal sites but decreased during the survey period. The rate of change of sites older than three years is, however, similar. No statistically significant results exist to indicate that diversity on ash disposal areas is on the decrease. Most results illustrate an increase in diversity primarily due to increase in evenness. The species diversity of the ash disposal area is considerably lower in comparison to the nearby natural grasslands. The period of study is, however, too short to provide conclusive results. A higher diversity on some sites can be attributed to the occurrences of annual species.

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* Partially submitted for publication in *Journal of Applied Ecology*

CONTENTS

7.1 INTRODUCTION

Succession is synonymous with community change in composition and structure (Myster & Pickett, 1994). The use of diversity and similarity/dissimilarity indices is a logical way to measure the magnitude of change (Myster & Pickett, 1994). This can be achieved by measuring and comparing turnover rates, similarities and diversities.

7.1.1 Similarity/dissimilarity Indices

Similarity/dissimilarity indices were developed to detect the degree of association or similarity between samples or communities (Beta (β)-diversity) (Kent & Coker, 1994). Similarity/dissimilarity indices can however also be used to detect vegetation change (Myster & Pickett, 1994; Smyth, 1997 and Bornkamm, 1981). An important hypothesis that is tested by this method is that succession should show a decrease in change over years with periodic fluctuations (Myster & Picket 1994; Facelli & D`Angela, 1990). This is the consequence of the control exerted by late successional species on the community structure (Facelli & D`Angela, 1990) through the replacement of annual species by long-lived (perennial) species (Connel & Slatyer, 1977). During the process of succession, long-lived (perennial) species and those best adapted to a particular habitat accumulate (Hulst, 1978).

7.1.2 Diversity

Species diversity indices are related to the population structure in a sample plot according to the number of species (species richness) and their abundances (evenness), and is described as the diversity (alpha (α)-diversity) of that sample. Species diversity can be regarded as an informative and easily interpretable measurement to analyse ecological data (Magurran, 1988). High species diversity is also considered indicative of stable ecosystems (Robinson, 1994 and Kent & Coker, 1994) and it is believed that diversity increases during ecosystem development (Bazzaz, 1975). According to Kent & Coker (1994) no automatic relationship exists between high diversity or species richness and community stability. Environmental stability is more important, because community stability will ultimately depend on environmental stability (Kent & Coker, 1992).

According to Barbour *et al.* (1987) a stable ecosystem can be defined as an ecosystem with a lack of change and with the dominant occurrence of long lived species. Changes occurring in a stable ecosystem appear as random minor fluctuations around a long term mean. Goodman (1975) considered stability as the degree of species persistence, and argued that the rate of extinction in a system determines stability. Fluctuations, therefore, do occur, but a stable community is characterised by a relative constancy of species (Begon *et al.* 1990; Goodman, 1975). The existence of total stable climax vegetation is, however, questioned by Begon *et al.*

(1990), Brown (1994) and Whalley (1994). According to above authors ecosystem stability is more closely related to change in species composition than to diversity of the ecosystem.

7.1.3 Aims and objectives

The aim of this study was to quantify vegetation change on rehabilitated ash disposal sites with similarity and diversity indices.

The following questions exist with regard to vegetation change and diversity of communities on the ash disposal sites at Hendrina Power Station:

7.1.3.1 What is the magnitude of vegetation change on different sampling grids during the three-year survey? It is expected that vegetation change will be the lowest on the oldest rehabilitated sites.

7.1.3.2 Does diversity vary between grids surveyed or is diversity uniform?

7.1.3.3 Does the rehabilitation treatment remain a significant factor over a number of years?

7.1.3.4 Does diversity changes over time and is this change constant? High species diversity is considered indicative of a stable ecosystem (Robinson 1994, Kent & Coker 1994) and it is believed that diversity increases during ecosystem development (Bazzaz 1975, Peet 1992).

7.1.3.5 What is the diversity between newly rehabilitated and older rehabilitated sites? It is expected that older rehabilitated sites will have a higher diversity.

7.1.3.6 Does any difference in diversity exist between rehabilitated sites and a nearby natural grassland? One of the major concerns of rehabilitated sites is its low diversity in comparison to natural vegetation (Roberts *et al.* 1981).

7.1.3.7 What is the effect of topography on diversity?

7.1.3.8 The relation between species composition and diversity is finally investigated. The question is asked: what is the relationship between species occurrence (functional groups and species) and diversity on old rehabilitated sites?

7.2 MATERIALS AND METHODS

7.2.1 Data sampling

Survey data of eight survey plots (grids 1, 2, 3, 4, 9, 10, 11 and 12), consisting of three transects each (Chapter 2, Table 2.4), were used for this study. The survey grids were all situated on rehabilitated areas older than three years (at the start of the study). Transects of the two remaining survey grids (7 and 8) were divided according to age. The middle transect was situated on newly rehabilitated slopes and the bottom transect on an area rehabilitated during 1992. Transects on the newly rehabilitated areas were grouped together to form an additional unit referred to in the text as newly rehabilitated areas. Due to the differences in species composition of transects along the bottom of the slope, only grids 7 and 8 could not be grouped together. Surveys of all plots extended over a period of three years (March 1997-February 1999) and included frequency, basal cover and density surveys. During the three years similar studies were conducted on two grids situated in natural grassland. The descending point method was used to obtain frequency and basal cover data. Approximately 120 points were surveyed along each transect. The nearest plant was noted at each point within a radius of 30 cm. If no plant occurred within this radius, the point was noted as bare ground. Additionally, basal hits were also noted to obtain the basal cover of each species. Density surveys were conducted in five quadrats along each transect. The five quadrats were summed to give an indication of the species densities over the entire transect. These surveys were repeated annually during the growing season (January March) from 1997 to 1999.

Data were analysed using the importance values for each species on each transect. Importance values were calculated from the sum of relative frequency, relative basal cover and relative density for each species at each transect (Mueller-Dombois & Ellenberg, 1974). Importance values were expressed as a fraction and ranged from 0 to 3. Importance values rarely exceeded 2. The vegetation change over three years at each of the survey plots was determined using three different indices.

7.2.1.1 Sørensen Similarity Coefficient

The Sørensen Similarity Coefficient is one of the oldest coefficients used, but also one of the most useful indices according to Magurran (1988). This coefficient is normally used for qualitative data, and is calculated from presence/absent data sets and indicates the similarity between two samples. The Sørensen Similarity Coefficient is preferred above other qualitative coefficients, because it gives more weight to species that are common to both samples plots, rather than to those that only occur in either of the sample plots used (Kent & Coker, 1994). The Sørensen Similarity Coefficient can be calculated from the equation:

$$Ss = 2a/(2a+b+c)$$

Where:

a= number of species common to both quadrats/samples

b= number of species in quadrat /sample1

c= number of species in quadrat /sample 2

7.2.1.2 Squared Euclidean Distance

The second index is a coefficient based on the Euclidean properties of a right-angled triangle (Kent & Coker, 1994) and is termed squared Euclidean Distances (SED). This coefficient is also a measure of the dissimilarity between two sample plots and is normally expressed as a distance in a geometric space. The lower the distance value between sample plots the more similar they are in species composition. The lower limit of the coefficient is 0 and represents complete similarity. It is also described as a dissimilarity coefficient due to the fact that it has no upper limit.

7.2.1.3 Shannon Diversity Index

The Shannon Diversity Index is derived from the number of species and their proportional occurrence in a community. It therefore considers both the species richness and evenness (equability) of a community. Idealistically it is assumed that individuals are randomly sampled from an "infinitely" large population. The index also makes the assumption that all the species of the community are included in a sample (Magurran, 1988). This makes the application of this index problematic, because most studies only sample a small portion of the community, and most of the time it is not possible to assume that all the species of a community are included (Kent & Coker, 1994). The representativeness of the index to the community as a unit must be considered in terms of the sample representativeness. The Shannon Diversity Index can be calculated from the equation (Kent & Coker, 1994):

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Where s = the number of species (species richness)

p_i = the proportion of individuals or the abundance of the i_{th} species

Log $base_n$ (the natural algorithm, ln, was used for this study)

Values of the index usually lie between 1.5 and 3.5 although it may exceed 4.5 in exceptional cases (Kent & Coker, 1994).

7.2.2 Data analysis

Different survey years were compared with each other on each grid with respect to their similarity in species composition according to Sørensens and SED s.

Sørensens Similarity Coefficients and Shannon Diversity Index were calculated with the MVSP (MultiVariate Statistics Package) computer program (Kovach, 1983-1993). The calculation of square Euclidean distances and all statistical analysis on the data were conducted with STATISTICA for Windows (1995). All parametric analyses assumed that data are normally distributed and are of homoscedasticity. Normality of the data set was tested using the Kolmogorov-Smirnov test (Sokal & Rohlf, 1969). Homogeneity of variance (homoscedasticity) was tested using the Univariate test (Cochan C, Hartley, Bartlett) (Winer, 1971) with the STATISTICA for Windows (1995) program. Homoscedasticity and normality were assumed if data were not significant at a $p \leq 0.05$. Multivariate data were analysed by a one way ANOVA (Sokal & Rohlf, 1969). If the overall effect was significant, the interactions between variables were tested with Tukey's honest significant differences (HSD) test if groups consisted of equal populations (Sokal & Rohlf, 1969). In cases where groups had unequal sample sizes Tukey's test for unequal populations (Spjotvoll & Stoline, 1973) were used. The Student-Newman-Keuls procedure (Sokal & Rohlf, 1969) was also used to test results (where indicated). The Student's t-test was employed to data of two subsets. Non-parametric data were compared with the

Kruskal-Wallis median test and Mann-Whitney U test (Sokal & Rohlf, 1969). Data over a time series were tested with repeated measurement ANOVA if parametric or with Friedman's ANOVA for non-parametric data (STATISTICA for Windows 1995).

Linear relationships between independent and dependent variables were also tested with Pearson's Product-Moment Correlation Coefficient (for parametric data) or Spearman's Rank Coefficient (non-parametric data) (Sokal & Rohlf, 1969). Significant correlation may indicate directional change in species composition and may indicate that succession and community development has occurred. Statistical significance is accepted if $p \leq 0.05$ level.

7.3 RESULTS

7.3.1 Rate of change on old rehabilitated sites during 1997-1999

Differences in Squared Euclidean Distance (SED) and Sørensens Similarity Coefficient were compared with Friedman's ANOVA for the 1997-1998, 1998-1999 and 1997-1999 periods (Table 7.1). No overall statistically significant changes over the time series of three years existed for the Sørensens Similarity Coefficients (Table 7.1). Change in SED was statistically significant between the three periods (Table 7.1). The largest difference in SED was between the 1997-1999 period in comparison to the 1997-1998 and 1998-1999. The overall change over the three-year period (1997-1999) in SED was smaller than the change during the two periods (1997-1998 and 1998-1999) (Table 4.1).

Grid 4 illustrated the largest change in Sørensens Similarity Coefficient between 1997-1998 and 1998-1999 (Table 7.2). The decrease in similarity between consecutive years on grid 4 indicated that vegetation increased in rate of change. Vegetation on grid 3 also increased in rate of change (Table 7.2). The Sørensens Similarity Coefficients between consecutive periods for most other grids increased indicating a decrease in the successional tempo, or remained the same (Table 7.2).

On most grids the average SED changed during the study, although only SED on grid 9 between the periods 1997-1998 and 1998-1999 was significant. Change in SED on grid 9 (p-value< 0.05) decreased statistically significantly over the study period according to a Friedman's ANOVA test (Table 7.3). Grids 1 and 2 decreased in SED and grids 4, 10 and 11 increased in SED (Table 7.3).

An important question that came to mind during the analysis is if SED is correlated with Sørensens Similarity Coefficient, because Sørensens Similarity Coefficient is a binary index (presence/absent of species) while SED considers species occurrence and abundances of all species.

Linear regression indicates that Sørensens Similarity Coefficient and SED values are negatively correlated (r=-0.506), but no significant relationship between these two indices can be assumed. Inspection of the SED and Sørensens Similarity Coefficient results on grid 10 indicated that, although the similarity between the 1998-1999 year was higher than the 1997-1998 period, the dissimilarity calculated with SED was also higher. This indicates that changes are entirely due to change in the abundance of certain species. Results from Chapter 4 indicated that this could be due to a sharp increase in the annual forb *Chamaecrista biensis* during the 1998-1999 period. *Eragrostis curvula* and *Cyperus esculentus* also decreased considerably during this period.

Table 7.1: A comparison of rate of change during the periods 1997-1998, 1998-1999 and 1997-1999 with Square Euclidean Distances and Sørensens Similarity Coefficients on old rehabilitated ash disposal sites at Hendrina Power Station

	Average Square Euclidean Distance (p- value: 0.018)		Average Sørensens Similarity Coefficient (p-value: 0.082)	
1997-1998	0.655	*0.860*	0.716	*0.121*
1998-1999	0.618	*0.620*	0.736	*0.094*
1997-1999	0.991	*1.367*	0.686	*0.113*

The statistical results are according to Friedman's ANOVA test. Standard deviation from average indicated in italics.

Table 7.2: Summary of average Sørensens Similarity Coefficients (indicated as a percentage) according to sampling grids on rehabilitated ash disposal sites at Hendrina Power Station

Grid	1997-1998 (%)		1998-1999 (%)		1997-1999 (%)		
1	74.50	*6.10*	79.40	*2.30*	75.00	*10.60*	3
2	76.50	*12.60*	78.10	*7.90*	72.80	*11.80*	3
3	70.30	*17.80*	64.00	*8.70*	64.00	*3.50*	3
4*	79.70	*4.20*	67.70	*11.00*	70.00	*3.00*	3
9	77.30	*4.00*	76.70	*10.30*	73.00	*5.60*	3
10	67.00	*9.00*	79.70	*5.80*	76.70	*9.80*	3
11	69.70	*9.60*	69.80	*5.30*	59.60	*7.30*	3
12	76.70	*3.00*	81.40	*5.10*	74.90	*6.10*	3
T1Y	42.80	*3.90*	61.50	*10.00*	42.90	*2.10*	2

T1Y: transect on newly rehabilitated areas. Standard deviation from mean indicated in italics

Significant changes over time period: p< 0.10*, p<0.05**, 0.01*** according to Friedman's ANOVA

Table 7.3: Summary of average Square Euclidean Distances (SED) according to sampling grids on rehabilitated ash disposal sites at Hendrina Power Station

Grid	1997-1998		1998-1999		1997-1999		
1	0.420	*0.465*	0.253	*0.098*	0.413	*0.323*	3
2*	0.610	*0.407*	0.470	*0.465*	1.413	*1.202*	3
3	0.380	*0.115*	0.483	*0.398*	0.523	*0.346*	3
4	0.253	*0.117*	0.467	*0.394*	0.232	*0.222*	3
9**	0.613	*0.341*	0.293	*0.188*	0.714	*0.397*	3
10*	0.230	*0.026*	0.520	*0.105*	0.543	*0.170*	3
11	0.857	*1.016*	0.873	*0.490*	1.090	*0.612*	3
12	0.267	*0.050*	0.440	*0.111*	0.407	*0.193*	3
T1Y	3.065	*1.322*	2.330	*0.919*	4.880	*2.461*	2

T1Y: transect on newly rehabilitated areas. Standard deviation from mean indicated in italics

Significant changes over time period: p< 0.10*, p<0.05**, 0.01*** according to Friedman's ANOVA

7.3.2 Differences in rate of change between survey grids

No statistically significant differences in Sørensens Similarity Coefficients or SED existed between survey grids (Table 7.4 and 7.5). Changes in the rate of Sørensens Similarity Coefficients between grids were the most pronounced during 1998-1999 (Table 7.4). The rate change of Sørensens Similarity Coefficients and SED for old rehabilitated sites with different rehabilitation ages and treatments were also not statistical significant (Table 7.4 and 7.5). The effect of time and treatment was therefore not significant.

Table 7.4: Summary of ANOVA's for differences in Sørensens Similarity Coefficients between grids and the effect of year of rehabilitation on vegetation change

	1997-1998		1998-1999		1997-1999	
	F-statistics	p-value	F-statistics	p-value	F-statistics	p-value
Grids	0.650	0.710	2.215	0.089	1.742	0.169
Year of rehabilitation	0.539	0.709	1.800	0.171	1.245	0.326

Table 7.5: Summary from the Kruskal-Wallis test for differences in Square Euclidean Distances (SED) between grids and the year of rehabilitation on vegetation change

	1997-1998		1998-1999		1997-1999	
	H Statistic	p-value	H Statistic	p-value	H Statistic	p-value
Grids	3.489	0.836	6.837	0.4461	11.056	0.136
Year of rehabilitation	1.948	0.745	4.092	0.394	4.280	0.370

Sørensens Similarity Coefficients between consecutive years on old rehabilitated sites, varied between 67% (grid 10) and 79.7% (grid 4) for 1997-1998 and between 64% (grid 3) and 81.4% (grid 12) for 1998-1999 (Table 7.2). According to Sørensens Similarity Coefficients for 1997-1999 period, grids 3 (64%) and 11 (59.6%) experienced the most change during the survey period (Table 7.2).

SED varied between 0.23 (grid 10) and 0.86 (grid 11) for 1997-1998, and for the 1998-1999 period between 0.25 (grid 1) and 0.87 (grid 11) (Table 7.3). If SED for the entire period is compared then grid 2 (SED=1.413) and grid 11 (SED=1.090) experienced the most change. Vegetation on grids 1 (SED=0.413), 4 (SED=0.232) and 12 (SED=0.407) experienced the least change (Table 7.3). These results also correspond with the Sørensens Similarity Coefficients. The low successional rate of the vegetation at grid 1 is not as expected because this area was rehabilitated during 1995 (see Chapter 2).

7.3.3 Rate of change on newly rehabilitated sites during 1997-1999

Data from surveys conducted on sites that were rehabilitated less than a year before our surveying started in 1997 were compared. Unfortunately these data could not be analysed together with older rehabilitated areas due to the small sample size (n=2). The data that were used originated from the middle transects of grids 7 and 8. Data of the transects were combined and results are illustrated in box plots (Figures 7.2 and 7.3).

Figure 7.2 indicates the change in similarity from 1997-1998 to 1998-1999 and the similarity between the 1997 and 1999 survey. Changes between the two periods were substantial. Results indicated a decrease in rate of change from the 1997-1998 season to the 1998-1999 season.

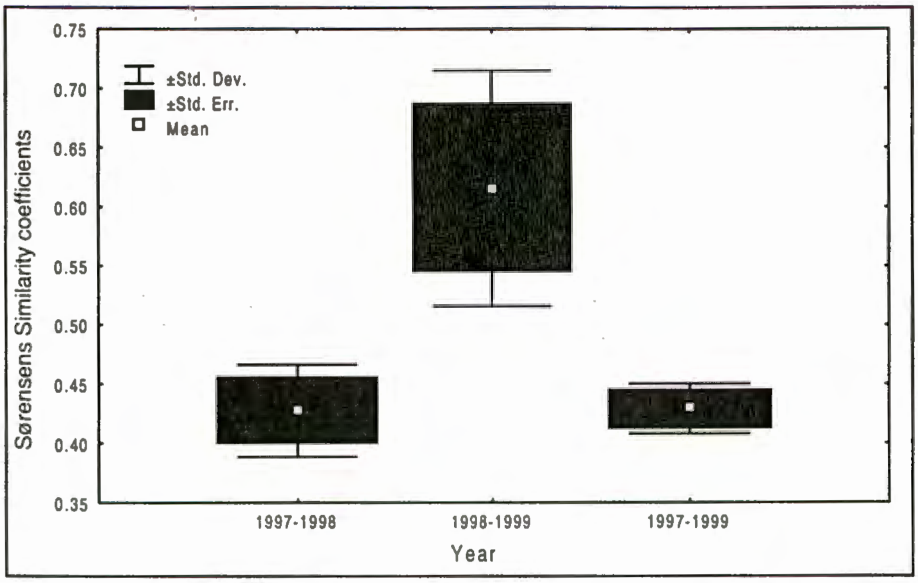

Figure 7.1: Rate of change indicated by Sørensens Similarity Coefficients from data of the middle transects of grids 7 and 8 on ash disposal sites at Hendrina Power Station, rehabilitated less than a year before the survey started in 1997.

Changes in SED from 1997-1998 to 1998-1999 (Figure 7.3) were not as pronounced as indicated by Sørensens Similarity Coefficients. A decrease in the SED was, however, observed over the two periods (Figure 7.3). The total change from 1997 to 1999 illustrated a large amount of variance. Rate of change between the two transects was, therefore, very different (Figure 7.3).

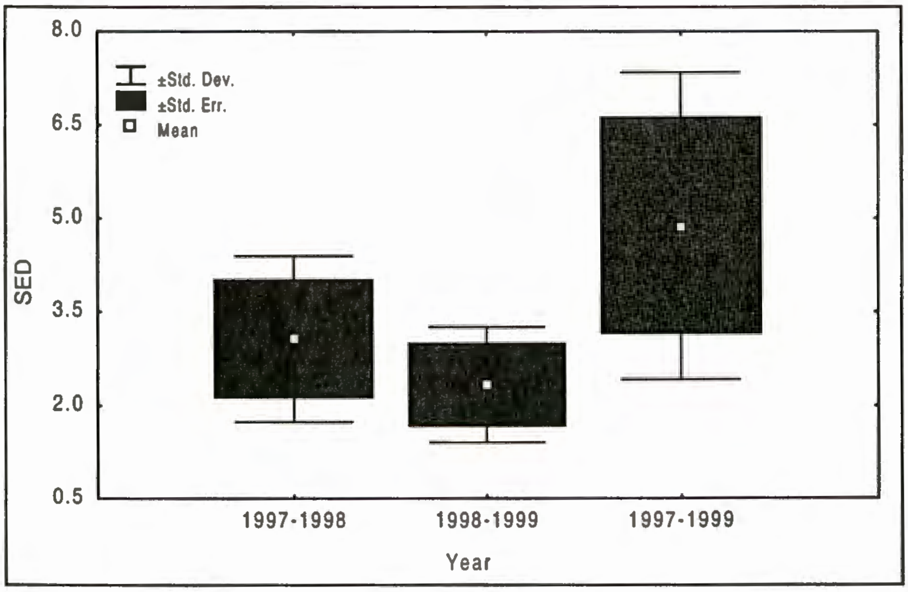

Figure 7.2: Rate of change indicated by Square Euclidean Distances (SED) from data of the middle transects of grids 7 and 8 on ash disposal sites at Hendrina Power Station, rehabilitated less than a year before the survey started in 1997.

If the results from the average Sørensens Similarity Coefficients and SED of old rehabilitated sites are compared with those of the newly rehabilitated sites, it is then clear that rates of change on older rehabilitated sites are relative small (Tables 7.4 and 7.5). The fact that grids also have similar rates of change illustrate that these changes were constant throughout the study period.

7.3.4 Changes in species diversity on old rehabilitated sites during 1997-1999

Grids 1, 9, 10 and 11 illustrated significant changes in Shannon Diversity Indices during the three-year period (Table 7.6). Figure 7.3 indicates that most changes in Shannon Diversity Indices occurred during the 1997-1998 season. These statistically significant changes in Shannon Diversity Index values can be attributed to changes in evenness rather than changes in species richness because the F statistic values for the comparison of evenness between years were generally higher than values indicated for species richness between years (Table 7.6). Statistical significant changes in evenness over the three year period were found in the vegetation of grids 9 and 10, which correspond with changes in Shannon diversity on these grids (Table 7.6). Change in average Shannon Diversity Index values on grid 11 were not constant, but decreased during 1999 (Figure 7.4.4). Evenness in the vegetation increased statistically significantly during 1997-1998 at grids 9 (Figure 7.5.1) and 10 (Figure 7.5.2).

The only grid at which a statistically significant increase of species richness was observed was on grid 1 (Table 7.6). Results from most grids illustrated a similar pattern in diversity. The average Shannon diversity, Evenness and species richness increased between 1997-1998 but decreased slightly during 19998-1999 (Figures 7.3.1, 7.3.4, 7.4.1, 7.4.2 and 7.5). A possible explanation is the influence of annual forbs and grasses on diversity.

Table 7.6: Changes in α-diversity during 1997-1999, for grids on old rehabilitated ash disposal sites at Hendrina Power Station according to an ANOVA with repeated measurements

Grid (df=2)	Shannon Index F-value	Evenness F-value	Species richness F-value
1	7.362**	3.783	25.103***
2	1.824	2.343	0.130
3	4.997*	5.517*	0.261
4	0.935	0.824	0.743
9	9.647**	11.05**	2.925
10	18.315***	11.800**	1.727
11	15.281**	2.555	1.064
12	3.474	5.919*	0.864

*, **, *** Significant at $p \leq 0.10$; $p < 0.05$; $p \leq 0.01$ levels respectively

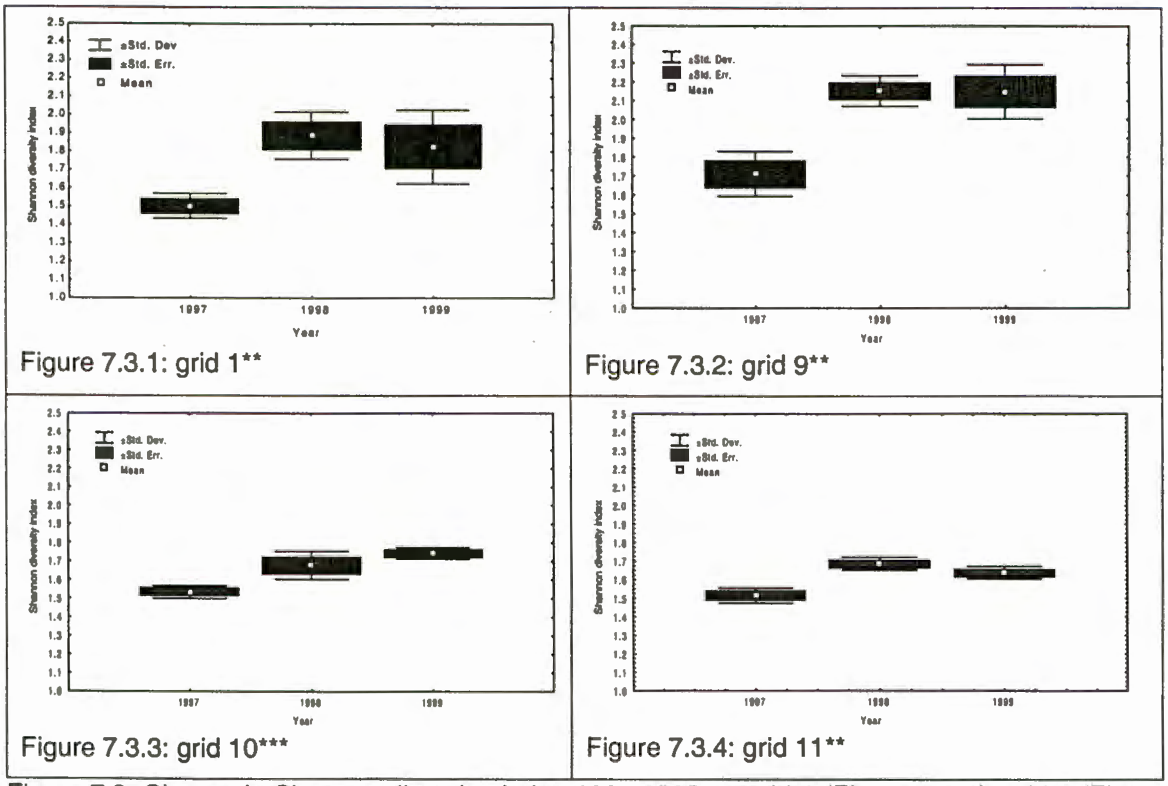

Figure 7.3.1: grid 1**

Figure 7.3.2: grid 9**

Figure 7.3.3: grid 10***

Figure 7.3.4: grid 11**

Figure 7.3: Change in Shannon diversity during 1997-1999 on grid 1 (Figure 7.3.1), grid 9 (Figure 7.3.2), grid 10 (Figure 7.3.3) and grid 11 (Figure 7.3.4) on rehabilitated ash disposal areas at Hendrina Power Station.

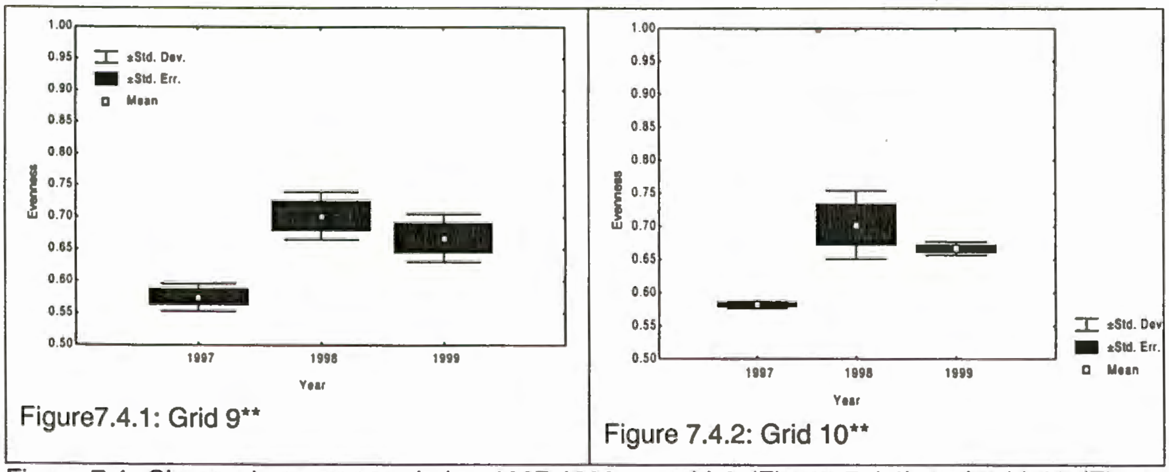

Figure7.4.1: Grid 9**

Figure 7.4.2: Grid 10**

Figure 7.4: Change in evenness during 1997-1999 on grid 9 (Figure 7.4.1) and grid 10 (Figure 7.4.2), on rehabilitated ash disposal areas at Hendrina Power Station.

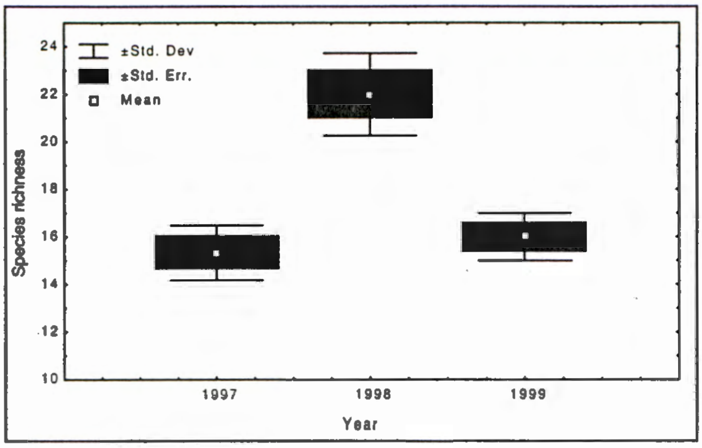

Figure 7.5: Change in species richness during 1997-1999, at grid 1 (F statistic 25.103, p ≤0.01) on rehabilitated ash disposal areas, at Hendrina Power Station.

Statistically significant, linearly correlated increases in Shannon diversity were observed at grids 3, 9, and 10. Changes were therefore not an annual fluctuation (Table 7.7), but increased linearly over time. Although statistically significant changes in the Shannon Diversity Index values (Table 7.6) was observed for grid 11, these changes was not correlated with the temporal gradient (Table 7.7). Although species richness occurred as a fluctuational increase during 1998 on grid 1, the increase in evenness on grid 1 was statistically significantly correlated with the temporal gradient. Species richness was also statistically significantly correlated with temporal change on grid 9 (repeated measurement ANOVA results for species richness on grid 9 was, however, not significant).

Table 7.7: Correlation matrix to test the linear relationship between temporal change and diversity on old rehabilitated ash disposal sites over the three year period at Hendrina Power Station.

Grids	Shannon diversity	Evenness	Species richness
1	0.643	0.682*	0.085
2	0.628	0.619	0.152
3	0.725*	0.749*	0.142
4	0.146	0.148	0.098
9	0.782*	0.630	0.735*
10	0.880**	0.617	-0.068
11	0.640	0.234	0.276
12	-0.141	-0.335	0.200

*, ** Significant correlation with p≤0.05; p≤0.01 levels respectively, N=9

7.3.5 Changes in species diversity on newly rehabilitated sites during 1997-1999

Steady increases in Shannon diversity, evenness and species richness can be detected on newly rehabilitated grids (Figure 7.6). Pearson's Product-Moment Correlation Coefficients were significant between Shannon Diversity Index and time elapse (r= 0.856). Correlation for evenness (r= 0.702) and species richness (r= 0.691) were also high, but not statistically significant. Shannon indices increased from 1.326 during 1997, to 1.71 for 1999. The average number of species for the newly rehabilitated areas increased from 16 to 19 species.

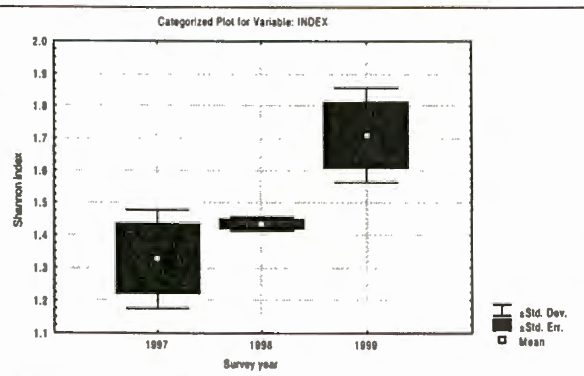

Figure 7.6.1: Shannon diversity

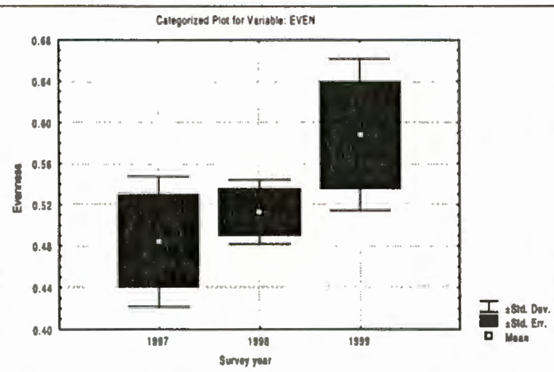

Figure 7.6.2 Evenness

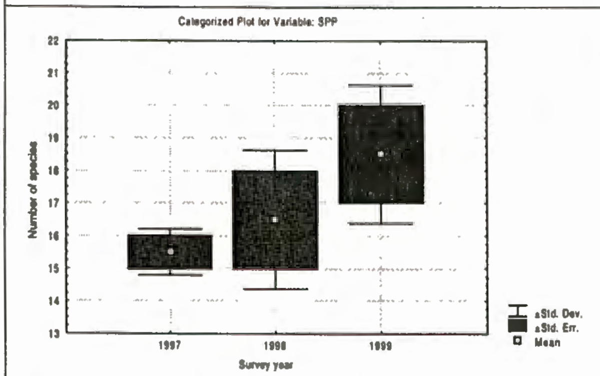

Figure 7.6.3: Species richness

Figure 7.6: Changes in Shannon indices (Figure 7.6.1), Evenness (Figure 7.6.2) and species richness (Figure 7.6.3) on newly rehabilitated areas of ash disposal area 4 at Hendrina Power Station.

7.3.6 Differences in diversity between survey grids on old rehabilitated sites

Vegetation of grids on old rehabilitated areas (age of rehabilitation > 2 years) differed significantly in Shannon diversity indices (p= 0.000), evenness (p= 0.015) and species richness (p= 0.000).

Grid 9 had the highest diversity (Shannon diversity =2.004) and was the only grid that illustrated statistically significant differences from the remaining grids. Grids 2, 4 and 12 had the lowest Shannon diversity (average Shannon diversity< 1.6) (Figure 7.7). Grids situated on top of ash disposal site 3 (Chapter 2; Figure 2.1) were relatively similar in Shannon diversity and species richness, but were very different in evenness (Figure 7.8). Grids situated on the slopes of ash dam 1 were variable in diversity. Grids 2 and 4 occurring on opposite sides of ash dam 1 were lower in diversity than grid 3 (Figure 7.7). On both grids 4 and 9, a road transects the grid above or below the second transects. If the effect of the road is therefore considered, it must be concluded that it had no real effect on diversity, due to the statistically significant differences in the Shannon diversity (P= 0.000) and species richness (P-value=0.000) between the two grids. Grid 9 had a higher Shannon diversity (Figure 7.6), evenness (Figure 7.8) and species richness (Figure 7.9) in comparison to grid 4. Grid 1, which had a very different rehabilitation treatment, showed no statistically significant differences from the rest of the grids (Figures 7.7, 7.8 and 7.9). Tukey's test also failed to indicate any statistically significant differences between grids 2 and 4, in comparison to grid 3. The Shannon Diversity Index values and species richness between grids 2 and 4, in comparison to grid 3 were, according to Figures 7.7 and 7.9, higher. Evenness was, however, found to be the same for the three grids (Figure 7.8). All three grids were rehabilitated during the same year with the same treatment, and still showed variation in species richness. It must be reminded that Tukey's test was used for analysis between groups. A different test, for instance the LSD test in the STATISTICA module, would have indicated more statistical differences due to the low resistance of the LSD test to type I errors.

Although the ANOVA for evenness between grids were statistically significant, the Tukey's test failed to indicate any statistically significance between grids. The box plot for evenness (Figure 7.7) indicated that grids 9 and 10 had the highest evenness (average evenness ≅ 0.65). Grids 2, 3 and 4 were very similar in evenness, while grid 12 had the lowest evenness (average evenness=0.565).

Tukey's test between groups indicated that grid 9 had the highest species richness (average species richness =22.1 species) and that the species richness of this grid was statistically significantly different from grids 2, 4, 10, 11 and 12 (Figure 7.9). Grids 10 and 11 had the lowest species richness (13-14 species) for grids on the ash disposal area of Hendrina Power Station. Species richness for grid 12 (16 species) should also have fallen in the region of 13-14 species, and therefore has a species richness of little more than was expected. This is due to the fact that grid 12 extends into an area that contains *Pennisetum clandestinum* and *Agrostis eriantha* that is not typical of the rest of the grid.

Although the evenness for grid 10 was relative high, its species richness and Shannon diversity remained low. The situation for grid 9 was however quite different. Evenness and species richness were both higher at grid 9 in comparison to the remaining grids. Pearson's Product-moment correlation indicated that Shannon diversity can both be related to species richness (r= 0.677; p=0.001) and evenness (r= 0.741; p= 0.001), but no relationship between evenness and species richness (r= 0.025; p= 0.838) existed.

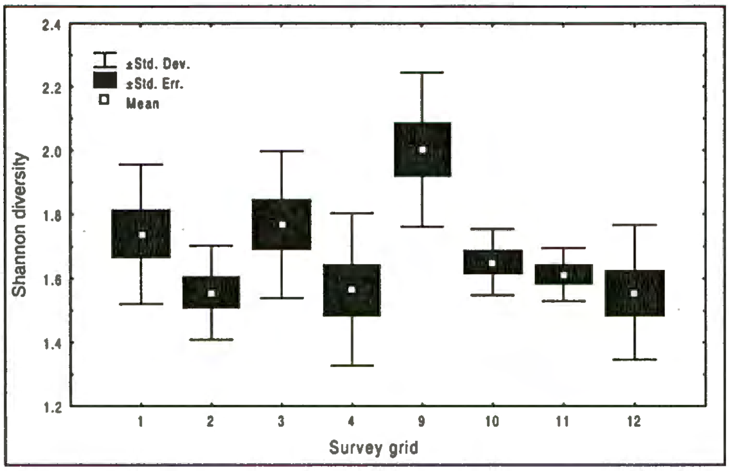

Figure 7.7: Differences in Shannon diversity indices between grids on ash disposal sites rehabilitated for more than two years at Hendrina Power Station.

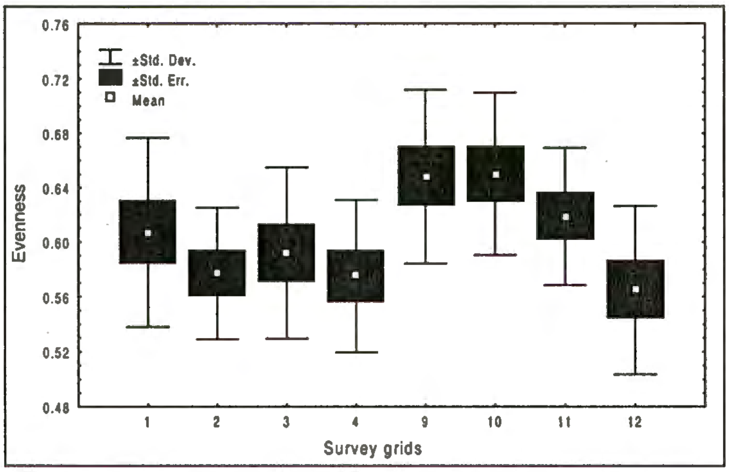

Figure 7.8: Differences in evenness between grids on ash disposal sites rehabilitated for more than two years at Hendrina Power Station.

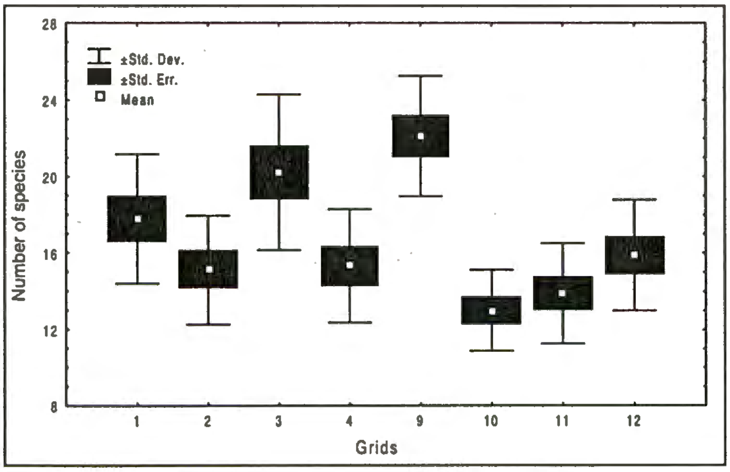

Figure 7.9: Differences in species richness between grids on ash disposal sites rehabilitated for more than two years at Hendrina Power Station.

7.3.7 Differences in diversity between newly and old rehabilitated sites

A t–test was performed between grids that were situated on sites which were rehabilitated less than one year ago, and sites more than two years ago at the start of the study in 1997. Evenness was found to be statistically significantly higher (p= 0.015) for sites rehabilitated more than two years ago. No differences between Shannon diversity indices or in species richness were encountered (Table 7.8) between newly and old rehabilitated sites.

Table 7.8: Differences in the averages and standard deviations (Std. dev.) for Shannon diversity, Evenness and Species richness between newly rehabilitated (< 1 years) and old rehabilitated (>2 years) ash disposal sites at Hendrina Power Station

Factor	Shannon Index (p=0.082)		Evenness (p= 0.015)		Species richness (p=0.915)	
	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Newly rehabilitated (n=6)	1.420	0.201	0.529	0.066	16.833	1.941
Old rehabilitated(n=78)	1.667	0.241	0.599	0.0671	16.654	4.054

7.3.8 Differences in diversity between rehabilitated and natural grasslands

Diversities between old rehabilitated ash disposal areas and a nearby natural grassland were compared with the non-parametric Mann-Whitney test. It was decided to use this test due to the heteroscedasticity of the data sets. Differences in Shannon diversity, evenness and species richness between rehabilitated ash disposal areas and a nearby natural grassland (Table 7.9) were all highly significant (p< 0.000). Average Shannon diversity for rehabilitated areas were 1.682, which was statistically significantly lower than the Shannon diversity of the natural grassland of 2.538. Species encountered in the natural grassland (Species richness =41.941) were more than twice as much as were found on old rehabilitated grids (16.667).

Table 7.9: Differences in the averages and standard deviations (Std. dev.) for Shannon diversity, Evenness and Species richness between old rehabilitated grassland and the natural grassland at Hendrina Power Station

Factor (Mann-Whitney U test)	Shannon Index (p=0.000)		Evenness (p= 0.000)		Species richness (p=0.000)	
	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Rehabilitated grassland (n=72)	1.682	0.234	0.604	0.064	16.667	4.145
Natural grassland (n=17)	2.538	0.185	0.683	0.041	41.941	8.081

7.3.9 Differences in diversity between ash disposal slopes and plateaus of ash disposal sites

The topographical effect of slope against plateaus was tested with the non-parametric Mann-Whitney U test. Species evenness was higher (P= 0.051) on the plateau's than on the sides of the ash disposal sites. Therefore, fewer species did occur on the ash disposal plateaus, but they occurred more evenly (Figure 7.10.1). Species richness was found to be statistically significantly higher (p= 0.000) on the sides than on the plateau's of the disposal sites (Figure 7.10.2). No differences in the Shannon Diversity Index was found, and the averages between values were similar (average index value = 1.6).

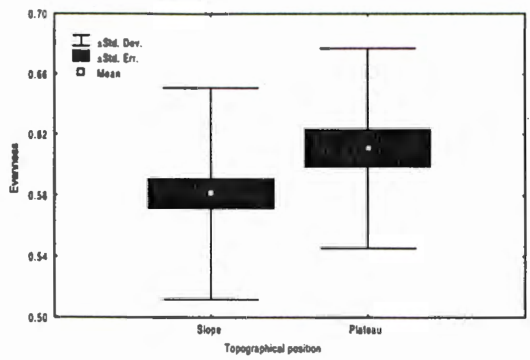

Figure 7.10.1

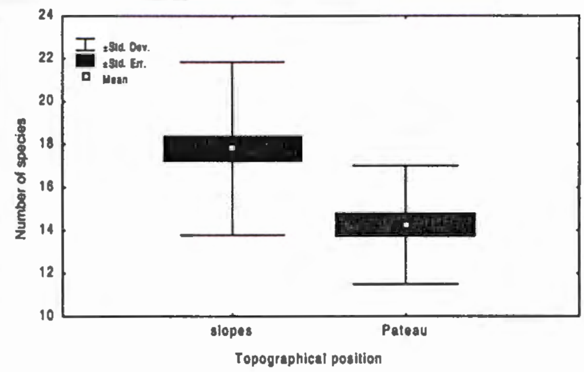

Figure 7.10.2

Figure 7.10: Differences in evenness (Figure 7.10.1) and species richness (Figure 7.10.2) between slopes and plateau's of ash disposal sites at Hendrina Power Station.

7.3.10 Differences in diversity on different slope positions on the slopes of ash disposal sites

The effect of slope position on species composition was already mentioned in Chapter 3. To investigate this effect further, the transects on the grids (grids 2, 3, 4, and 9) situated on slopes, were grouped according to upper, middle and bottom slope positions (see Chapter 2, Figure 2.7). ANOVA on Shannon diversity, evenness and species richness indicated that only species richness (p= 0.017) differed statistically significantly. A further test with Tukey's test indicated that bottom transects had a statistically significant lower species richness (average: 15.417, p=0.016) than the middle transects (20.250) (Figure 7.11). The upper transects also had a slightly lower species richness (average: 18.917) than the middle transect.

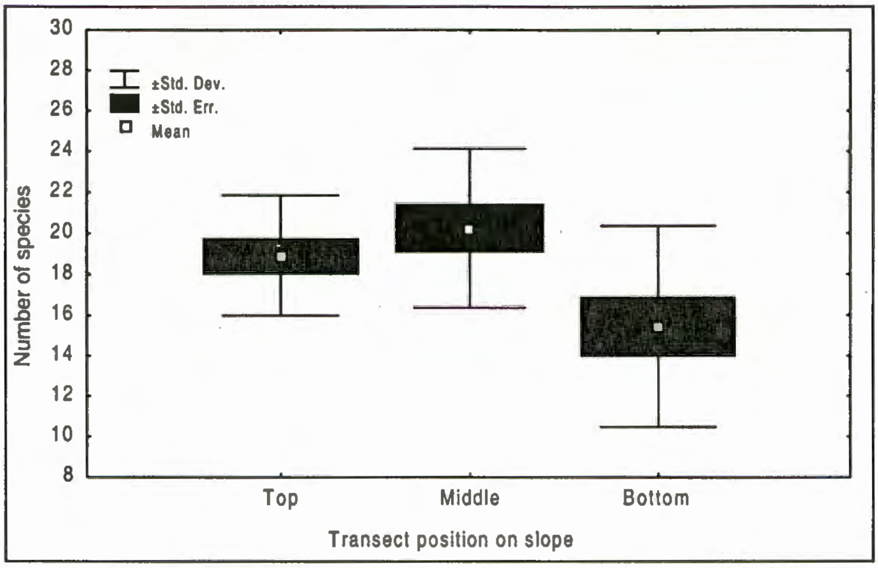

Figure 7.11: Differences in species richness between transects situated on different slope positions of grids on ash disposal sides at Hendrina Power Station.

Pearson's product-moment correlations also indicated that no statistically significant linear increase or decrease in Shannon indices, evenness or species richness existed down the slope. All of the correlations were, however, negative (Table 7.10).

Table 7.10: Linear relationship (Pearson's product-moment r) between diversity and slope position on ash disposal sites at Hendrina Power Station (correlation down the slope)

	Shannon diversity	Evenness	Species richness
Slope position	-0.2936	-0.1446	-0.3289

*, ** Significant correlations at p≤0.05;p ≤0.01 levels respectively

7.3.11 Differences in rank-abundances between survey areas

Figures 7.12.1 to 7.12.4 represent rank-abundance diagrams for survey grids situated on the different ash disposal areas. Rank abundance of the natural grassland (control) is different from all the grids situated on the ash disposal area (Figures 7.12.1 to 7.12.4). Species importance values in the natural grassland are more evenly distributed and decreased slower. Levelling of the species importance values also occur above 0.01. Grids 1, 2 and 4 have a similar distribution in importance values. The vegetation on grid 3 is the most evenly distributed in comparison to grids 1, 2 and 4 (Figure 7.12.1).

Figure 7.12.2 Illustrates the rank-abundances for survey grids situated on ash disposal area 3. As indicated by previous analysis, survey grid 9 had the highest evenness among grids situated on the ash disposal area. This grid represents one of the oldest rehabilitated sites (rehabilitated during 1992) and occurs on one of the east facing slopes of the dam. No fire has occurred on this slope for the past three years, but according to the previous manager of the ash disposal area, a fire swept through this area during 1996. The reason for this difference in evenness is therefore difficult to explain. Due to the dominance of large tufted *Eragrostis curvula* plants on grid 12, the area has low species evenness.

Figure 7.12.3 illustrates the change in rank-abundance for the newly rehabilitated area on ash disposal area 4. The newly rehabilitated area is characterised by the dominance of a few species during the first year (1997) with a subsequent increase in species richness during the second year.

Figure 7.12.4 illustrates the species abundances on the sides of ash disposal area 4, rehabilitated during 1992. Either *Eragrostis curvula* or *Hyparrhenia hirta* dominates the vegetation at ash disposal area 4. This can also be observed in Figure 7.12.4, which indicates a sharp decline in the importance ranking of the first three species. The overall pattern is very much the same for all the grids situated on the ash disposal areas. Most of the rank-abundances decline fast, which indicates the dominance of two or three species. This pattern is also observed for the natural grassland. The rank-abundances of less frequent species, thereafter, show a fast decline in the importance of species and level out between 0.010 and 0.001. This is where the distribution of species abundances between the natural grassland and the rehabilitated grasslands of the ash disposal areas differs. Levelling of the species importance values already occurs above 0.01 on the natural grassland (Figure 7.12.4).

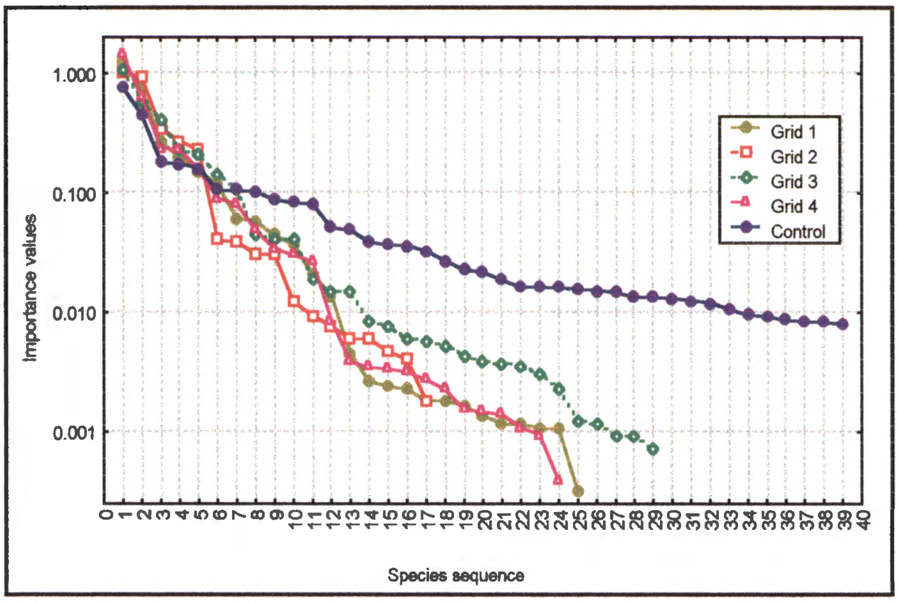

Figure 7.13.1

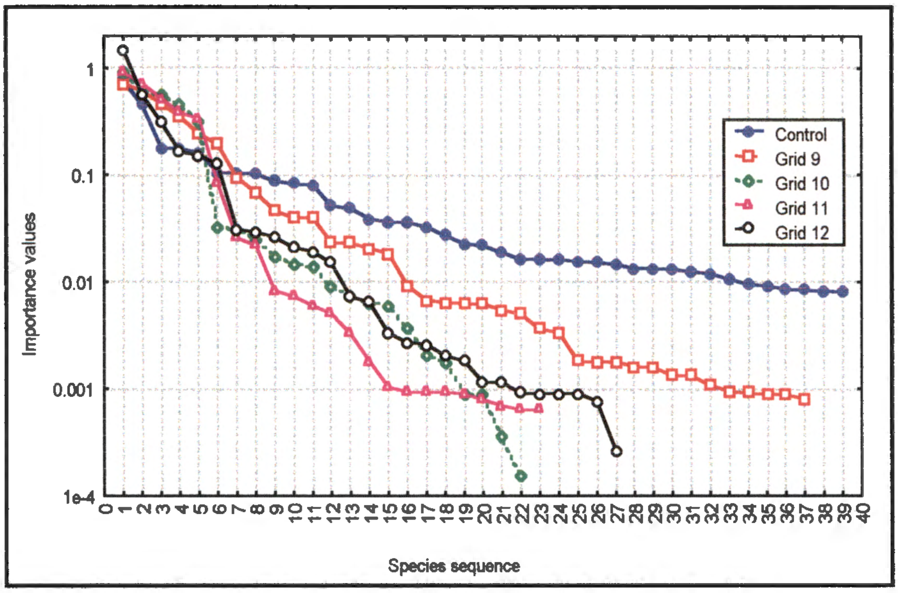

Figure 7.13.2

Figure 7.13: Rank abundance diagrams for grids situated on ash disposal site 1 (Figure 7.13.1) and ash disposal site 3 (Figure 7.13.2) in relation to the natural grassland (control) at Hendrina Power Station.

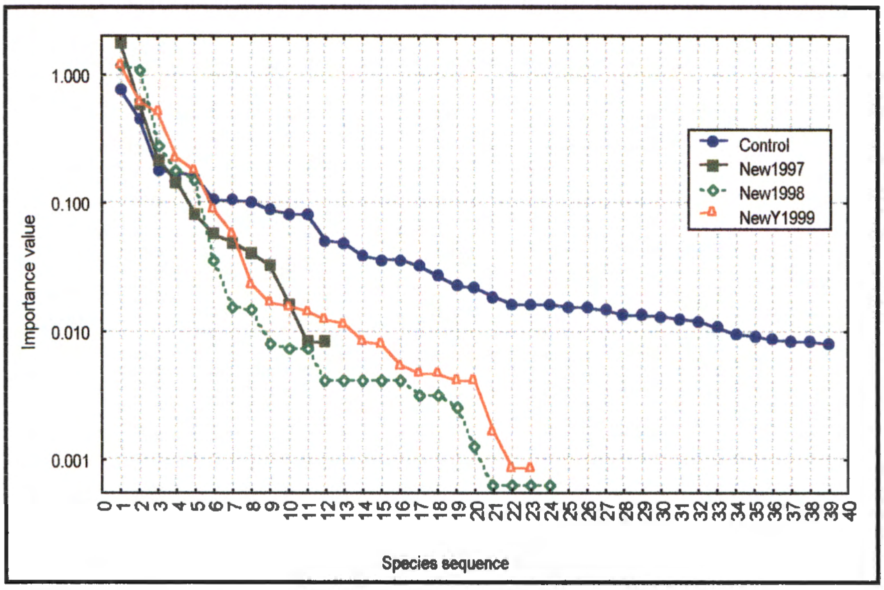

Figure 7.13.3

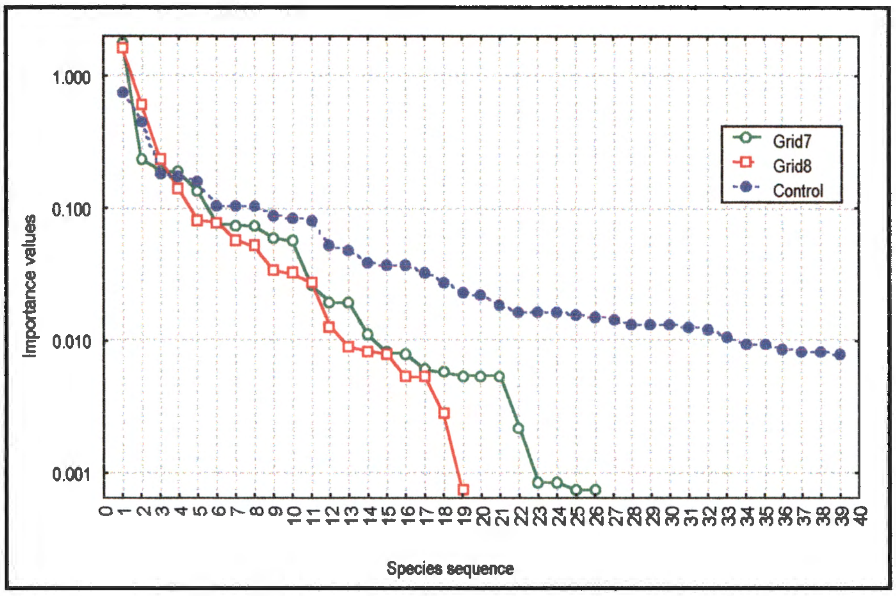

Figure 7.13.4

Figure 7.13: Rank abundance diagrams for grids situated on ash disposal site 4 rehabilitated in 1997 (Figure 7.13.3) and rehabilitated in 1992 (Figure 7.13.4) in relation to the natural grassland (control) at Hendrina Power Station.

7.3.12 The effect of selected species on species diversity

A significant positive correlation was found between Shannon diversity and species richness for *Bidens formosa*, *Bidens bipinnata* and annual Asteraceae (Table 7.10). Higher occurrences of these species were, therefore, associated with higher diversity. The occurrence of *Conyza bonariensis* was also significantly positively correlated with higher species richness but did not contribute to an increase of a higher Shannon diversity (Table 7.10). Higher evenness was significantly positively correlated with an increase occurrence of a number of species such as *Chamaecrista biensis* and *Hyparrhenia hirta* (Table 7.10). Perennial forbs and annual grass species were also significantly positively correlated with higher species richness.

Table 7.10: Spearman rank correlations between selected species and species groups with Shannon Index values, Evenness and species richness on rehabilitated ash disposal sites at Hendrina Power Station.

Species	Shannon Index	Evenness	Species richness
Bidens bipinnata	0.458***	0.179	0.569***
Bidens formosa	0.268**	0.142	0.271**
Chamaecrista biensis	0.225*	0.386***	-0.13
Conyza bonariensis	0.171	-0.101	0.350**
Cynodon dactylon	0.139	0.313**	-0.166
Digitaria eriantha	0.13	0.250*	-0.111
Eragrostis curvula	-0.057	-0.052	-0.092
Eragrostis plana	0.236*	0.077	0.274*
Bare Ground	-0.099	0.068	-0.236*
Hyparrhenia hirta	0.209	0.34**	-0.057
Schkuhria pinnata	0.348**	0.345**	0.146
Tagetes minuta	0.244*	0.006	0.412***
Annual Asteraceae	0.325**	0.023	0.453***
Legume species	0.346**	0.472***	-0.054
Annual grass species	0.094	-0.105	0.387***
Perennial forb species	0.226*	-0.034	0.391***
Perennial grass species	0.04	0.099	-0.114

Significance p<0.05 *, <0.01**, <0.001*** N=84

7.4 DISCUSSION AND CONCLUSIONS

The rate of succession is the highest in newly rehabilitated areas. Vegetation change is, in comparison to that of the newly rehabilitated areas, considerably lower on older rehabilitated sites. Changes in Sørensen Coefficients are more important during early succession and SED less important. This indicates that changes in species composition are more prominent during the first year after rehabilitation. Vegetation on older rehabilitated sites are influenced more by changes in abundances of established populations. Changes in species composition still took place, but to a lesser degree. Successional changes are already in equilibrium after three years, because no differences in the general successional rate are experienced after three years. The heterogeneity between sites were also found to be the same if the eigenvalues of DCA ordinations between consecutive years were compared (Chapter 5). Drastic changes are therefore only evident during the first three years after rehabilitation has started. Bornkamm (1981) and Lepš (1987) provided similar results for their studies of secondary succession in abandoned old fields. Rate of succession is determined by the life span and life history traits of the dominant species (Facelli & D'Angela, 1990). Differences between years can be ascribed to possible changes in the abundance of dominant perennial grass species, as already indicated, and compositional changes of annual species.

A possible explanation for the change in species diversity on grids 1, 9, 10 and 11 may be that all four grids experienced fire during 1996 or 1997 as far as could be determined and were infested by the small mammal *Tatera brantsii*. Regular fire and infestations of small mammals can have an effect on the Importance Values of dominant species and promote increases in less dominant species and forbs.

Newly rehabilitated areas illustrate increases in evenness and species richness. Shannon diversity indices also illustrate a strong positive correlation with temporal change over the three-year period.

Statistical results indicate that evenness is an important indicator of change. Results show that evenness is the one factor that is still changing after nine years of rehabilitation.

Results from Sørensen Similarity Coefficient and species richness are compliant to each other. Both indicate that little colonisation of new species occur on older rehabilitated areas. However, there is no evidence of loss of species from the rehabilitated sites during the study period.

Species richness between sites rehabilitated during approximately the same year, or with similar seed mixtures, varied considerably. A possible explanation is the use of topsoil excavated from different depths and locations, which result in the use of topsoil with different nutrient status and seed bank characteristics.

Results have also shown that rehabilitated grasslands and nearby natural grasslands are quite different in species diversity. Both grasslands (rehabilitated and natural) are characterised by the dominance of only a few grass species. The vegetation of the natural grassland was dominated by mainly eight perennial, tuft forming grass species. Dominance of species is therefore a common characteristic of grasslands studied at Hendrina Power Station (which is possibly the case in most South African Highveld grasslands). Large portions of the remaining habitat or niches in the natural grassland are shared by a vast number of perennial forbs and grasses, which is not the case in the rehabilitated grassland. The rest of the resources or habitat niches are shared by more than a hundred other species, mostly perennial forbs and grasses in the natural grassland.

Topography has according to results a definite affect on diversity, especially species richness. The higher diversity on slopes may be attributed to the different environmental effects down the slope. Examples hereof are the increasing runoff rate down the slope, higher moisture conditions at the bottom of the slope and differences in microclimate.

Results of the present study also indicate that diversity benefit through the occurrence of annual grass and forb species. Dominance by selected perennial grass species, which mostly control ecosystem functioning (Grime 1998), do not necessarily affect the diversity of the vegetation negatively. A competitive grass species such as *Hyparrhenia hirta* has a positive effect on the evenness and does not significantly negatively affect species richness.

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Chapter 8 EFFECT OF SELECTED ENVIRONMENTAL VARIABLES ON PLANT COMMUNITY DEVELOPMENT ON ASH DISPOSAL SITES AT HENDRINA POWER STATION

Abstract: Plant community development is dependent on prevailing environmental conditions. This is especially true for rehabilitated areas where the growth medium plays a major role in the success of vegetation establishment. The effects of the quality of the growth medium, types of treatment, slope position, two small mammal species and fire on vegetation community development are investigated. It is the hypothesis of this study that one or all of these factors plays a significant role in plant community development.

The CCA and RDA ordination techniques are used to analyse data with the CANOCO ordination program. Statistically significant influences of environmental variables are tested with the Monte Carlo permutation test. Analysis of variance (ANOVA) is also used to determine if statistically significant differences between grids exist.

No serious adverse soil chemical conditions exist in areas rehabilitated more than three years ago. Boron concentrations and pH are all at acceptable levels in the growth medium of old rehabilitated sites and compare favourably with soil of the natural grassland. The growth medium of the newly rehabilitated area has higher boron, sodium, and sulphate levels than the older rehabilitated area. Soil chemical variables that can be related to gradients in plant species composition on older rehabilitated sites are bicarbonate, nitrate, ammonium, potassium and pH. The growth conditions at Hendrina Power station compares favourably to those of other areas studied internationally and locally. Further important factors influencing species composition are treatment and fire, as well as the effect of large populations of the small mammal *Tatera brantsii,* due to extensive burrowing systems. Community development is driven by the initial treatment, soil fertility, the frequency of fire on ash disposal areas, as well as the effect of *Tatera brantsii* colonisation patterns.

CONTENTS

8.1 INTRODUCTION

Plant community development is dependent on prevailing environmental conditions and is therefore one of the most important driving forces, besides competition, in community development. Inouye & Tilman (1988) found that different supply rates of nitrogen could result in the divergence in vegetation composition between similar old fields. Conditions in derelict and disturbed land are especially harsh for plant growth. It is therefore not surprising that most of the literature available on rehabilitation of coal ash focus on the characteristics of the growth medium and plant species selection for rehabilitation. Literature available and main research topics on coal ash rehabilitation are listed in Table 8.1 for easier reference. Comprehensive reviews of coal ash rehabilitation and associated problems are also provided by Townsend and Hodgson (1973), Hodgson and Townsend (1973), Bradshaw and Chadwick (1980) and El-Mogazi *et al.* (1988).

Most of the studies listed in Table 8.1 were conducted in the United States, Britain or Australia. Very little research has been conducted on ash disposal sites in South Africa. Van Rensburg *et* *al.* (1998) did the only study on rehabilitation of ash disposal sites in South Africa to date, and found *Cynodon dactylon* var. *dactylon, Eragrostis curvula* and *Eragrostis tef* to be the most successful species to revegetate ash disposal areas. According to Van Rensburg *et al.* (1998), the most effective amelioration mediums proved to be 5000 kg/ha compost, 500 kg/ha kraal manure or 480 kg/ha 2:3:2 fertiliser. Glasshouse and field trials aimed to test a low input rehabilitation method were also conducted in Zimbabwe (Piha *et al.*, 1995a). However, due to the greater toxicity problems of coal ash (Piha *et al.*, 1995b), a low input approach was found to be less successful for coal ash lagoons than for tin mine tailings (Piha *et al.*, 1995a).

A number of limiting factors exists in coal fuel ash as a rehabilitation medium which can have a substantial effect on the success of the rehabilitation effort. During the evaluation and monitoring of reclaimed areas, these limiting factors must be kept in mind and should be overcome by effective management.

Coal ash waste material can be disposed of as a dry waste, or as a form of slurry to lagoons where it settles out. Considerable research on the factors hindering plant growth on coal ash or pulverised fuel ash (PFA) has been carried out. Coal ash is characterised by a variety of soil physical and chemical properties.

According to Bradshaw and Chadwick (1980), coal ash settled out in lagoons has a typical pH of 8-9. Because lagoon ash is a by-product of combustion, it is virtually devoid of nitrogen and the high pH results in the loss of ammonium by volatilisation. High levels of aluminium can inhibit phosphate availability, and phosphate deficiencies can, therefore, occur in plants (Bradshaw & Chadwick, 1980). The dry ash contains about 48% silica, 26% aluminium, 10% iron oxides and relative small amounts of other elements. It has a particle size distribution of 60% fine sand, 40% silt and is nearly devoid of clay sized particles (Bridge, 1991). Because of extremely light cenospheres (hollow spherical particles with a bulk density which is half of the rest of the ash) constituting about 5% of the ash, it is easily blown around by wind. Dry ash can therefore causes considerable dust problems. The physical properties of lagoon ash can have a negative effect on plant establishment as well. The pozzolanic properties of ash result in the formation of impermeable layers that can impede drainage and reduce root development. The pozzolanic nature of ash is related to the occurrence of calcium sulphate, or to the formation of ettringite ($3CaO\ Al_2O_3\ CaSO_4\ 31H_2O$) (Townsend & Hodgson, 1973). Because of a low clay and organic content, ash has a low capability to contain nutrients (Bridge, 1991). Although it has a low clay composition, the water holding properties of fly ash are reasonable (Bradshaw & Chadwick, 1980). Salter *et al.* (1971) indicated that water holding capacity and the amount of readily available water of sandy soil could be increased by the addition of ash. According to Piha *et al.* (1995b), fresh mixtures of pulverised fly ash (PFA) have high salt concentrations but these usually disappear over time (Jones & Lewis, 1960). Boron can pose a long-term phytotoxic problem (Bradshaw & Chadwick, 1980) but the concentrations gradually diminish because of weathering (Jones & Lewis, 1960).

Table 8.1: List of literature evaluating the effect of different coal ash properties on plant growth

Author	Plant species selection	Agricultural use	General rehabilitation	Ash properties & effect on plant growth	Country
Aitken *et al.*, 1984	/	/	/	Physical and chemical	Australia
Gillham & Morley Davis, 1972	Grass seed mixture	/	/	Soil depth on biomass	England
Hammermeister *et al.*, 1998	3 spp	/	Ash for acid soil amendment	chemical	Canada
Hodgson & Holliday, 1966	/	Review of agronomic properties	/	Phytotoxicology & deficiencies	England
Hodgson *et al.*, 1963	/	5 crop spp.-	9 amendments	Soil depth on crop production	England
Holliday *et al*, 1958	/	Barley	Pot trial	Boron toxicity	England
Jones & Lewis, 1960	/	/	/	Fly as weathering	England
Jusaitis & Pillman, 1997b	37 spp	/	9 amendments	/	Australia
Page *et al.*, 1979	/	/	/	Physical and chemical	USA
Piha *et al.*, 1995b	13 grasses, 19 legumes, 17 trees	/	Glasshouse and field trials	/	Zimbabwe
Pillman & Jusaitis, 1997a	2 spp	/	Seedling transplant, nutrition	/	Australia
Rees & Sidrak, 1955	/	/	*Atriplex hastata* var. *deltoidea* coloniser	Phytotoxicology & deficiencies	England
Rees & Sidrak, 1956	10 spp.	/	/	Phytotoxicology & deficiencies	England
Salé *et al.*, 1997	/	/	/	Soil physical conditions	Canada
Salo *et al.*, 1996	44 spp.	/	Germination test		USA
Salter et *al.*, 1971	/	4 vegetables	8 amendments	Soil moisture	England
Van Rensburg *et al.*, 1998	12 grass spp.	/	8 amendments	/	South Africa

Piha *et al.* (1995b) indicated that boron concentrations above 4 $\mu g\ g^{-1}$ are phytotoxic and values as high as 250 $\mu g\ g^{-1}$ have been recorded on PFA. According to Piha *et al.* (1995b), it has been found that plant productivity is directly proportional to the depth of the topsoil.

Ultimately, the properties of the coal ash are dependent on the geological origin of the coal, methods of combustion, type of emission control devices as well as age and method of disposal of the ash (Adriano, *et al.*, 1980 & Van Rensburg *et. al.*, 1998).

The natural colonisation of untreated ash disposal sites is usually slow (Hodgson & Townsend, 1973), mainly because appropriate species that could colonise these derelict sites are not always in the vicinity (Bradshaw & Chadwick, 1980). Xerophytes and halophytes of the families Aizoaceae, Chenopodiaceae and Zygophyllaceae performed the best during species selection for revegetation of fly ash lagoons in Australia (Jusaitis & Pillman, 1997). Most of the species that first colonise ash disposal heaps belong to these families. The following are examples of species that grow readily on ash disposal heaps:

a) *Atriplex hastata* var. *deltoidea* is normally the first flowering plant that colonises ash disposal heaps in England. The next species to colonise are *Chenopodium album, Sisymbrium altissimum, Lotus corniculatus, Medicago lupulina* and *Agrostis stolonifera.* If natural colonisation is allowed to continue, a *Betula pendula-Salix* spp. Community develops later (Hodgson & Townsend, 1973 and Bradshaw & Chadwick, 1980).
b) Ash (1991) indicated that *Atriplex prostrata* and *Chenopodium rubrum* are also natural colonisers of ash disposal heaps. During later stages numerous other species, including the perennial grass *Festuca rubra* and the clovers *Trifolium repens* and *Trifolium pratense,* colonise ash disposal sites (Ash, 1991). This colonisation has a double advantage, because of the tolerance of those clover species to high boron levels and their capability to fix nitrogen.
c) Salo *et al.* (1996) indicated that, after ten years, Flue Gas Desulphurization (FGD) sludge ponds in Kansas (USA) were covered by vegetation characterised by the species *Elytrigia pontica* (Tall Wheatgrass), *Phragmites australis* (Common Reedgrass) and *Festuca arundinacea* (Tall Fescue). Species of less common occurrence were *Lespedeza stipulacea* (Korean Lespedeza) and *Populus deltoides* (Eastern Cottonwood). *Robinia pseudo-acacia* (Black Locust), *Cynodon dactylon* (Bermuda grass), *Panicum virgatum* (Swichgrass) and *Melilotus alba* (White sweetclover) were found to be the best species to establish on FGD (Salo *et. al.*, 1996).

In general, two types of ash are generated by power stations. Fly ash is the fine ash fraction carried out of the boiler in the flue gas, and bottom ash is the material that drops to the bottom of the boiler. Fly ash contributes to the largest percentage of ash created. Possible methods of ash disposal on land are ponding or land filling (Santhanam *et al.*, 1986).

The current study is, in many respects, different from the studies previously discussed. Most of the past research projects mentioned were conducted under controlled experimental conditions with controlled treatments. During this study it is not possible to know all conditions affecting plant community development, since the research was not conducted under controlled conditions. The purpose of this study is to give an account of as many ecological processes as possible that are involved with rehabilitated areas under uncontrolled, natural conditions.

The aim of this chapter is to determine environmental factors that can be regarded as driving forces behind plant community development on rehabilitated ash disposal sites. The hypothesis of this study that the one or all of the studied environmental factors (soil chemistry, physical characteristics, treatments, fire and small mammal disturbances) plays a significant effect on plant community development is tested. Due to the large number of environmental factors studied a Canonical Correspondence Analysis (CCA) approach is best suited to the identification of environmental gradients in ecological data sets, and to determine which environmental variables has the largest effect on community composition (Ter Braak & Verdonschot, 1995).

8.2 MATERIAL AND METHODS

8.2.1 Data sampling

Species importance values from surveys conducted during the summers of 1997, 1998 and 1999 were used. The survey methods are similar to those described in previous chapters (see chapter 5, 6 and 7). The importance values of the following species were combined in broader species groups: *Cyperus esculentus* and *Cyperus usitatus* were combine and are indicated as *Cyperus* spp.; *Pseudognaphalium undulatum* and *Pseudognaphalium luteo-album* were combined and are indicated as *Pseudognaphalium* spp. (Pseu spp).

Soil physical and chemical properties were analysed from soil samples collected during May 1997 using a soil auger. One soil sample was taken along each transect from each fourteen grids at depths of 0-10cm and 10-20cm. The average depth of the topsoil was also measured at each transect. Soil penetrability and the amount of crust formation was measured with a rod that was dropped from a fixed height (penetrometer). Soil chemical analyses included the basic cations calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{-}), and the trace elements iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and boron (B). Concentrations of the anions phosphate (PO_4^{3+}), nitrate (NO_3^{-}), sulphate (SO_3^{2-}), chlorine (Cl^{-}) and bicarbonate (HCO_3^{-}), as well as the percentage carbon content (C%), ammonia (NH_4^{+}), electrical conductivity (EC) and the pH were also determined. Particle size distribution was determined according to the procedure advocated by the American Society for Testing and Materials (1961). All soil chemical and physical analyses were performed according to methods described in Van Rensburg *et al.* (1998) by the Soil Laboratory of EKO-REHAB, Potchefstroom[1].

Dr. G. Bronner [2] and Miss. A. Vermaak [3] (who are currently researching the small mammal ecology on rehabilitated ash disposal areas at Hendrina Power Station) kindly provided the results of the small mammal population dynamic studies carried out on a seasonal basis. The population numbers of small mammal species were estimated by using a total of 25 Sherman traps, set out seasonally in each survey grid. The number of species trapped was recorded over two twenty four hour cycles during each sampling period.

Canonical Correspondence Analysis (CCA) and RDA (Redundancy analysis) ordinations were used to analyse the data (Ter Braak, 1987-1992). CCA is based on the Correspondence Analysis or Reciprocal Averaging (RA) ordination technique with the additional advantage of regression analysis. The CCA ordination technique is therefore based on the method of weighted averaging and conforms to the Gaussian response curve model (Ter Braak, 1986). Redundancy analysis is, however, based on the PCA (Principle Component Analysis) ordination technique and is therefore related to linear methods of ordination (Ter Braak, 1994). The aim of a CCA or RDA ordination is to extract synthetic environmental gradients from ecological data-sets to study the relationship between differences in species composition, sample distribution and environmental variables (Ter Braak & Verdonschot, 1995). The CCA ordination technique is used in heterogeneous data sets whereas the RDA ordination is more suitable for homogenous data sets with small gradients (Ter Braak & Prentice, 1988). The CCA ordination technique was used when data from new and old rehabilitated areas were combined. The RDA ordination technique was found to be more informative when data of only old rehabilitated areas (areas rehabilitated over 3 years ago) were analysed.

8.2.2 Interpretation of a CCA ordination (Ter Braak & Verdonschot, 1995)

A CCA ordination diagram may consist of points for species, sites or classes of qualitative environmental variables, and arrows for quantitative environmental variables. Each species point in the diagram is at the centroid (weighted average) of the site points in which it occurs. The arrows for a quantitative variable run from the centre (origin) of the diagram to an arrowhead. The length of the arrow indicates the correlation of the variables with the ordination axes.

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There are four possible alternatives to infer the fitted relative abundances from the CCA diagram. Firstly the **centroid principle** states that species are at the centre of their niche and therefore sites that contain a particular species are scattered around that point. This has the effect that sites close to the species point tend to have a higher abundance of that species than sites further away from the species point. The inferred abundance of a species is at a maximum if the site point coincides with the species point and decreases in all directions from the site point. This is called the **distance rule**. The third and fourth rules are related to the interpretation based on the environmental arrows. The points and arrows form a biplot. The **biplot rule** states that the arrow points in the direction of maximum change for the associated variable, and the arrow length is proportional to this maximum rate of change. In a perpendicular direction, the variable does not change in value. Variables with short arrows do not vary much across the diagram. In ranking, the projected points, the origin (0,0) indicates the mean of the variable. For environmental variables the origin also indicates a zero correlation. The ordination diagram, however, does not display a data set exactly because a multidimensional data table is projected in a two-dimensional way. An alternative qualitative rule of interpretation is the **sign of the correlation coefficients** between variables. The importance of the extracted gradients can be interpreted by the magnitude of the eigenvalue (as a rule of thumb an eigenvalue > 0.3 indicates a strong gradient), or the percentage variance accounted for by dividing the eigenvalue by the total inertia. A more important indication is the statistical significance indicated by the Monte Carlo Permutation Test. On the other hand, it does not matter how statistically significant the results are, as long as the results are still ecologically interpretable as well.

8.2.3 Interpretation of an RDA diagram (following Ter Braak & Prentice, 1988 and Kent & Coker, 1994)

The rule of interpretation of a RDA biplot is very similar to a PCA biplot (Ter Braak & Prentice, 1988). The difference between a CCA and RDA ordination is that in a RDA ordination species represent vectors (not points) in an ordination space and it is, therefore, more correct to indicate species as arrows. The direction of the arrow indicates the direction in which the species increased most. A diagram in which sites are marked by points and species and/or environmental variables by arrows is called a biplot (Ter Braak & Prentice, 1988). The length of the arrow shows the rate of change. Species on the edge of the diagram are the most important for indicating a site, and species near the origin are of less importance. Arrows pointing in the same directions indicate a high positive correlation. Arrows at right angles to each other are the least correlated, and arrows pointing in opposite directions indicate high negative correlation. Arrows for species and environmental variables therefore indicate approximate linear correlation coefficients between plant species and environmental variables. Quantitative rules for the interpretation of RDA plots are provided by Jongman *et al.* (1987).

8.2.4 Data analysis

Environmental variables were split into three data sub sets. At first the general habitat (slope position and survey year) and managerial variables (age of rehabilitation, rehabilitation treatment) were analysed separately from the soil physical and chemical data. This was done because general habitat variables could be compared over the total study period, but soil chemical and physical data were only available for 1997. Soil chemical data were then separated from soil physical data and each component was analysed separately. Forward selecting of environmental variables (Ter Braak, 1987-1992) was conducted on the different data sets to reduce the number of environmental variables to a manageable number for further analysis. Forward selection also gives additional information on the importance of each environmental variable relative to the species data (Ter Braak & Verdonschot, 1995). Environmental variables were tested stepwise. In the first step of this method all environmental variables were ranked on the basis of the fit for each separate variable, and best variables were selected. After the first variable was selected all other environmental variables were calculated as a cumulative extra fit of the previous selected variables. The extra fit is the change in the sum of all canonical eigenvalues. The Monte Carlo permutation test (199 random permutations) was also performed on each variable during the stepwise forward selection of variables, to test the statistical significance of the effect of each variable. The Monte Carlo Permutation test does not require the assumption of normality (Ter Braak & Verdonschot, 1995) and replaces the F- and t-tests in forward selection in univariate multiple regression. Unfortunately, it also shares the shortcomings of multiple regression. The test does not, however, control the overall size of the test, which may result in too many variables to be judged as significant variables (Ter Braak, 1987-1992).

Quantitative data was also compared between grids and year of rehabilitation as independent variables with Analysis of Variance (ANOVA) (Sokal & Rohlf, 1969). If data did not conform to normality or did not have homogeneous variance, the non-parametric Kruskal Wallis test was performed instead (Sokal & Rohlf, 1969). Statistical analysis was performed with the computer program (STATISTICA for Windows, 1995).

8.3 RESULTS AND DISCUSSION

8.3.1 Soil chemical conditions

CCA ordinations were performed separately on soil chemical data for the 0-10 cm soil sample, 10-20 cm soil sample and for the average obtained between the two samples (0-20 cm) together for all samples on all rehabilitated areas. Due to the depth of the topsoil that was used to cover the ash, which was about 10 cm thick, it can be presumed that the soil chemistry from the 0-10 cm layers would be different from the 10-20 cm layers and therefore the effect on the vegetation would be distinctive (Table 8.2).

Results of the stepwise forward selection of the CCA ordination of vegetation data with soil chemical data for the 0-10 cm sample indicated sulphate chlorine, boron, ammonium and potassium to be statistically significantly related to the species data (Table 8.2). Results from the stepwise forward selection of the CCA ordination between plant species data and soil chemical data for the 10-20 cm sample indicated sodium, nitrate and manganese as soil chemical variables that showed statistically significant gradients with species data (Table 8.2). The stepwise forward selection of the CCA ordination of vegetation and average chemical soil analysis (0-20cm) indicated aluminium, chlorine and boron as environmental variables that were statistically significantly related to species data (Table 8.2). CCA ordinations of soil chemical variables for 0-10 cm, 10-20 cm and 0-20 cm soil samples were all statistically significant ($P < 0.05$) according to the Monte Carlo Permutation (199 permutations). Results from the forward selection procedure and the Monte Carlo permutation tests are provided in Table 8.2.

Forward selection of the chemical data of each sample depth indicated that sulphate (0-10cm), chlorine (0-20cm), sodium (10-20cm), nitrate (10-20cm), manganese (10-20cm), boron (0-20cm) potassium (0-10cm) and ammonium (0-20cm) will be the best soil chemical variables to explain the variation in the species composition. If one element was significant at more than one soil depth then the parameter with the best fit was chosen.

In Figure 8.1 (Species ordination) the CCA ordination of plant species data for 1997 constrained to selected chemical variables, are illustrated. The Monte Carlo permutation test (199 permutations) indicated that overall, selected soil chemical variables were statistically significantly related to species data (P-value=0.00), as well as along the first canonical axis. According to the CCA ordination, high concentrations of sodium, sulphate, ammonium and boron in the growth medium are all associated with species occurring on newly rehabilitated areas which include *Eleusine coracana* (Eleu cor), *Eragrostis tef* (Erag tef), *Enneapogon cenchroides* (Enne cen), *Commelina benghalensis* (Comm ben) and *Amaranthus hybridus* (Amar hyb) (Figure 8.1). These soil chemical gradients are especially associated with the first canonical ordination axis. Differences in species composition on older rehabilitated areas are associated with differences in chlorine, nitrate, manganese, potassium and iron in the growth medium, and can be seen along ordination axis 2 (Figure 8.1). Differences in manganese and iron might be indirectly linked to differences in the type of topsoil used during different treatments. The legume *Chamaecrista biensis* (Cham bie) was associated with lower nitrate levels. This relation between legume species and nitrate levels is of extreme importance due to this ability of legumes, in symbioses with *Rhizobium* bacteria, to fix nitrogen (Bradshaw, 1984), and will be investigated further elsewhere in this chapter.

Table 8.2: Results from the stepwise forward selection CCA ordinations of soil chemical variables at soil depths of 0-10 cm, 10-20 cm and 0-20 cm on all rehabilitated ash disposal sites at Hendrina Power Station

Variables	P-value	Cumulative fit	Stepwise Fit
SO_4(0-10)	0.005	0.35/1.51	0.35
Cl (0-10)	0.035	0.46/1.51	0.11
B (0-10)	0.160	0.55/1.51	0.12
Fe (0-10)	0.085	0.64/1.51	0.09
K (0-10)	0.08	0.73/1.51	0.08
NH_4 (0-10)	0.045	0.91/1.51	0.10
PO_4 (0-10)	0.145	0.98/	0.07
pH (0-10)	0.295	1.04	0.05
Overall (0-10)	**0.00**		
First axis (0-10)	**0.04**	**0.41**	
Na (10-20)	0.005	0.35/1.36	1.36
NO_3 (10-20)	0.02	0.48/1.36	0.13
Mn (10-20)	0.02	0.59/1.36	0.11
NH_4 (10-20)	0.160	0.67/1.36	0.08
PO_4 (10-20)	0.190	0.74/1.36	0.07
B (10-20)	0.280	0.80/1.36	0.06
Overall (10-20)	**0.01**		
First axis (10-20)	**0.01**	**0.38**	
NH_4 (0-20)	0.005	0.34/1.46	0.34
Cl (0-20)	0.005	0.50/1.46	0.20
B (0-20)	0.06	0.60/1.46	0.34
K (0-20)	0.180	0.67/1.46	0.22
Mn(0-20)	0.195	0.75/1.46	0.08
pH (0-20)	0.185	0.82/1.46	0.07
PO_4 (0-20)	0.155	0.89/1.46	0.07
Fe (0-20)	0.160	0.96/1.46	0.07
Na (0-20)	0.145	1.03/1.46	0.07
Overall (0-20)	**0.00**		
First axis (0-20)	**0.00**	**0.39**	

Pennisetum clandestinum (Penn cla) was best related to higher concentrations of manganese in the substrate (Figure 8.1). This is probably because the area only rehabilitated with *Pennisetum clandestinum* was ameliorated with a soil layer consisting of oxides high in manganese. Other species that were also more associated with higher substrate concentrations of nitrate and manganese are *Imperata cylindrica* (Impe cyl), *Urochloa mosambicensis* (Uroc mos), *Stylosanthes fruticosa* (Styl fru), *Tagetes minuta* (Tage min), *Schkuhria pinnata* (Schk pin) and *Eragrostis trichophora* (Erag tri). Species to the bottom of ordination axis 2 were less associated with higher substrate concentrations of manganese, chlorine and nitrate, but were associated with higher substrate concentrations of iron oxides and potassium. Species ordinated to the bottom of ordination axis 2 include *Tephrosia capensis* (Teph cap), *Melinis repens* (Meli rep), *Bidens formosa* (Bide for), *Hyparrhenia tamba* (Hypa tam), *Digitaria eriantha* (Digi eri*), Oxalis* spp (Oxal spp) and *Pogonarthria squarrosa* (Pogo squ).

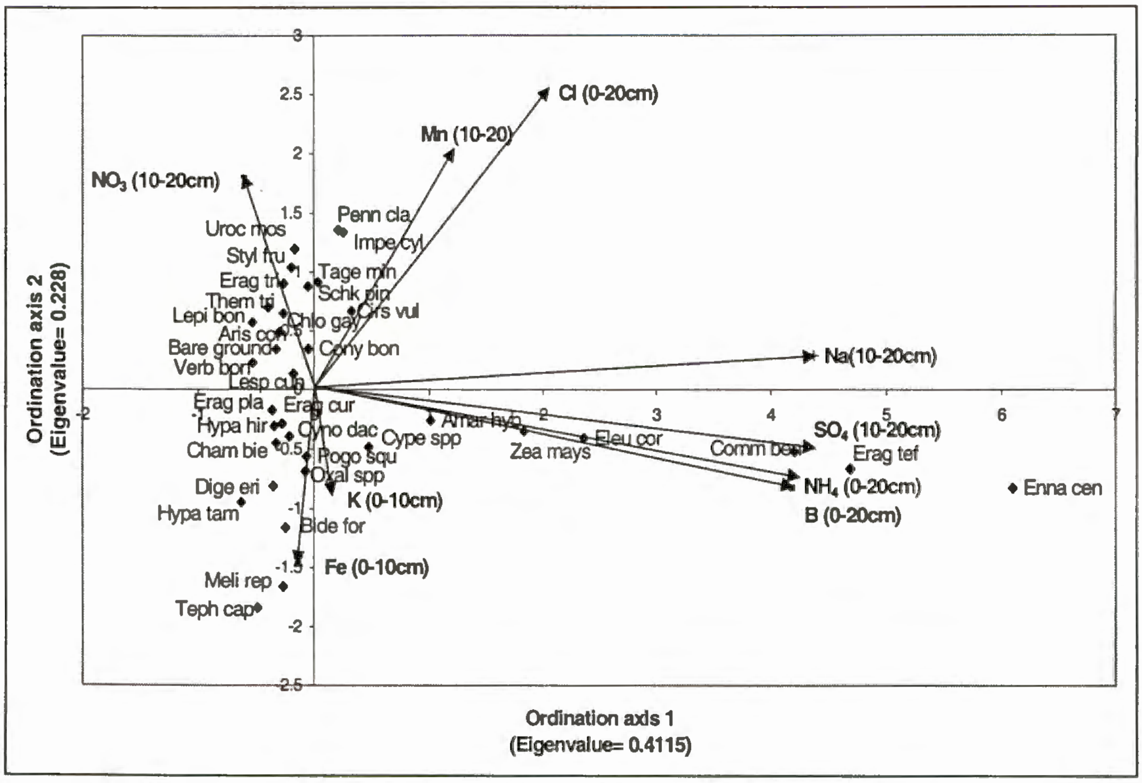

Figure 8.1: CCA ordination joint plot of plant species (diamonds) and chemical soil conditions (arrows) on rehabilitated ash disposal areas at Hendrina Power station.

To investigate the effect of soil chemical variables on established old rehabilitated sites in more detail, the newly rehabilitated sites and the transects from grid 1 in which no seed mixture was used, were omitted from the data set. Similar procedures were followed as for the analysis of all the rehabilitated sites combined. After selection of the best soil chemical variables, an RDA (Redundancy Analysis) ordination was conducted on the data set due to the reduction in the variation of the data set, after the recommendations by Ter Braak (1987-1992) and Ter Braak & Prentice (1988). Forward selection of the three soil chemical sets indicated that potassium (0-10cm), nitrate (10-20cm) and bicarbonate (0-20cm) were the best variables to explain plant ecological gradients in the RDA ordination space (Table 8.3). Important variables such as electrical conductivity ((0-10cm; p-value=0.110), boron (0-10cm; p-value=0.115) manganese (0-10; p-value=0.115), pH (0-20cm p-value=0.170) and ammonium (0-20cm) were also added to the model to enhance interpretability of the data.

Table 8.3: Results from the stepwise forward selection RDA ordinations of soil chemical variables at soil depths of 0-10 cm, 10-20 cm and 0-20 cm on old rehabilitated ash disposal sites at Hendrina Power Station

Variables	P-value	Cumulative fit	Stepwise Fit
K (0-10)	0.065	0.08/0.90	0.08
B (0-10)	0.115	0.16/0.90	0.07
EC (0-10)	0.110	0.22/0.90	0.07
Fe(0-10)	0.175	0.29/0.90	0.07
Mn (0-10)	0.115	0.35/0.90	0.06
pH (0-10)	/	0.41/0.90	0.06
Overall (0-10)	**0.03**		
First axis (0-10)	**0.85**	**0.13**	
NO_3 (10-20)	0.025	0.11/0.88	0.11
%C (10-20)	0.025	0.19/0.88	0.08
K (10-20)	0.210	0.25/0.88	0.06
B (10-20)	0.220	0.30/0.88	0.05
HCO_3 (10-20)	0.190	0.36/0.88	0.06
Overall (0-10)	**0.00**		
First axis (0-10)	**0.05**	**0.13**	
K (0-20)	0.020	0.09/0.87	0.09
HCO_3 (0-20)	0.015	0.18/0.87	0.08
Mn (0-20)	0.200	0.24/0.87	0.06
pH (0-20)	0.170	0.30/0.87	0.07
Cl (0-20)	0.155	0.36/0.87	0.06
Na (0-20)	0.295	0.41/0.87	0.05
Cu (0-20)	0.380	0.45/0.87	0.04
Overall (0-10)	**0.05**		
First axis (0-10)	**0.63**	**0.16**	

Figure 8.2 illustrates the biplot of the RDA ordination of species and selected soil chemical variables. Selected statistically significantly soil chemical variables explained the variation in the species composition of old rehabilitated ash disposal sites (P-value=0.03). Ordination axis 1 was, however, not statistically significantly related to environmental gradients. The length of the arrows indicated that the percentage carbon, nitrate, potassium and bicarbonate content were the strongest gradients that could be correlated to species data. The relation between species and environmental variables can be interpreted as follows. The species *Tagetes minuta* (Tage min), *Themeda triandra* (Them tri), *Heteropogon contortus* (Hete con), *Aristida congesta* (Aris con), *Eragrostis trichophora* (Erag tri), *Eragrostis plana* (Erag pla) and *Hyparrhenia tamba* (Hypa tam) could be positively correlated to higher levels of carbon content, manganese, and to

a lesser extent, higher levels of ammonium (Figure 8.2). These species that occur to the right of ordination axis 1 were also negatively correlated with the gradients in bicarbonate concentrations, boron, electrical conductivity, as well as pH (Figure 8.2). The strong positive correlation of *Hyparrhenia hirta* (Hypa hir) and *Setaria pallide-fusca* (Seta pal) to the ammonium gradient, and the negative correlation to gradients of bicarbonate and boron concentrations as well as electrical conductivity, indicate that these species also prefer acidic growth conditions as can be created by the presence of ammonium and low bicarbonate. *Eragrostis curvula* (Erag cur) and *Cynodon dactylon* (Cyno dac) were positively related to gradients in bicarbonate and boron concentrations as well as electrical conductivity. The legume *Chamaecrista biensis* (Cham bie) was the best related to gradients of nitrate and potassium (negatively correlated), and the gradients of ammonium, and to a lesser extent pH (positively correlated) (Figure 8.2). The legumes *Lespedeza cuneata* (Lesp cun) and *Stylosanthes fruticosa* (Styl fru), which had lower importance values than *Chamaecrista biensis*, were, however, positively correlated to the gradients of nitrate and potassium, therefore higher fertility, and negatively correlated with ammonium concentrations in the substrate. Other species that were also positively correlated with potassium and nitrate were *Lepidium bonariensis* (Lepi bon), *Conyza bonariensis* (Cony bon) and *Bidens bipinnata* (Bide bip).

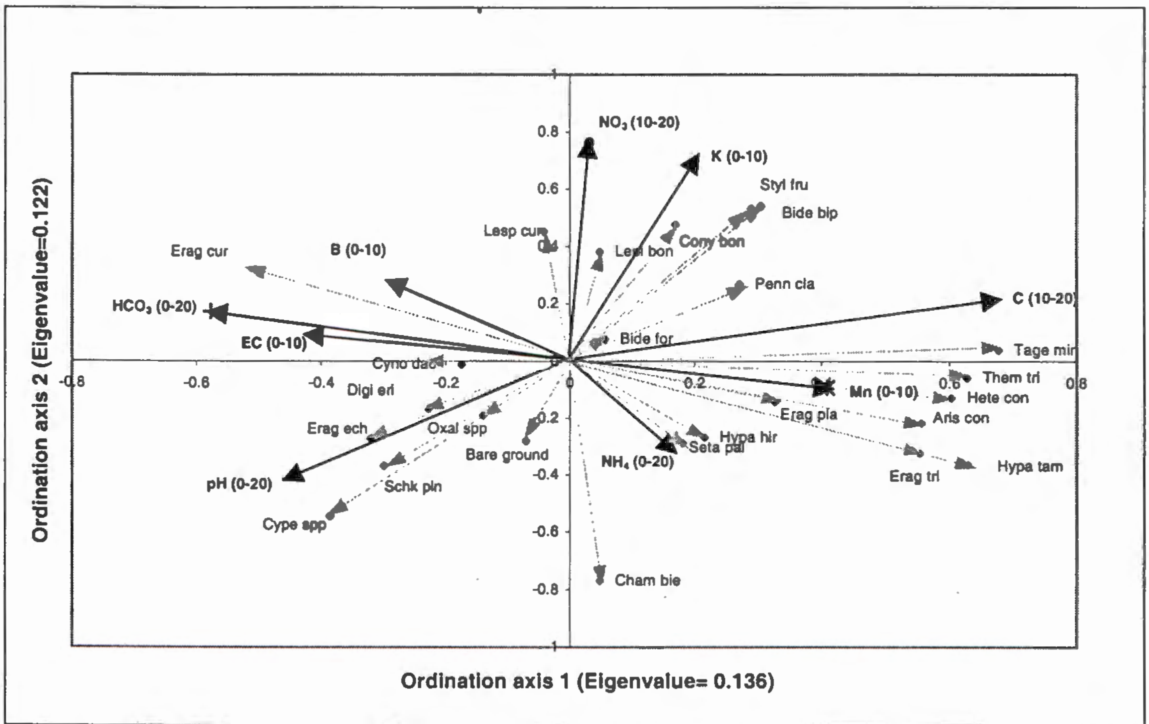

Figure 8.2: RDA biplot of species data together with soil chemical variables of old rehabilitated sites at Hendrina Power Station.

Table 8.4: Soil chemical characteristics of survey grids at Hendrina Power Station (Standard deviation in italics)

	Grid 1		Grid 2		Grid 3		Grid 4		Grid 9		Grid 10		Grid 11		Grid 12		Untreated ash		Newly Rehabilitated		Natural Grassland	
Macro elements (mmol dm^{-3})																						
Ca*	0.86	*0.28*	1.83	*2.25*	0.73	*0.14*	0.77	*0.48*	1.14	*1.31*	0.63	*0.10*	0.97	*0.63*	0.57	*0.24*	4.12	*0.90*	1.89	*1.64*	0.03	*0.06*
Mg	0.15	*0.10*	0.61	*0.85*	0.33	*0.04*	0.24	*0.13*	0.23	*0.20*	0.16	*0.10*	0.23	*0.08*	0.16	*0.05*	0.76	*0.71*	0.51	*0.36*	0.10	*0.06*
K***	0.04	*0.03*	0.16	*0.05*	0.16	*0.07*	0.11	*0.05*	0.09	*0.05*	0.06	*0.03*	0.08	*0.04*	0.09	*0.06*	0.65	*0.07*	0.19	*0.20*	0.06	*0.04*
Na**	0.16	*0.02*	0.25	*0.14*	0.16	*0.04*	0.16	*0.02*	0.31	*0.18*	0.16	*0.01*	0.14	*0.03*	0.15	*0.09*	1.46	*0.32*	0.53	*0.62*	0.21	*0.25*
P***	0.02	*0.01*	0.01	*0.01*	0.01	*0.01*	0.01	*0.01*	0.00	*0.00*	0.02	*0.01*	0.00	*0.00*	0.01	*0.01*	0.00	*0.01*	0.00	*0.00*	0.01	*0.01*
SO_4**	0.23	*0.14*	1.72	*3.28*	0.32	*0.28*	0.51	*0.74*	1.14	*1.42*	0.11	*0.03*	0.55	*0.52*	0.08	*0.04*	5.11	*1.64*	2.18	*2.08*	0.11	*0.11*
NO_3**	0.03	*0.04*	0.03	*0.05*	0.14	*0.07*	0.02	*0.02*	0.02	*0.02*	0.02	*0.02*	0.01	*0.01*	0.05	*0.03*	0.00	*0.00*	0.03	*0.06*	0.08	*0.05*
NH_4**	0.00	*0.00*	0.00	*0.00*	0.00	*0.00*	0.00	*0.01*	0.01	*0.02*	0.00	*0.01*	0.00	*0.00*	0.01	*0.02*	0.05	*0.04*	0.04	*0.05*	0.02	*0.01*
Cl***	0.10	*0.06*	0.14	*0.09*	0.14	*0.09*	0.04	*0.03*	0.08	*0.05*	0.03	*0.01*	0.06	*0.08*	0.04	*0.01*	0.47	*0.16*	0.12	*0.08*	0.13	*0.17*
HCO_3**	1.54	*0.43*	1.61	*0.21*	1.42	*0.55*	1.26	*0.54*	0.82	*0.28*	1.48	*0.16*	1.42	*0.34*	1.54	*0.27*	0.96	*0.18*	1.01	*0.23*	0.34	*0.16*
Micro elements (µmol dm^{-3})																						
Fe	1.25	*1.36*	6.09	*7.08*	3.12	*1.74*	53.91	*106.04*	6.46	*6.76*	13.91	*25.57*	3.05	*5.53*	67.68	*114.9*	0.22	*0.27*	61.74	*118.27*	175.52	*57.80*
Mn**	0.44	*0.32*	0.40	*0.21*	0.04	*0.06*	0.21	*0.19*	0.37	*0.28*	0.00	*0.00*	0.22	*0.21*	0.26	*0.20*	0.28	*0.20*	0.38	*0.23*	0.65	*0.19*
Cu***	0.11	*0.07*	0.31	*0.05*	0.20	*0.06*	0.29	*0.31*	0.14	*0.07*	0.09	*0.06*	0.21	*0.14*	0.44	*0.29*	0.06	*0.05*	0.26	*0.39*	0.43	*0.14*
Zn	0.14	*0.24*	0.17	*0.11*	0.08	*0.10*	0.20	*0.36*	0.06	*0.12*	0.23	*0.23*	0.23	*0.18*	0.45	*0.76*	0.06	*0.13*	0.21	*0.42*	0.33	*0.32*
B**	22.33	*8.91*	61.83	*57.70*	35.00	*9.12*	53.17	*36.97*	26.33	*11.71*	30.67	*12.29*	32.50	*14.58*	44.00	*38.69*	478.25	*173.56*	168.75	*181.29*	88.83	*33.23*
Other																						
%C**	0.62	*0.18*	1.05	*0.30*	0.90	*0.19*	0.85	*0.16*	0.78	*0.52*	0.65	*0.27*	0.59	*0.19*	0.80	*0.24*	0.29	*0.03*	0.62	*0.30*	1.60	*0.74*
EC (mS cm^{-1})*	0.22	*0.07*	0.53	*0.63*	0.24	*0.02*	0.24	*0.11*	0.32	*0.29*	0.18	*0.02*	0.26	*0.14*	0.19	*0.03*	1.20	*0.29*	0.57	*0.44*	0.09	*0.04*
pH*	7.51	*0.16*	7.41	*0.09*	7.24	*0.41*	7.20	*0.26*	7.18	*0.27*	7.61	*0.23*	7.57	*0.38*	7.46	*0.31*	7.82	*0.26*	7.21	*0.47*	6.18	*0.39*

*,**,*** Significant at P≤0.05, P≤0.01 and P≤0.001 (Kruskal Wallis ANOVA)

All chemical soil characteristics of each grid are summarised in Table 8.4. The ANOVA test with the non-parametric Kruskal Wallis indicated that, except for zinc, all other soil chemical characteristics showed statistical significantly differences among the grids (Table 8.4).

According to the literature, adverse soil chemical properties are normally related to high boron concentrations (Hodgson & Townsend, 1973), deficiencies in nitrogen (Pillman & Jusaitis, 1997;) and high pH and salinity (Pillman & Jusaitis, 1997). Aluminium, although not truly phytotoxic, may indirectly effect the uptake of phosphate (Hodgson & Holliday, 1966 and Bradshaw & Chadwick, 1980) and calcium. To determine if similar conditions prevail on ash disposal sites at Hendrina Power Station, certain chemical characteristics, that were mentioned to be problematic in the literature, were compared at different stages of rehabilitation, and also to soil from the nearby natural grassland (Figure 8.3).

If the soil chemistry between different stages of rehabilitation is compared, only zinc and phosphorus are not statistically significantly different. The electrical conductivity of unrehabilitated sites (UR) was considerably higher than that of the natural grassland (Control) and the old rehabilitated sites (OR) (Figure 8.3.1). In relation to the natural grassland (average pH: 6.2), both old (average pH: 7.4) and newly rehabilitated ash disposal sites (average pH: 7.2) were considerably more alkaline. An important regulating factor on the alkalinity of the soil is the amount of organic material in the soil, clay content and leaching in the soil, which have an influence on the cation exchange capacity of the soil medium. The average pH of unrehabilitated sites was again higher than both other stages, as well as the natural grassland (control). The average pH for unrehabilitated sites (average pH: 7.8) was, however, lower than indicated in most of the literature. According to Bradshaw and Chadwick (1980), the pH of lagooned coal ash can range between 8-9, while Van Rensburg *et al.* (1998) found the average pH for untreated ash as 9.47. Results for potassium (Figure 8.3.3) and calcium (Figure 8.3.4) were in both cases very similar. The concentrations for the two macronutrients potassium and calcium were in both cases higher in unrehabilitated sites and newly rehabilitated sites (NR), in relation to old rehabilitated sites (OR) and the natural grassland (Control). As indicated by the results of the natural grassland it can be expected that concentrations of these and other element in the soil solution may decrease due to leaching over time. The average potassium for old rehabilitated sites (OR) and the natural grassland (Control) were both very similar ($K^+ \cong 0.6$ $mmol.dm^{-3}$). Potassium was therefore not a limited factor in the ash, and availability depended more on the level of potassium in the topsoil.

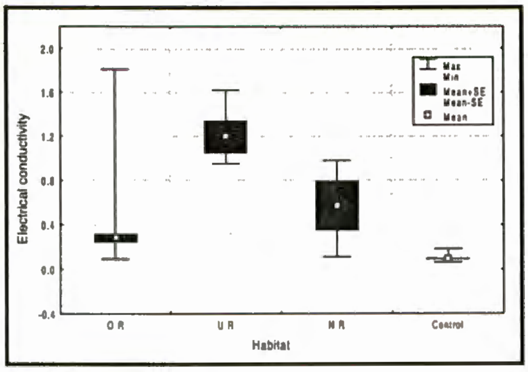

Fig. 8.3.1: Electrical conductivity (P= 0.000)

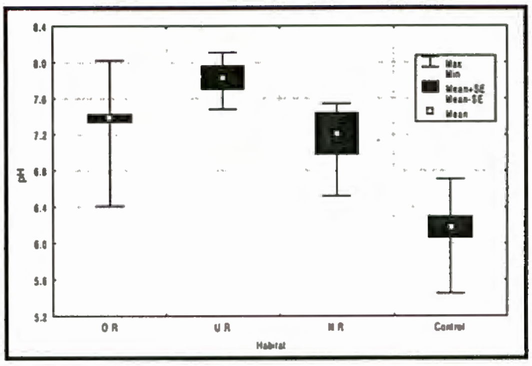

Fig. 8.3.2: pH (P=0.000)

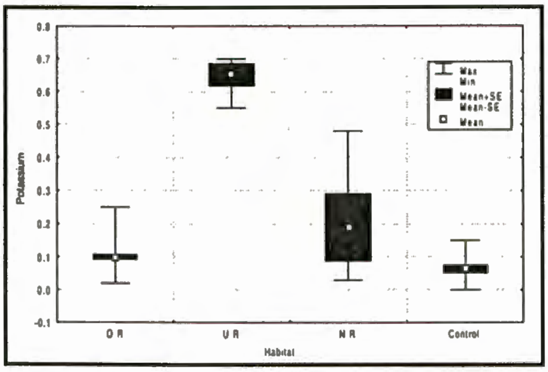

Fig 8.3.3: Potassium (P=0.002)

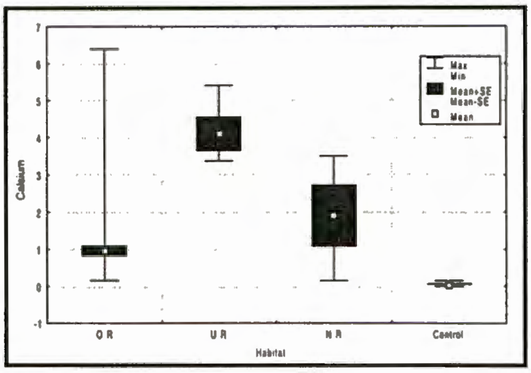

Fig 8.3.4: Calcium (P= 0.000).

Figure 8.3: Differences in soil electrical conductivity, pH and concentrations of potassium and calcium between old rehabilitated (OR), unrehabilitated (UR), newly rehabilitated (NR) and a nearby natural grassland site (Control) at Hendrina Power Station. P-values indicate the magnitude of statistical significance between groups obtained from the non-parametric Kruskal Wallis test.

One of the major concerns of derelict land is its insufficient levels of available nitrogen (Marrs *et al.*, 1981 and Bradshaw & Chadwick, 1980). This is especially true for coal ash disposal sites that are practically devoid of nitrogen, due to the combustion of the coal (Aitken *et al.*, 1984 and Townsend & Gillham, 1975). Figures 8.4.1 and 8.4.2 indicate the nitrogen levels for the three stages of rehabilitation (unrehabilitated sites (UR), newly rehabilitated sites (NR) and old rehabilitated sites (OR) and a nearby natural grassland site (Control). No nitrate could be detected by the capillary electrophoresis method on the unrehabilitated sites (UR). Nitrate soil concentrations for the newly and old rehabilitated areas were very similar (average nitrate ≅ 0.03 mmol.dm^{-3}), but still lower than the average concentration obtained in the natural grassland. The high pH of coal ash results in the volatilisation of ammonium (Hodgson & Townsend, 1973), which results in a low concentration of ammonium in untreated ash with a high pH. The average ammonium concentrations (0.05 mmol.dm^{-3}) of the unrehabilitated sites (UR) were, therefore, unexpectedly high if the high pH is considered. The newly rehabilitated sites (NR) also had higher average concentrations of ammonium than the old rehabilitated sites (OR). An important gradient related to species differences, identified in the CCA ordination of species data and soil chemical variables, involved ammonium (Figure 8.1). A probable reason for this is the 150 kg/ ha KAN (Potassium Ammonium Phosphate) fertiliser, which was used as a fertiliser treatment (Michael, pers. comm.)[4]. Another possible source of ammonium was the fertilisers containing NH_3/NH_4 that was sprayed on maize fields adjacent to the ash disposal sites resulting in contamination due to strong wind from the direction of the maize fields while being sprayed.

The relation between available nitrogen and nitrogen-fixing legumes is also an important aspect of the fertility of the growth medium. Bradshaw (1984) and Hodgson and Townsend (1973) considered the inclusion of legumes as an important component during restoration and rehabilitation programs in order to minimise fertilisation treatments. Results indicated that nitrate was negatively correlated with the abundance of legume species in general, and the occurrence of the legume *Chamaecrista biensis* on old rehabilitated sites. The reverse is, however, true for ammonium, which was positively statistically significantly related with legume abundance (Table 8.5). According to Mengel and Kirby (1987), ammonium and nitrate differ in their mobility in the soil. Ammonium is more readily lost due to leaching while nitrate is readily adsorbed by clay minerals in the soil and is, therefore, not easily leach out of the root zone. Nitrate concentrations is, therefore, 100 times higher than ammonium concentrations due to difference in mobility between the two compounds and remains in the soil for longer. No further investigation was done on the effect of legumes on nitrogen fixation. Root nodules were, however, found on all three dominant legume species *(Chamaecrista biensis, Stylosanthes fruticosa* and *Lespedeza cuneata*). Although nitrate was statistically significantly correlated to species data in the RDA ordination on old rehabilitated sites (Figure 8.2), Spearman Rank (Table 8.5) indicated that densities and importance values of legume species were significantly related to ammonium concentrations but negatively so with nitrate.

Most literature indicated boron as the most important element that could occur in phytotoxic concentrations in the soil, which explains the limitations of coal ash for agricultural use (Aitken *et al.,* 1984). Jones and Lewis (1960), however, found that boron levels decrease rapidly from a level toxic to plants (216 ppm), to levels of 20 ppm over a period of fourteen years. Lagooning of coal ash also contributes to the reduction of boron levels (Hodgson & Holliday, 1966). Hodgson and Holliday (1966) found the addition of calcium and aluminium silicates to be the best treatment to ameliorate the boron phytotoxicity in ash. The addition of especially calcium is a symptomatic treatment to improve the Ca:B ratio in the soil. The slow release of boron from the glassy phase of the ash may result in long term toxicity of this element (Hodgson & Holliday, 1966 and Hodgson & Townsend, 1973). Figure 8.4.3 illustrates the differences in boron concentrations between the four different scenarios from the study at Hendrina Power Station, and indicates that available boron concentrations fall rapidly after rehabilitation. Boron

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concentrations on old rehabilitated sites (OR) were found to be similar to that of the nearby natural grassland (Control) (Figure 8.4.3).

A major contributory element to salinity is the concentration of sodium in the soil, together with magnesium, calcium and potassium (Mengel & Kirby, 1987). Appreciable quantities of sodium may lead to deflocculation of clay particles resulting in highly unstable soil physical conditions extremely prone to erosion. Sodium concentrations for old rehabilitated areas (OR) at Hendrina Power Station were, however, similar to the natural grassland (Control) (Figure 8.4.4).

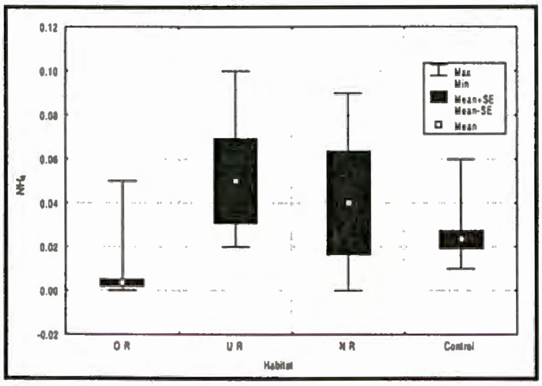

Fig. 8.4.1: Ammonium (p= 0.000)

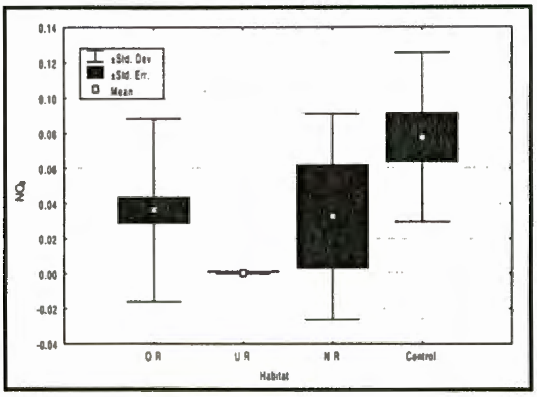

Fig. 8.4.2: Nitrate (p= 0.003)

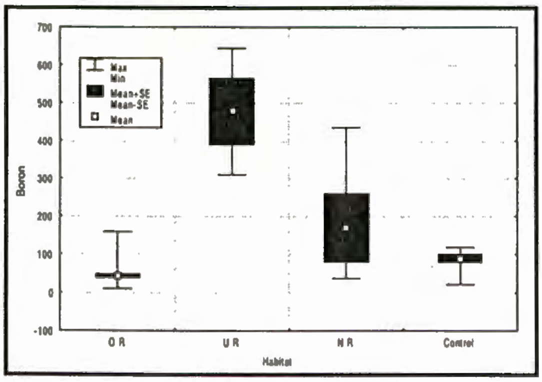

Fig. 8.4.3: Boron (p= 0.000)

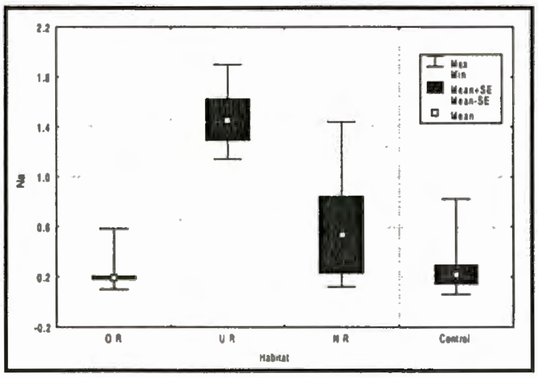

Fig. 8.4.4: Sodium (p=0.000)

Figure 8.4: Differences in soil concentrations of ammonium, nitrate, boron and sodium between old rehabilitated (OR), unrehabilitated (UR), newly rehabilitated (NR), and a nearby natural grassland (Control) at Hendrina Power Station (p-values indicate the magnitude of statistical significance between groups obtained from the non-parametric Kruskal Wallis test.)

In many cases nutrients deficiencies are not the result of a low concentration of the particular nutrient, but rather due to cation antagonism or incorrect element ratios (proportions), which is caused by nutrient imbalances. An example of nutrient imbalances is the effect of high concentrations of magnesium on calcium uptake or the effect of high concentrations of potassium on magnesium uptake (Mengel & Kirby, 1987). Buys (1986) indicated desirable proportions for the three macronutrients, calcium, potassium and magnesium. If proportions are out of range, they may result in nutrient imbalances and the nutrient status of the growth medium must be investigated. Table 8.6 indicate that the average proportions for Ca/Mg and Mg/K on old rehabilitated sites (OR) were all in the desired range as indicated by Buys (1986). Small nutrient imbalances occur in unrehabilitated sites (UR) (Table 8.5). The Mg/K ratio was also higher than the desired value on newly rehabilitated sites (NR). The salinity in relation to the sodium adsorption ratio (SAR) was also investigated. The sodium adsorption ratio (SAR) indicates the relation of the concentration of soluble sodium to the soluble divalent cations. SAR values can be used to predict the exchangeable sodium percentage of the soil in equilibrium to the soil solution (Van der Walt & Van Rooyen, 1990). Average values were all below 1 indicating that no salinity problems due to high sodium levels exist (Table 8.6).

Table 8.5: Spearman Rank Order Correlations between Nitrogen compounds and legume abundances on old rehabilitated ash disposal sites at Hendrina Power Station

Pair of variables	N	R	t(N-2)
NH_4 & *Chamaecrista biensis*	26	0.495**	2.793
NH_4 & Legume importance	26	0.482*	2.692
NH_4 & Density of legume species	26	0.468*	2.595
NO_3 & *Chamaecrista biensis*	26	-0.183	-0.914
NO_3 & Legume importance	26	-0.159	-0.787
NO_3 & Density of legume species	26	-0.070	-0.343

*, ** Significant correlations at $p \leq 0.05$; $p \leq 0.01$ levels respectively

Table 8.6: Cation relationships on three levels of rehabilitation (OR (old rehabilitated), UR (Untreated ash) and NR (Newly rehabilitated)), and in natural grassland soil (Control) at Hendrina Power Station

	SAR		Ca/Mg		Mg/K	
OR	0.288	*0.236*	4.678	*3.476*	3.440	*2.989*
UR	0.977	*0.341*	9.672	*7.178*	1.118	*1.012*
NR	0.476	*0.375*	3.372	*1.059*	5.152	*5.786*
Control	0.741	*0.658*	0.529	*0.997*	3.319	*5.695*
All Groups	0.412	*0.407*	4.192	*3.902*	3.386	*3.656*
Desired ratio	< 1 (saline< 4)		1.5-4.5		3.0-4.0	

Desired ratios according to Buys (1986). Std. dev. values in italics.

8.3.2 Soil physical conditions

Figure 8.5 represents a joint plot between plant species data and selected soil physical variables. A forward selection procedure based on the p-values (Table 8.7) of twenty-three soil physical variables indicated silt (0-10cm), gravel (0-10cm) and soil depth as the soil physical variables that were the best related to species data. All three soil variables mentioned could be related to the topsoil that was used, because all were from the first 10cm substrate layer. The species gradient along ordination axis 1 that divided the newly rehabilitated areas (left side of first axis) from the older rehabilitated ash disposal sites (right side of the first axis) could be related to differences in the silt content. The species *Enneapogon cenchroides* (Enne cen), *Eleusine coracana* subsp. *africana* (Eleu cor), *Eragrostis tef* (Erag tef) and *Commelina benghalensis* (Comm ben) could not be directly connected to silt content. These species are all pioneer annual grass species and cannot be linked to silt content *per se*. More important gradients are the effect of percentage gravel and low soil penetrability (crust formation) on the species composition along ordination axis 2. These two soil characteristics could be connected to a higher percentage of bare ground and a higher importance of annuals, for example *Acanthospermum glabratum* (Acan gla), *Schkuhria pinnata* (Schk pin), *Melinis repens* (Meli rep) and *Tagetes minuta* (Tage min) (top of ordination axis 2). A higher percentage of bare ground also enabled annual forbs to establish due to a lack of competition from perennial grass species. The effect of competition from large tufted perennials is lower if bare ground increases and a niche for less competitive annual species is created. The higher occurrence of gravel can be an indication of soil quality in this case, because most of the coarse grained soil fraction consisted of concretions originating from the plinthic horizon of the Westleigh soil form (Soil Classification Work Group, 1991) that was used as a topsoil layer.

Heteropogon contortus (Hete con), *Digitaria eriantha* (Digi eri), *Sporobolus africanus* (Spor afr), *Pogonarthria squarrosa* (Pogo squ), *Oxalis* spp. (Oxal spp) and *Chamaecrista biensis* (Cham bie) were positively correlated with higher soil penetrability (bottom of ordination axis 2). Figure 8.5 also indicates that the species *Bromus catharticus* (Brom cat), *Pelargonium luridum* (Pela lur), *Conyza bonariensis* (Cony bon) and *Cirsium vulgare* (Cirs vul) were the least associated with higher silt levels. *Digitaria eriantha* (Digi eri), *Cynodon dactylon* (Cyno dac), *Aristida congesta* (Aris con), *Chamaecrista biensis* (Cham bie), *Pogonarthria squarrosa* (Pogo squ) and *Eragrostis curvula* (Erag cur) were more associated with substrate consisting of a shallow topsoil layer, whereas *Tagetes minuta* (Tage min) probably prefers a substrate with a thicker topsoil layer, according to Figure 8.5.

Table 8.7: Results from the stepwise forward selection CCA ordinations of soil physical variables at soil depths of 0-10cm, 10-20cm and 0-20cm on all rehabilitated ash disposal sites at Hendrina Power Station

Variables	P-value	Cumulative fit	Stepwise Fit
Silt (0-10)	0.005	0.25/0.80	0.25
Gravel (0-10)	0.035	0.39/0.80	0.14
Soil depth	0.005	0.52/0.80	0.13
Silt (10-20)	0.140	0.60/0.80	0.08
Fine sand (0-10)	0.150	0.68/0.80	0.08
Gravel (10-20)	0.350	0.74/0.80	0.06
Soil penetrability	/	**0.78/0.80**	**0.04**
Overall (0-10)	**0.00**		
First axis (0-10)	**0.00**	**0.32**	

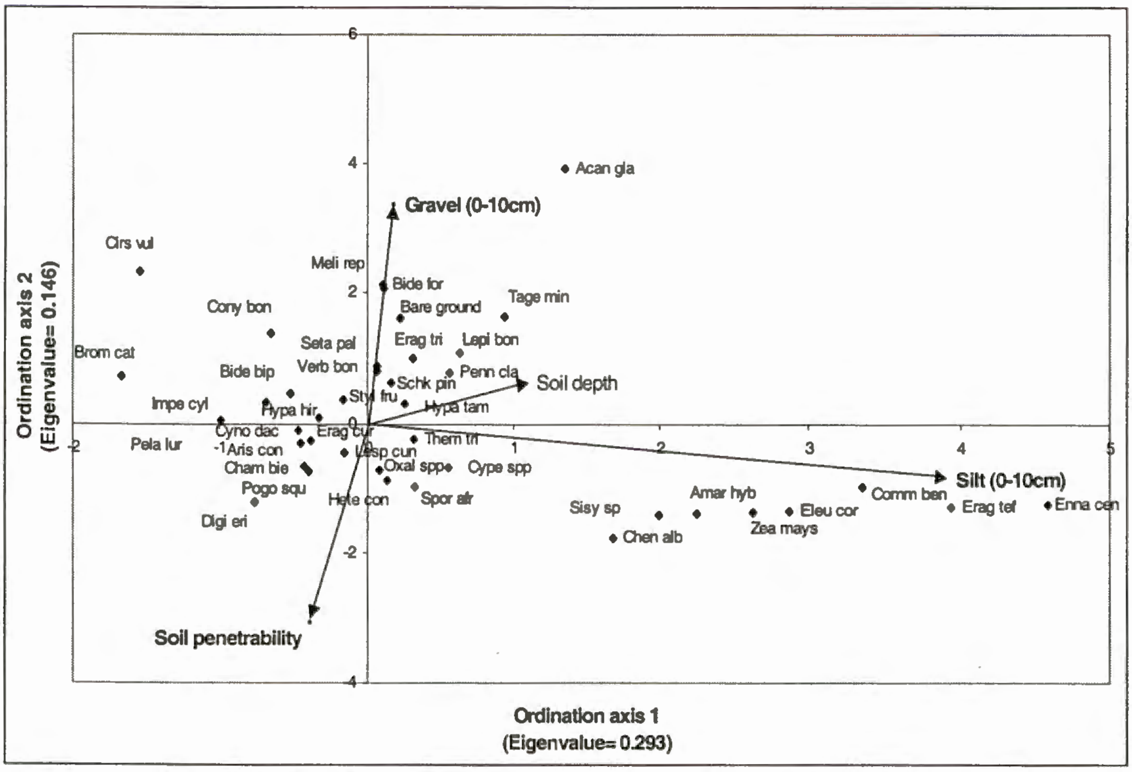

Figure 8.5: CCA joint plot of species (diamonds) and soil physical variables (arrows) on rehabilitated ash disposal areas at Hendrina Power Station.

A RDA was performed on old rehabilitated areas that were seeded. Stepwise forward selection indicated the silt content, soil penetrability, average clay content and soil depth to be the best variables to explain variances in species data (Table 8.8). The low eigenvalues indicate that gradients along the first (Eigenvalue=0.1208) and second ordination axes (Eigenvalue=0.0863) were small.

The result of the biplot (Figure 8.6) was found to be highly informative. Species such as *Hyparrhenia hirta* (Hypa hir), *Tagetes minuta* (Tage min), *Bidens formosa* (Bide for) and *Eragrostis echinochloidea* (Erag ech) were all associated with low soil penetrability. Bare ground also illustrated a strong negative correlation to higher soil penetrability. *Eragrostis curvula* (Erag cur) preferred high soil penetrability and substrates with deeper topsoil layers and lower silt content. *Stylosanthes fruticosa* (Styl fru), *Bidens bipinnata* (Bide bip) and *Lepidium bonariense* (Lepi bon) were strongly associated with substrates consisting of a deeper topsoil layer. *Chamaecrista biensis* (Cham bie), *Digitaria eriantha* (Digi eri) and *Cynodon dactylon* (Cyno dac) were negatively correlated with topsoil depth, but positively correlated with higher soil clay content. *Cyperus esculentus* (Cype esc), *Eragrostis trichophora* (Erag tri) and *Schkuhria pinnata* (Schk pin) were associated with a shallower topsoil layer, but with substrates of a higher clay and silt content. Species which were positively correlated with higher silt content were *Aristida congesta* (Aris con), *Hyparrhenia tamba* (Hypa tam), *Themeda triandra* and *Heteropogon contortus* (Hete con). These species were more associated with soil of lower soil penetrability and topsoil depth.

Table 8.8: Results from the stepwise forward selection CCA ordinations of soil physical variables at soil depths of 0-10cm, 10-20cm and 0-20cm on old rehabilitated ash disposal sites at Hendrina Power Station

Variables	P-value	Cumulative fit	Stepwise Fit
Silt (10-20)	0.015	0.10/0.41	0.10
Soil penetrability	0.075	0.18/0.41	0.08
Clay (0-20)	0.085	0.24/0.41	0.07
Soil depth	0.130	0.31/0.41	0.06
Overall (0-10)	**0.00**		
First axis (0-10)	**0.09**	**0.12**	

In Figure 8.7, the different particle size distribution curves for the "growth mediums" on the plateau of ash disposal site 1, rehabilitated ash disposal slopes, plateau of ash disposal site 3, soil from the natural grassland and untreated ash, are indicated. The particle size curve for unrehabilitated sites (Untreated) showed the slowest decrease, indicating that most of the growth medium consisted of fine sand particles. The growth medium on the plateau of ash disposal site 1 (Plateau 1) consisted of a high amount of gravel and a large percentage of silt (Figure 8.7). Particle size curves for the rehabilitated slopes and the remainder of the rehabilitated plateaus were very similar (Figure 8.7). Natural soil (Control) from the nearby grassland illustrated a more equal distribution in soil particle sizes (Figure 8.7).

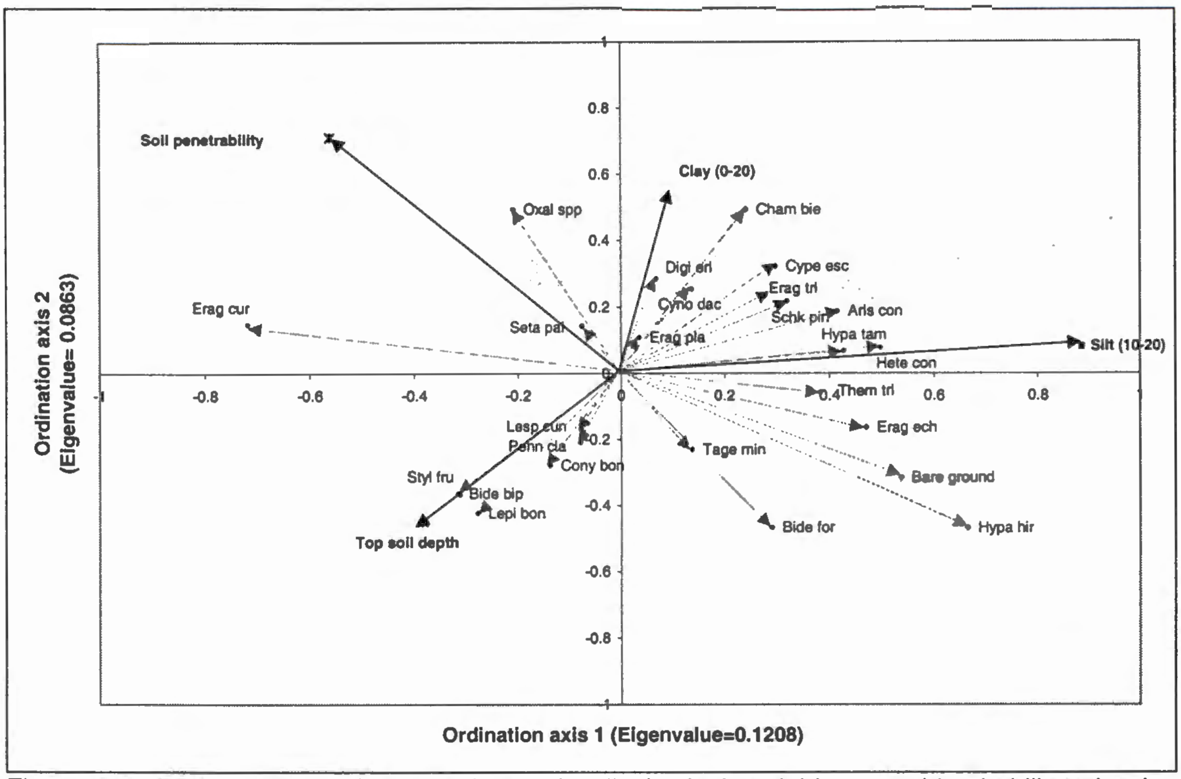

Figure 8.6: RDA biplot of plant species and soil physical variables on old rehabilitated ash disposal sites at Hendrina Power Station.

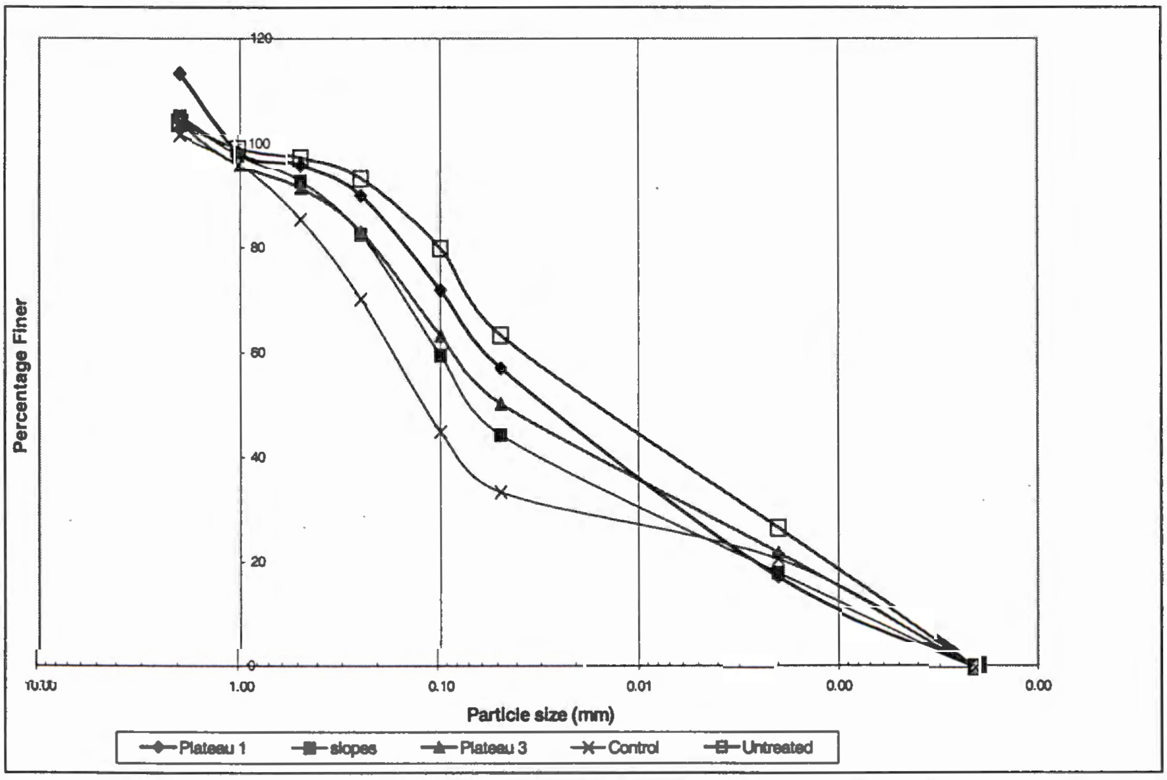

Figure 8.7: Particle size distribution curves for plateau of ash disposal site 1 (Plateau 1), rehabilitated ash disposal slopes (Slopes), plateaus of ash disposal site 3 (Plateaus 3), soil from the natural grassland (Control) and unrehabilitated sites (Untreated) at Hendrina Power Station.

The penetrability of the soil was measured with a descending rod apparatus that was used as a penetrometer and can probably be described as a function of the soil consistency, density and the amount of crust formation and compaction of the surface layer. Analysis of variance with the Kruskal Wallis median test indicated that the soil penetrability between grids varied statistically significantly (p-value=0.000). According to Figure 8.8, the soil penetrability of grid 1, the unrehabilitated sites (UR) and the natural grassland (control) were lower than most of the other areas investigated. The growth mediums of grid 1 and the natural grassland (Control) had an average penetrability of 2.64 and 2.683, respectively, and were the lowest for the areas analysed. The highest average penetrability was recorded in grid 12 (6.798). The penetrability of the substrate of grid 12 and the unrehabilitated sites were, however, also found to be highly variable (std. 5.484 and 3.808 respectively). The soil penetrability was lower on grid 10 in comparison to grids 2, 3, 4, 9, 11, 12 and the newly rehabilitated sites (Figure 8.8). The soil penetrability of grids 2 and 3 were very similar to each other as well as the soil penetrability of grids 4, 9, and 11. The variation in the soil penetrability of substrates on the ash disposal sites was higher in comparison to the soil penetrability of soils in the natural grassland (control). On older rehabilitated sites the soil penetrability will be dependent on the particle size distribution and soil physical characteristic of the substrate as well as the amount of burrowing by small mammals, in particular *Tatera brantsii.*

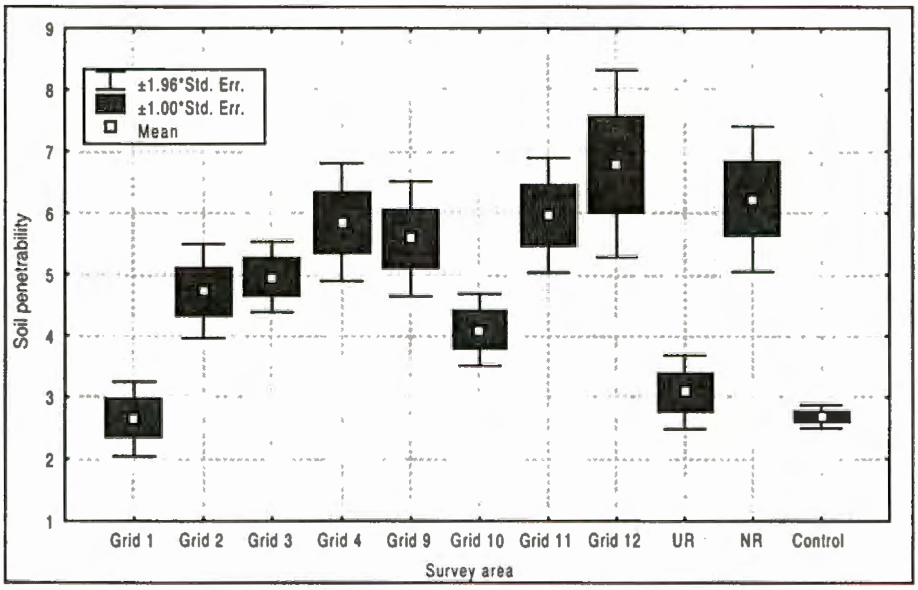

Figure 8.8: Soil penetrability between the different grids on old rehabilitated sites as well as for unrehabilitated and newly rehabilitated sites at Hendrina Power Station.

According to Table 8.9, the deepest layer of topsoil was on slopes of the ash disposal sites. The measured topsoil depths on the surfaces of the ash disposal areas were also lower than the specified depth of 100mm (see Chapter 2). In certain places it was, however, difficult to determine the actual depth of the topsoil due to mixing of topsoil and ash from the burrowing activities of the small mammal, *Tatera brantsii.*

Table 8.9: Differences in depth of top soil (mm) at survey grids and on newly rehabilitated areas on ash disposal sites at Hendrina Power Station

	Mean (mm)	Std. dev	Valid N
Grid 1	69.467	*30.900*	3
Grid 2	127.667	*17.090*	3
Grid 3	140.333	*64.864*	3
Grid 4	113.600	*57.107*	3
Grid 9	104.333	*67.670*	3
Grid 10	59.133	*8.103*	3
Grid 11	36.267	*9.192*	3
Grid 12	96.267	*28.288*	3
NR	131.900	*70.852*	2
All groups	96.346	*50.208*	26

(NR: newly rehabilitated)

8.3.3 The effect of treatment and other environmental variables on plant community development

8.3.3.1 Treatment

A CCA ordination was conducted on plant species importance values from 1997 to 1999 on old rehabilitated ash sites to test the effect of treatment and topography on plant community development. Each treatment was tested separately by using binary (0/1) codes. The effect of species changes over the three years of the survey period was eliminated by choosing the year of survey as a co-variable. A partial Canonical Correspondence Analysis (Ter Braak, 1994) was therefore conducted on the data. Treatments and general habitat variables were again submitted to forward selection with the Monte Carlo permutation test (Table 8.10). Treatments 2 and 4 were automatically omitted from the forward selection procedure due to the problem of collinearity. Due to the importance of the two variables in explaining the variation in the species, treatments 2 and 4 were not excluded from the CCA analysis.

Table 8.10: Results of the CCA ordination of species data of old rehabilitated areas with topography, rehabilitation treatments and fire frequency as environmental variables indicating statistics of the forward selection procedures and Monte Carlo Permutation test

Variable	P-value	Extra fit (eigenvalue)	Cumulative fit
Treatment 1	0.005	15	15
Treatment 3	0.005	13	28
Topography	0.005	10	38
Fire Frequency	0.010	4	43
Slope	0.010	3	46
Overall test	**0.00**		
First canonical axis	**0.00**		

Sum of all constrained eigenvalues: 1.441

Sum of all canonical eigenvalues: 0.46

In Figure 8.9, the first and second ordination axis of the partial CCA ordination of species grouped together with treatments, fire frequency and topography as environmental variables are illustrated. Discussion of treatments was provided in Chapter 2 of this study. The ordination diagram indicated that species were strongly grouped according to treatments. Treatment 1 is associated with the rehabilitation efforts on top of ash disposal site 1. Previously planted *Cortaderia jubata* was removed and the surfaces were covered with a layer of topsoil which originated from a mixture of top and sub soils consisting of a high percentage of concretions. Figure 8.9 indicated that treatment 1 was associated with the species *Acanthospermum glabratum (Acan gla), Melilotus alba (Meli alb)*, a legume (Leg) and *Paspalum scrobiculatum (Pasp scr)*. All slopes of ash disposal sites 1 and 3 were rehabilitated with treatment 2 (Figure 8.9). Species characterising sites where treatment 2 was applied were *Heteropogon contortus* (Hete con), *Lespedeza cuneata* (Lesp cun) and *Stylosanthes fruticosa* (Styl fru). According to Figure 8.9, treatments 2 and 1 occur in the same direction in the ordination space and therefore share a number of species, including *Pennisetum clandestinum* (Penn cla) and *Tagetes minuta* (Tage min), which are common to both treatments. The arrow indicating the direction in which treatment 2 was best associated with species in the ordination diagram was very short in relation to other variables. This indicates that the variance explained by treatment 2 was small in comparison to the other variables. *Enneapogon cenchroides* (Enne cen), *Amaranthus hybridus* (Amar hyb), *Pogonarthria squarrosa* (Pogo squ), *Digitaria eriantha* (Digi eri), *Chamaecrista biensis* (Cham bie) and *Themeda triandra* (Them tri) were all associated with treatment 3 which was applied on the plateau of ash disposal site 3. The grass *Calamagrostis* sp. (Cala sp) and the annual herbs *Epilobium salignum* (Epil sal), *Cirsium vulgare* (Cirs vul) and *Verbena bonariensis* (Verb bon) were strongly related to treatment 4, which was applied to the lower terraces of ash disposal site 4. It can also be inferred that the species *Melinis repens (Meli rep)*, *Hyparrhenia tamba* (Hypa tam), *Conyza spp.* (Cony spp), *Pseudognaphalium* spp (Pseu spp) and *Hypochoeris radicata* (Hypo rad) had their highest occurrence on areas rehabilitated with treatment 4. Topography and fire were nearly antagonistic to each other indicating that sites on the plateau of ash disposal sites were the most effected by fire. No species were strongly related to the fire frequency gradient but the occurrence of bare ground and the species *Aristida congesta* (Aris con), *Cyperus* spp (Cype spp) and *Schkurhria pinnata* (Schk pin) had the highest frequencies on sites which were most frequently burned. Species associated with treatment 4 were the least affected by fire (Figure 8.9).

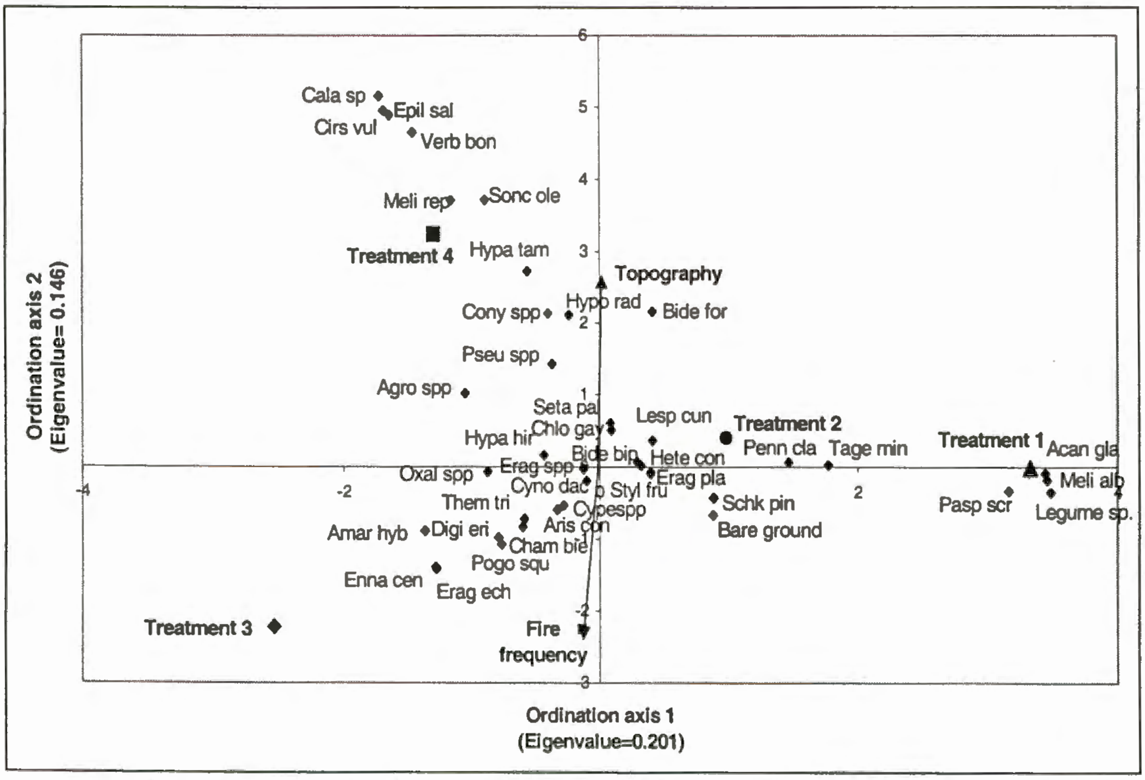

Figure 8.9: Scatter diagram of the partial CCA ordination of plant species together with the different treatments used, fire frequency and topography (position on ash disposal site.) on ash disposal sites at Hendrina Power Station.

8.3.3.2 Effect of fire frequency and *Tatera brantsii* infestations

A partial Redundancy Analysis (RDA) was performed on grids on old rehabilitated areas to test the effect of fire frequency and the activities of the small mammal, *Tatera brantsii* on plant species composition. Plant species importance values from the 1998-1999 season were used. Treatments were added as co-variables to the analysis. A stepwise forward selection was also performed to test if the effect of fire frequency and the small mammal specie on plant composition was statistically significant. Table 8.11 indicates that both variables were statistically significantly correlated to species data.

Table 8.11: RDA ordination statistics results of the Monte Carlo permutation test during the forward selection procedure, overall test and for the first Canonical axis of the effect of fire frequency and the activities of the small mammal *Tatera brantsii* on plant composition on old rehabilitated ash disposal sites at Hendrina Power Station. The different treatments were used as co-variables

Variable	P-value	Extra fit (eigenvalue)	Cumulative fit
Tatera brantsii	0.005	0.05	0.05/0.09
Fire frequency	0.005	0.04	0.09/0.09
Overall test	**0.01**		
First canonical axis	**0.01**	**0.05**	

Although the eigenvalues for the first two axes were small, results illustrated that strong correlations between the two environmental gradients and species data exist (Figure 8.10). *Lepidium bonariensis* (Lepi bon), *Imperata cylindrica* (Impe cyl), *Cynodon dactylon* (Cyno dac) and *Cleome monophylla* (Cleo mon) were best correlated to higher occurrence of fire (fire frequency-gradient). According to Figure 8.10 *Digitaria eriantha* (Digi eri), Bare ground, *Cyperus* spp. (Cype spp) and *Eragrostis echinochloidea* (Erag ech) correlate with increasing population size of *Tatera brantsii*. *Hyparrhenia hirta* (Hypa hir) was positively correlated with both gradients according to Figure 8.10, because this species occurs in the centre of the two gradients in the ordination biplot. Higher intensity of both factors would therefore favour the establishment of *Hyparrhenia hirta*.

Conyza spp. (Cony spp), *Pseudognaphalium* spp. (Pseu spp), *Bidens bipinnata* (Bide bip) and, to a lesser extent, *Chloris gayana* (Chlo gay) and *Themeda triandra* (Them tri), were negatively correlated with increase in fire frequency (Figure 8.10). Species that were negatively correlated with increasing population size of *Tatera brantsii*, were *Eragrostis chloromelas* (Erag chl), *Agrostis* spp. (Agro spp) and *Oxalis* spp. (Oxal spp). According to Figure 8.10, *Eragrostis* spp. (*Eragrostis trichophora* and *Eragrostis curvula*) were negatively associated with the gradients of *Tatera brantsii* population size and fire frequency. The gradient associated with *Tatera brantsii* population size can be related to the effect of infestations of this species and higher burrowing activities by the small mammal. *Pennisetum clandestinum* (Penn cla), *Aristida congesta* (Aris con), *Chamaecrista biensis* (Cham bie) and *Eragrostis plana* (Erag pla) were weakly correlated with the gradient of fire frequency.

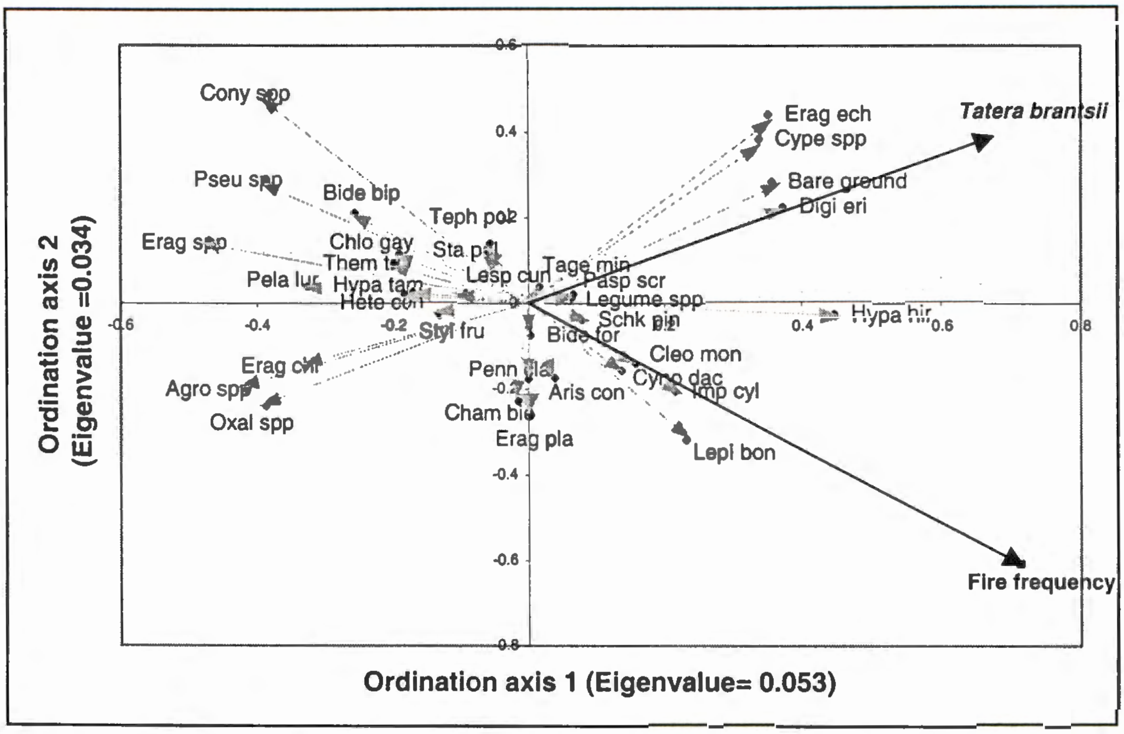

Figure 8.10: RDA biplot of plant species together with the small mammal, *Tatera brantsii* and frequency of fire as environmental variables on old rehabilitated ash disposal sites at Hendrina Power Station.

8.4 CONCLUSIONS

The largest differences in soil chemical conditions existed between sites of old rehabilitated areas and newly rehabilitated areas. The CCA ordination diagram of all rehabilitated sites (Figure 8.1) indicated that the annual species *Amaranthus hybridus, Commelina benghalensis* and *Eleusine coracana* subsp. *africana* did prefer more saline conditions. These species were, however, not all typical of saline environments. Most of the other species that were correlated with the saline conditions were annual grasses from the seed mixture, which included *Eragrostis tef* and *Enneapogon cenchroides.* To ascribe the species composition of rehabilitated ash disposal areas entirely to soil chemical effects is, therefore, incorrect. The agricultural origin (the occurrence of *Zea mays* in the species composition is a strong indication of the origin of the topsoil) of the species must also be considered, as well as the seed input from the seed mixture used during rehabilitation. Also the soil chemical variables *per se* did not explain differences in species composition between old and newly rehabilitated areas. The CCA ordination, however, indicated that high boron and high salinity levels were only evident on newly rehabilitated areas and decreased considerably after two to three years.

The most important soil chemical gradients on old rehabilitated areas were the bicarbonate, potassium and ammonium content of the soil. Although bicarbonate and pH were positively correlated (R= 0.74) with each other, the influence of this gradient on species composition was different. High pH was for instance related to a higher percentage of bare ground and most of the species preferred lower salinity and bicarbonate levels. Mengel and Kirby (1987) mentioned that high bicarbonate levels are normally a result of insufficient aeration, which results in an accumulation of carbon dioxide. Calcareous conditions and high pH can induce high levels of bicarbonate. This may result in a physiological disorder where the uptake of iron is effected by high levels of excess bicarbonate.

It would also seem that the nitrogen recycling and mineralisation on rehabilitated ash disposal sites were not as effective as in soil in the natural grassland (Bradshaw & Chadwick, 1980). Comparison between data from revegetated ash disposal sites at Sasolburg (van Rensburg *et al.,* 1998) with data from this study indicated that, except for phosphate', copper, iron, manganese and zinc, all other chemical soil characteristics were lower at the Hendrina Power Station. The soil chemical data indicated that no adverse soil chemical conditions could be detected on old rehabilitated areas. The nutrient status of the growth medium therefore does not seem to be the most important factor but do has a effect due to the significant association between soil chemistry and species composition.

Although no analysis for heavy metals and trace elements was conducted on soil or leaf samples, it was realised that levels toxic to plants and animals may exist. Van Rensburg *et al.* (1998) found high concentration levels of Selenium, which could be toxic. Another problem associated with fly ash is molybdenosis, which is caused if the ratio between copper and molybdenum decreases below the critical ratio of 2:1 (Hammermeister *et al.*, 1998). Although a sufficient supply of micronutrients existed, the availability of these nutrients can be affected by alkalinity in the growth medium, which may result in precipitation of micronutrients and induce the immobilisation (Singer & Munns, 1992).

Considerable variation existed in the characteristics of the topsoil that was used. Species on newly rehabilitated areas were strongly associated with high silt content, and species on the plateau of grid 1 were associated with a high amount of gravel. Species composition was highly effected by the soil penetrability. Bare ground, which can be described as a good indication of lack of vegetation cover, was the lowest on sites with low soil penetrability. The occurrence of *Eragrostis curvula* was highly affected by soil penetrability and this may even have been a contributory factor in the facilitation of a *Hyparrhenia hirta* dominated grassland (Figure 8.6). A problem, which was not addressed in this study, was the occurrence of impermeable soil layers deeper down the soil profile. Numerous root systems that were dug up indicated mat formation at a depth of 30-40cm in the "soil" profile. Mat formation of the roots is one of the most serious soil physical problems associated with ash disposal areas, that is caused by the pozzolanic properties of the ash, resulting in the formation of cement like layers. The pozzolanic properties of coal ash, which makes it suitable for concrete production, may impede drainage and cause insufficient root penetration and aeration (Bradshaw & Chadwick, 1980 and Townsend & Gillham, 1975). Although not intensively studied observations indicated that this may be a serious problem especially on the flat top surfaces.

Differences in species composition between sites could be explained by variations in the application of rehabilitation treatments. Differences in treatments include different topsoils, different seed mixtures and the use of stoloniferous grasses, as well as differences in management strategies. Although nearly similar seed mixtures were used between treatments 2, 3 and 4, the species composition still varied considerably after the rehabilitation period (see Chapter 2, Figure 2.2 for a description of treatments). Initial condition also played an important role in the successional pathways of old fields as investigated by Myster and Pickett (1990). It was, however, found that successional pathways converge over time and were similar in species composition after eight years (Myster & Pickett, 1990). The vegetation of this study mostly developed to a species composition mostly dominated by four grass species. Results, however, indicated those significant differences in low occurrence species remains approximately three years after commencement of rehabilitation.

Results indicated that fire and large populations of the small mammal, *Tatera brantsii* might have a detrimental effect on the condition of rehabilitated grasslands. The only study examining the impacts of *Tatera brantsii* on plant communities in South Africa was conducted by Korn & Korn (1989), in subtropical savanna grasslands at Nylsvley Nature Reserve. Korn & Korn (1989) demonstrated that digging activities and selective feeding by these gerbils caused a marked reduction of 47% in grass biomass, with a corresponding increase in forb diversity. Korn & Korn (1989) postulated that the gerbils are important regulators of grassland dynamics. Studies conducted on the effect of *Tatera brantsii,* in the *Lepidium bonariense-Eragrostis trichophora* Variant on ash disposal areas at the Hendrina Power Station, indicated that the small mammal might promote the diversity and biomass of annual forbs. The legume *Chamaecrista biensis* and the sedge *Cyperus esculentus* have increased considerably on inactive sites previously colonised by *Tatera brantsii.* The effect of the small mammal was also found to be highly localised (Van Hamburg, 1999).

Treatments probably explained the differences in species composition the best from all factors examined whereas disturbances by small mammals and fires were the most important external driving forces in community development.

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Chapter 9 BIOMASS PRODUCTION ON REHABILITATED ASH DISPOSAL SITES

Abstract: An integral part of community functioning is biomass production. Studies of biomass production in South African grasslands concentrated mostly on the effect of grazing or mowing, the application of fertilisers, and the occurrence of fire or annual precipitation. Little information on the productivity of rehabilitated grasslands on industrial areas exists. The first objectives of this study is to estimate the biomass production of rehabilitated ash disposal sites, dominated by *Hyparrhenia hirta* and *Eragrostis curvula*, in relation to a natural grassland dominated by *Setaria sphacelata* var. *torta*, *Heteropogon contortus* and *Tristachya leucothrix*. A further objective is to determine the influence of species densities and diversity on biomass production and *vice versa*. Determination of the effect of soil chemical conditions on biomass production is the third objective.

The study was conducted on rehabilitated ash disposal sites with rehabilitation ages between 1 and 7 years (1997) at Hendrina Power Station. The biomass production is determined from samples cut annually in $0.25m^2$ quadrats during May over a three-year period at twelve grids consisting of fifteen plots each. Data are analysed using non-parametric methods including Friedman's ANOVA for comparison between repeated measurements, Kruskal-Wallis ANOVA and Spearman's Rank correlation methods.

Forb and litter mass are highly variable between survey grids, whereas grass biomass illustrates less variability. Grass biomass of older rehabilitated ash disposal sites is similar to the grass biomass of the natural grassland (318 g/m^2). Grass and forb biomass mostly fluctuates over years or increase during the study period. Litter mass, however, decrease in those sites which were regularly burned. Accumulation of excess litter negatively influences the productivity in the natural grasslands, which is not evident in the rehabilitated grassland. Species density is related to biomass production but no relationship exists between species diversity and biomass productivity. Grass biomass and litter biomass are positively influenced by higher concentrations of ammonium and iron in the substrate but negatively influenced by higher pH, and soil characteristics which indicates higher salinity (higher electrical conductivity, calcium and bicarbonate).

CONTENTS

9.1 INTRODUCTION

Biomass production and related parameters are frequently studied during investigations into community functioning and changes. Extensive literature therefore also exists which examines (Wiegert & McGinnis, 1975, Sala *et al.*, 1988, Silvertown *et al.*, 1994) and predicts (Rosenzweig, 1968, Leith, 1973 & Webb *et al.*, 1983) the productivity in ecosystems. A common estimator of primary productivity of terrestrial communities is climatological data, such as rainfall or evapotranspiration values, due to their high correlation with biomass production (Barbour *et al.* 1987). According to Silvertown *et al.*, (1994) community composition is closely related to biomass variation, which is enhanced by precipitation. Sims & Singh (1978) determined that biomass production shows a linear increase with an increasing precipitation during the growing season. A linear relationship was, however, less evident if precipitation increased beyond a certain point.

Biomass production research on grasslands in South Africa was most often associated with studies related to influences of agronomic activities on grasslands (Edwards & Nel, 1973, Le Roux, 1989, Tainton *et al.*, 1978 and Shackelton, 1991). Few biomass studies have been conducted on rehabilitated sites, although they are important for the determination of the level of ecosystem development. Van Rensburg *et al.* (1998) estimated the average biomass values as 29.9-46.4 g/m^2 for eight different amelioration treatments after one growing season. Corbett *et al.* (1996) concluded that the biomass of revegetated prairies after strip mining (Illinois, USA) increased over time because of the increase in non-prairie species. A study by McGinnies & Crofts (1986) observed that additional application of phosphorus could improve the yield of legumes such as *Medicago sativa* on rehabilitated open cast coal mines. Rutherford (1978) indicated the average biomass as approximately 2000 kg/ha/year in grasslands on the South African Highveld. Rutherford (1978) and O'Connor & Bredenkamp (1997) provided extensive overviews on biomass production of grasslands in Southern Africa.

Most biomass studies in South Africa only considered the influence of burning or mowing and fertilisation during biomass studies. Studies on the effect of fertilisation, which might also be considered an important factor during rehabilitation, showed that species biomass and composition are influenced by nitrogen and phosphate fertilisation of grasslands (Grunow *et al.*, 1970 and Edwards & Nel, 1973). Samual & Hart (1998) conducted a similar type of study to determine the effect of nitrogen fertilisation on biomass composition and biomass production on mixed grasslands in Wyoming, USA. According to Samual & Hart (1998) biomass production was closely related to annual precipitation but addition of nitrogen fertilisers did increase the biomass production in relation to treatments with no application of fertilisers. Most studies related to the application of N-fertilisers to vegetation reported an increase in forb (weed) biomass (Edwards & Nel, 1973 and Samual & Hart 1998).

The objectives of this study were to give an estimation of the biomass production of rehabilitated ash disposal sites, dominated by *Hyparrhenia hirta* and *Eragrostis curvula*, in relation to a ungrazed natural grassland dominated by *Setaria sphacelata* var. *torta*, *Heteropogon contortus* and *Tristachya leucothrix*, to determine the influence of species densities and diversity on biomass production and *vice versa*, and to determine the effect of soil chemical conditions on biomass production of grass and forb species as well as litter mass.

Three hypothesis are tested. The first hypotheses states that the rehabilitated areas will not have reached the same biomass as the natural grassland and biomass will remain constant over the three year period on rehabilitated sites. The second hypothesis states that the density of specific species will have a significant effect on the biomass of the ecosystem. The third hypothesis tested is that soil nutrient status will have an effect on biomass.

9.2 MATERIAL AND METHODS

9.2.1 Data sampling

The biomass production and accumulation were measured annually during May from 1997 until 1999. Biomass was sampled in $0.25m^2$ quadrats at five fixed locations along three transects (Chapter 2, Figure 2.1, and Table 2.2). Standing live material was cut as short as possible with sheep and pruning shears, and grasses and forbs were placed into separate bags. All dead material was collected and bagged separately as litter material and was used to determine litter biomass. Material was dried at 60°C for 24h and weighed afterwards. A longer drying period than 24h did not show any further reduction in dried biomass.

Species density was determined annually during March/April from 1997 until 1999, in $1m^2$ quadrats, at five fixed locations along the same three transects. Biomass sampling was conducted 1m from the transect to compensate for the effect of trampling during surveys along the transect.

Soil chemical data was obtained from samples taken during 1997 at depths of 0-10cm and 10-20cm (Chapter 8).

9.2.2 Data analysis

Non-parametric data analyses methods were used to analyse the data because the data did not conform to the normal distribution according to a Kolmorov-Smirnov distribution test and grouping factors were of unequal variance (high heteroscedasticity). Statistical significant differences between sampling grids were tested with the non-parametric Kruskal Wallis ANOVA. Results between repeated measurements were compared with Friedman's ANOVA for changes within all old rehabilitated sites and for each grid separately.

Spearman rank correlations were used to test if any meaningful relationship exist between plant densities of selected species and overall plant densities. The influences of soil chemical conditions and nutrient availability on biomass production and *vice versa* were also tested with Spearman Rank Correlations. The average value from soil samples taken at two depths, 0-10cm and 10-20 cm were used to correlate with biomass data. Eighteen soil chemical variables were correlated against biomass data from the 1997 season and the average biomass data from 1997 until 1999 (methods that relate to soil chemical analyses are discussed extensively in Chapter 8). Statistical significance was considered at p-values < 0.05. Statistical tests were performed with the STATISTICA for Windows (1995) program.

9.3 RESULTS

Table 9.1 gives a summary of the average biomass, grouped according to standing grass and forb biomass and litter for each of the ten sampling grids on old rehabilitated ash disposal sites (Grids 1, 2, 3, 4, 9, 10, 11, 12), the newly rehabilitated sites (NR) and natural grassland sites (NG). Differences in grass biomass between grids were highly significant according to a Kruskal-Wallis non-parametric ANOVA test. The most pronounced difference in grass biomass existed between grid 1 and the rest of the survey grids (Table 9.1). Grid 1 is situated on an area that was not over sown, and has, in comparison to all other areas, the lowest grass biomass (126.22 g/m^2). Vegetation on newly rehabilitated ash disposal sites (NR) also has a slightly lower grass biomass from those found in the older rehabilitated sites. Grass biomass was similar in all other grids on the rehabilitated grassland as well as between most rehabilitated areas and the natural grassland (Table 9.1). The highest grass biomass was measured at grids 9 and 11 and were due to the dominance of large-tuft perennial grass species. The grass biomass at grid 11 was, however, highly variable (large standard error) because of the occurrence a mixture of large tuft grasses and medium to small tuft grasses and stoloniferous grasses with large open spaces causing a variable structure. The natural grassland had a homogenous structure (inferred from the small standard error) because of a dense stand of short tuft forming grass species. The average grass biomass varied between 126.22 (grid 1) and 352.11 g/m^2 (grid 9), whereas the natural grassland had an average grass biomass of 318.44 g/m^2.

Differences in forb biomass were highly variable between grids in comparison to the grass biomass (Table 9.1), which can be attributed to a variable forb composition with some areas dominated with specific forb species (such as *Chamaecrista biensis*) for example grid 10 and 12 and other areas consisting of very few forb species (for example grid 2). The lowest forb biomass was recorded at grid 2 situated on a three-year-old (1997) rehabilitated slope (Chapter 2) (14.3 g/m^2). The forb biomass at grids 3 (31.25 g/m^2) and 11 (29.8 g/m^2) were also relatively lower than the rest of the survey grids (Table 9.1). The highest average forb biomass on the rehabilitated ash disposal sites (72.23 g/m^2) was recorded at grid 10 situated on the plateau of ash disposal site 3 (Chapter 2). In comparison to the natural grassland (86.46 g/m^2), which was used as a benchmark, the forb biomass was lower on rehabilitated ash disposal sites, except for grids 10 and 4 which were relatively similar to the forb biomass of the natural grassland. The newly rehabilitated ash disposal sites had a forb biomass of 44.33 g/m^2. The natural grassland was however typified by a large number of perennial forb species, whereas the forbs of the rehabilitated areas were predominantly annuals.

The litter mass, which included the standing dead material and necromass, were also found highly variable among grids. The average litter mass of the older rehabilitated areas (79.90-

168.57g/m^2) were lower than the average litter mass of the grids surveyed in the natural grassland (174.30g/m^2) but was higher than the litter mass of newly rehabilitated sites (59.80 g/m^2). The lowest litter mass was measured at grids 1, 9, 11 and the newly rehabilitated areas (see Chapter 2 for description of grids) (Table 9.1). The highest average litter mass was found at grids 2 and 4 and in the natural grassland (Table 9.1).

9.3.1 Change in biomass

Statistically significant changes in forb biomass occurred during the three-year period at grid 1. Changes in grass biomass and litter mass were also nearly statistical significant ($p<0.10$). Grass biomass decreased considerably during the first two years but increased again after 1998 (Figure 9.1.1). Litter and forb mass showed a continual increase, although, the only statistical significant change was in forb biomass (Figure 9.1.1).

The only statistically significant change on grid 2 (western facing slope rehabilitated in 1994) was in litter mass. Grass biomass increased considerably during 1997-1998 but remained the same during 1998-1999 (Figure 9.1.2). According to Figure 9.1.2 forb biomass remained low during the sampling period. The change in litter mass decreased during the three-year period. A possible reason for this constant decrease in litter was the regular burning of the vegetation in this grid.

Statistically significant changes were found in the forb and litter mass in the vegetation of grid 3 (north western facing slope rehabilitated in 1994). Although not significant the grass biomass showed a slight increase during the three-year period. Litter mass increased during the first period but decreased considerably after a veld fire during the winter of 1998 (Figure 9.1.3). Figure 9.1.3 indicated a continual statistically significant increase in the forb biomass during the three-year period.

The rehabilitated vegetation at grid 4 showed a statistically significant decrease in litter mass during the three-year period. Grass biomass decreased during 1998 but increased again during 1999 (Figure 9.1.4). The decrease in grass biomass was accompanied by an increase in the forb biomass. These changes were however not statistically significant (p-value>0.05).

All three grids (2, 3 and 4) burned during 1997-1999, which may account for the decrease of litter mass at these areas.

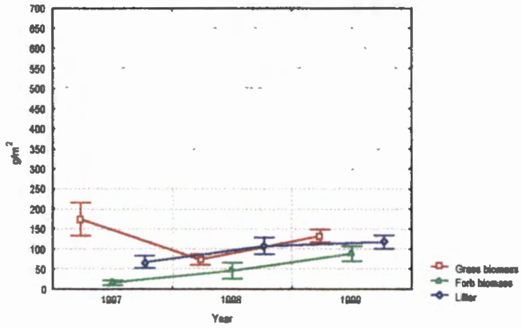

Fig. 9.1.1: Grid 1

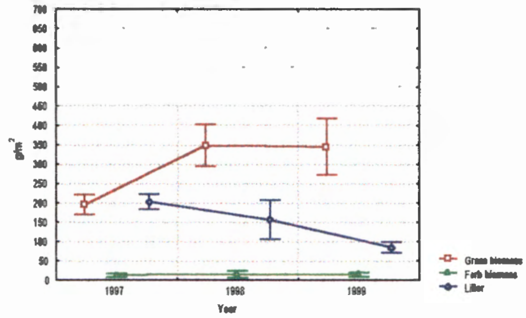

Fig. 9.1.2: Grid 2

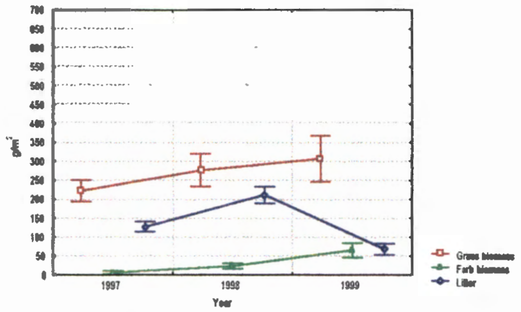

Fig. 9.1.3: Grid 3

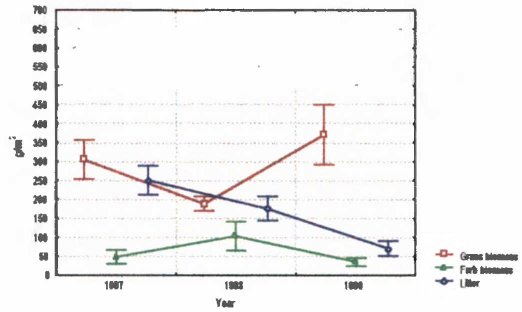

Fig. 9.1.4: Grid 4

Figure 9.1: Change in biomass on established rehabilitated sites (Fig 9.1.1-9.1.4) during 1997 until 1999 at Hendrina Power station (Whiskers indicate standard error deviation from mean value).

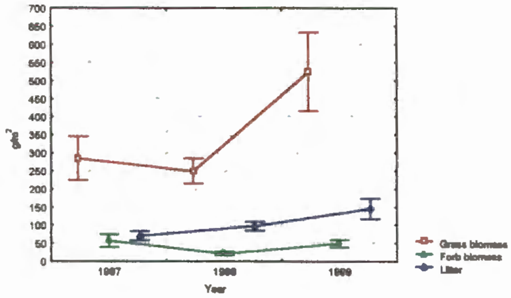

Fig. 9.1.5: Grid 9

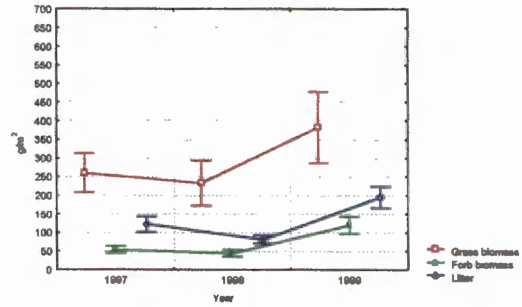

Fig. 9.1.6: Grid 10

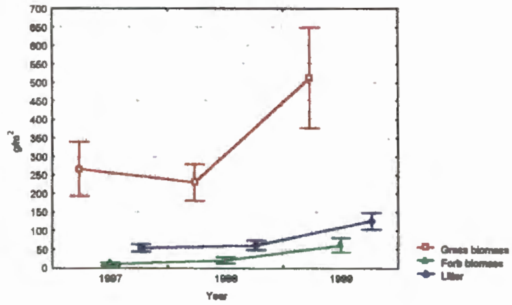

Fig. 9.1.7: Grid 11

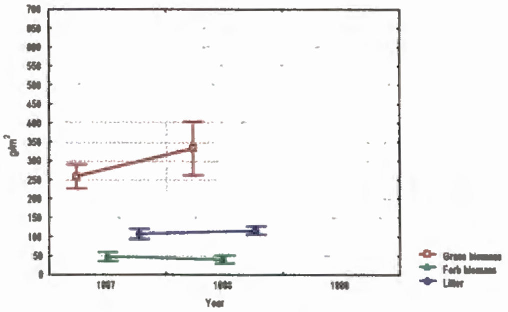

Fig. 9.1.8: Grid 12

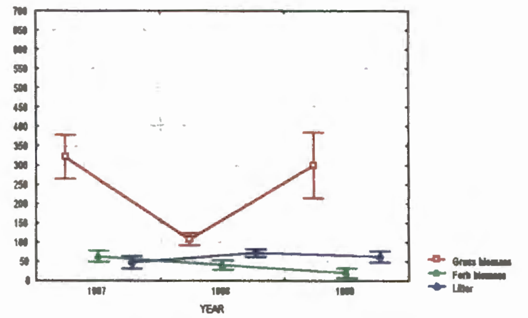

Fig. 9.1.9: Newly rehabilitated areas

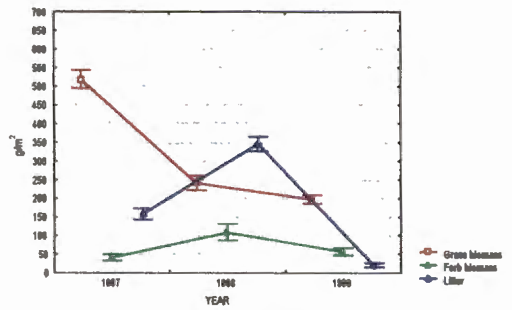

Fig. 9.1.10: Natural grassland

Figure 9.1: Change in biomass on established rehabilitated sites (Fig 9.1.5-9.1.8), newly rehabilitated sites (Fig. 9.1.9) on rehabilitated ash disposal sites and a natural grassland (Fig. 9.1.10) during 1997 until 1999 at Hendrina Power station (Whiskers indicate standard error deviation from mean value).

Table 9.1: Summary of the average biomass (standard deviation in brackets) grouped according to grass forbs and litter at the different grids on old rehabilitated ash disposal sites, newly rehabilitated ash disposal sites (NR) and a nearby natural grassland (NG) at Hendrina Power Station

	Biomass (g/m^2)								
Grid	**Grass biomass P<0.000**		**Forb biomass P<0.000**		**Litter biomass P<0.000**		Total biomass P<0.000		**N**
1	126.22	*110.18*	49.46	*68.79*	96.87	*70.92*	272.55	*155.30*	45
2	296.16	*217.06*	14.30	*24.58*	148.18	*130.52*	458.64	*237.21*	45
3	267.77	*178.15*	31.25	*51.85*	135.12	*88.44*	434.14	*186.86*	45
4	289.59	*226.46*	62.55	*100.49*	168.57	*138.90*	520.71	*286.65*	44
9	352.11	*307.49*	42.03	*49.02*	104.05	*79.76*	498.19	*337.93*	45
10	291.06	*279.47*	72.23	*66.86*	132.56	*93.65*	495.85	*300.66*	45
11	335.66	*376.42*	29.80	*52.28*	79.90	*69.48*	445.36	*421.84*	45
12	295.36	*211.46*	43.99	*42.68*	111.80	*46.90*	451.15	*218.78*	30
NG	318.44	*176.44*	68.08	*86.46*	174.30	*155.80*	560.82	*250.08*	90
NR	241.80	*207.79*	40.33	*45.53*	59.80	*44.38*	341.93	*206.69*	30

ANOVA results according to the non-parametric Kruskal Wallis test.

The only statistical significant change in biomass on grid 9 (situated on an eastern facing slope rehabilitated during 1992) was with respect to litter mass, which increased continuously during the study period (Figure 9.1.5). Grass biomass decreased during 1997-1998 but increased considerable during 1998-1999 (Figure 9.1.5). Similar types of changes in grass biomass were also experienced at grids 10 (Figure 9.1.6) and 11 (Figure 9.1.7).

Changes in forb biomass and litter mass during the three-year period were statistically significant at grid 10 (Figure 9.1.6). Both forb biomass and litter mass decreased during 1997-1998 but increased during 1998-1999. The decrease in forb biomass and litter can also be attributed to a veld fire during the winter of 1997. The high forb biomass can be due to an increase in the abundance of the legume *Chamaecrista biensis.*

Both forb biomass (nearly significant- p-value: p<0.074) and litter mass (statistically significant) increased during the three year period at grid 3 (Figure 9.1.7). As in previous grids a decrease in grass biomass occurred during 1998. Grass biomass however increased considerably during the 1999-growing season.

Biomass data was only available for the first two years on grid 12 because the area on which this grid was situated was recommissioned for further dumping of coal ash and the vegetation was therefore destroyed. During this period grass biomass showed a sharp but variable increase whereas forb biomass and litter mass remained the same (Figure 9.1.8).

Changes in grass biomass on newly rehabilitated areas was found to be statistically significant and decreased considerably during the second year but recovered during the third year of rehabilitation (Figure 9.1.9). The sharp fall in grass biomass was due to thinning of the grass cover during the second year because annual species did not regenerate and perennial species in the seed mixture were slow to establish. During 1999 perennial species has established to nearly the same productivity as during the first year. Although not significant, forb biomass decreased and litter biomass increased during the three-year period (Figure 9.1.9).

Statistically significant changes in grass, forb and litter mass were found at the nearby natural grassland. Grass biomass decreased sharply during the 1997-1998 period with a corresponding increase in litter and forb biomass (Figure 9.1.10). Litter mass however fell sharply during 1998-1999 after an intense veld fire swept through the area. Grass biomass showed a continual decrease and forb biomass also decreased during the 1998-1999 period (Figure 9.1.10). The sharp increase in litter was due to a build up of dead grass biomass and moribund tuft forming grass.

9.3.2 The relation between plant density and plant biomass

The relationship of selected plant species densities as well as overall plant density was related to plant biomass by Spearman Rank Correlations (Table 9.2). *Hyparrhenia hirta* plant densities in a vegetative (R= 0.458) and juvenile state (R=0.602) as well as total *Hyparrhenia hirta* density (R=0.528) was significantly positively correlated with grass biomass (Table 9.2). *Hyparrhenia hirta* is therefore a major contributor to grass biomass and seedling establishment is encouraged by higher grass biomass. Vegetative *Conyza* spp. plants were positively correlated to litter mass (R=0.292) but negatively correlated to grass biomass (R=-0.292) (Table 9.2). Total plant density was negatively correlated to grass biomass (R=-0.273) but positively correlated to forb biomass (R=0.260). Perennial grasses occur in lower densities but contributed most to plant biomass, therefore, the negative correlation between plant density and grass biomass. Annual forbs occur in high densities and therefore higher forb biomass will be positively correlated to higher plant density.

High litter mass was positively correlated to the density of *Conyza bonariensis* seedlings (R=0.348) and total seedling density (0.303). Results in Table 9.2 indicate that forb biomass was well correlated with the overall density of *Chamaecrista biensis* (R=0.431). Figure 9.2 illustrates the effect of *Chamaecrista biensis* on litter mass and forb biomass on areas where this species has a common occurrence. If the high density of this legume on the rehabilitated sites is considered, results indicate the important contribution i of this species to the biomass of forbs. Total *Schkuhria pinnata* (0.227) and *Aristida congesta* subsp. *congesta* (R=0.254) densities were positively correlated with forb biomass. Both the perennial grasses *Chloris gayana* and *Hyparrhenia tamba* was negatively correlated with forb biomass, which can be explained due to the large tuft size and therefore competitive nature of *Hyparrhenia tamba* on annual forb species. The forb *Cyperus esculentus*, which was often associated with degraded areas, was also negatively correlated to litter mass. The negative correlation of *Pennisetum clandestinum* with grass biomass indicated that this stoloniferous species contributed little to grass biomass production (Table 9.2).

The linear relationship between species diversity (Shannon Diversity Index values, evenness and species richness) calculated from importance data (Chapter 6) were also tested, using Spearman Rank Correlation, but no statistically significant relationship was found. Contradicting results exist if the relationship between productivity and diversity is investigated. A review by Grubb (1977) on the maintenance of species richness in plant communities indicated that a negative relationship exist between species richness and grassland productivity.

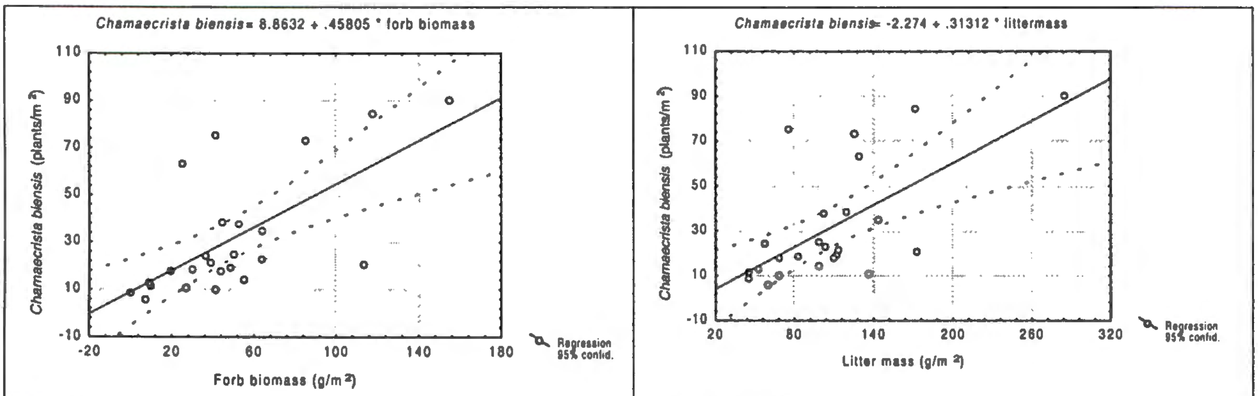

Figure 9.2.1

Figure 9.2.2

Figure 9.2: The relationship between *Chamaecrista biensis* plant density and forb (R= 0.647) (Figure 9.2.1) and litter mass (R= 0.601) (Figure 9.2.2) on the plateau of ash disposal site 3 at Hendrina Power Station.

Table 9.2: Relationship between species densities and biomass variables on rehabilitated ash disposal sites at Hendrina Power Station

Comparison	Spearman-R	p-value
1: Species densities vegetative state		
Grass biomass & *Hyparrhenia hirta*	0.458	0.000
Forb biomass & *Chloris gayana*	-0.402	0.002
Grass biomass & Total density	-0.265	0.017
Grass biomass & *Conyza* spp.	-0.298	0.027
Litter mass & *Conyza* spp.	0.292	0.031
Grass biomass & *Pennisetum clandestinum*	-0.256	0.032
2: Species densities in reproductive state		
Forb biomass & *Bidens bipinnata*	-0.510	0.003
Litter mass & *Lespedeza cuneata*	-0.291	0.028
Litter mass & *Hyparrhenia tamba*	0.278	0.040
Litter mass & *Tagetes minuta*	-0.241	0.043
Forb biomass & *Conyza canadensis*	-0.262	0.058
3: Species densities in juvenile state		
Grass biomass & *Hyparrhenia hirta*	0.602	0.000
Litter mass & *Conyza bonariensis*	0.348	0.004
Litter mass & Total	0.303	0.006
Grass biomass & *Bidens formosa*	-0.285	0.035
4: Total species density		
Grass biomass & *Hyparrhenia hirta*	0.528	0.000
Forb biomass & *Chamaecrista biensis*	0.431	0.000
Forb biomass & *Chloris gayana*	-0.361	0.001
Litter mass & *Cyperus esculentus*	-0.303	0.006
Litter mass & *Conyza bonariensis*	0.295	0.008
Grass biomass & Total density	-0.273	0.014
Forb biomass & Total density	0.260	0.019
Grass biomass & *Pennisetum clandestinum*	-0.256	0.021
Forb biomass & *Aristida congesta*	0.254	0.022
Forb biomass & *Hyparrhenia tamba*	-0.234	0.036
Forb biomass & *Schkuhria pinnata*	0.227	0.042

9.3.3 The relationship between nutrient availability and biomass production

Increase biomass was positively associated with higher levels of Boron (R=0.580, p= 0.000), iron (R=0.546, p= 0.001), ammonium (R=0.508, p=0.002) and manganese (R=0.490, p=0.003) (Table 9.3). Spearman Rank Correlations indicated that higher alkalinity (higher pH) (R=-0.598, p=0.000) and bicarbonate (R=-0.577, R= 0.000) concentrations were negatively related to grass biomass. These correlations were however not statistical significant (p>0.05) if the average grass biomass and soil chemical variables were compared (Table 9.3).

Both the 1997 forb biomass data and average forb biomass data illustrated a positive statistically significant correlation with ammonium (R> 0.5) and iron (R>0.4). Average forb biomass was also statistically significantly positively correlated with higher phosphate (R=0.458, p= 0.006) and iron (R= 0.462, p= 0.006) but negatively correlated with magnesium (R= -0.542, p=0.001), electrical conductivity (R= -0.532, p=0.001), sulphate (R= -0.519, p=0.002), and calcium (R= -0.514, p=0.002), (Table 9.3).

Percentage carbon content was the best correlated with litter mass (R= 0.385, p= 0.025). Higher alkalinity and boron were also negatively correlated with both litter mass for 1997 and average litter mass from 1997 until 1999 (Table 9.3).

Table 9.3: Statistically significant relationship between soil chemical variables and biomass of 1997 and the average biomass (1997-1999) on rehabilitated ash disposal sites including the natural grassland at Hendrina Power Station

Relationship	Spearman-R	p-level
Grass biomass		
Grass biomass & pH	-0.598	0.000
Grass biomass & Boron	0.580	0.000
Grass biomass & bicarbonate	-0.577	0.000
Grass biomass & iron	0.546	0.001
Grass biomass & ammonium	0.508	0.002
Grass biomass & manganese	0.490	0.003
Grass biomass & copper	0.364	0.034
Grass biomass & calcium	-0.353	0.041
Grass biomass & Electrical conductivity	-0.334	0.054
Average grass biomass & phosphate	-0.341	0.049
Forb biomass		
Forb biomass & ammonium	0.587	0.000
Forb biomass & iron	0.405	0.017
Average forb biomass & ammonium	0.560	0.001
Average forb biomass & magnesium	-0.542	0.001
Average forb biomass & electrical conductivity	-0.532	0.001
Average forb biomass & sulphates	-0.519	0.002
Average forb biomass & calcium	-0.514	0.002
Average forb biomass & iron	0.462	0.006
Average forb biomass & phosphate	0.458	0.006
Average forb biomass & sodium	-0.414	0.015
Average forb biomass & potassium	-0.375	0.029
Average forb biomass & zinc	0.356	0.039
Litter mass		
Litter mass & carbon content	0.385	0.025
Litter mass & boron	0.381	0.026
Litter mass & pH	-0.339	0.050
Average litter mass & pH	-0.510	0.002
Average litter mass & iron	0.414	0.015
Average litter mass & boron	0.384	0.025

9.4 DISCUSSION AND CONCLUSIONS

Although the grass biomass is variable, statistically significant results indicate that this is due to a considerably lower grass biomass on non-seeded rehabilitated areas (grid 1). Most other grids have a similar grass biomass and are also similar to the grass biomass of the natural grassland. This can be attributed to the dominant occurrence of Hyparrhenia hirta and Eragrostis curvula in the rehabilitated grassland which is both large tuft forming grass species. Forb biomass and litter mass are considerably variable between grids and between sample plots in grids. The forb biomass and litter mass show a near similar pattern between grids. Except for grid 2 the litter mass is probably influenced by the forb biomass and forb biomass considerably contributed to litter biomass. Although the grass biomass of rehabilitated areas are high they contributes little to the accumulated litter.

The biomass values on rehabilitated ash disposal sites are considerably higher than those values reported by Van Rensburg *et al.,* 1999 on ash disposal sites at Sasolburg. The change in biomass at grids show a fluctuate variation or increase in biomass over time. Due to burning on certain grids (for example grid 2, 3 and 10) the measured annual biomass can be considered the net primary productivity for that growing season.

Results indicate that fire did not have a negative impact on the grass biomass of the rehabilitated areas but it influenced the annual amount of litter on rehabilitated ash disposal sites. This, therefore, strengthens the suggestion that the population dynamics of *Hyparrhenia hirta* is enhanced by regular fire at the expense of other species (Chapter 8). Changes in grass biomass in the natural grassland are, however, more complicated. Grass biomass is highly influenced by a build-up of litter mass which resulted in an appreciable decrease in grass biomass and increase in forb biomass (February 1998). The veld fire during 1998 destroyed the litter but did not result in an increase in the grass biomass afterwards.

A characteristic of biomass on rehabilitated areas is the high variance in the standard error and standard deviation in comparison to the natural grassland, which had a very small standard error. This indicated that the community structure of rehabilitated areas is far more heterogeneous than the natural grassland, which had a homogenous, stable community structure consisting primarily of short grass species.

Grass biomass is influenced by the density of *Hyparrhenia hirta* and especially by higher densities of vegetative *Hyparrhenia hirta* plants. The density of *Eragrostis* spp. does not, according to results, influence grass biomass. The negative correlation between grass biomass and the density of *Pennisetum clandestinum* can be explained by the low biomass of *Pennisetum clandestinum* which negatively influenced biomass production. *Pennisetum clandestinum* can also be negatively affected by increase biomass due to competition from the other competitive grass species. The legume *Chamaecrista biensis* also contributed the most to forb biomass and where this legume was dominant it also resulted in an increase in the litter production. Biomass production did not have any significant relationship with species diversity. Al-mufti *et al.* (1977) indicated that biomass production might have a quadratic relationship with species richness. The possible effect of biomass on plant competition must also be considered. Bonser & Reader (1995) found a non-linear positive relationship between competition and biomass. Biomass-dependency of competition is, however, more likely to be found in vegetation with low to medium biomass values. The effect of biomass increase on competition due to an increase in the density of large perennial grasses will only be a significant effect in vegetation with low to medium biomass. Further biomass increases beyond a certain value will have a lesser impact on competitiveness because competition should reach a maximum. The density dependence of the species on the biomass production was difficult to assess because the density of *Hyparrhenia hirta* positively influenced biomass.

The level of ammonium in the soil influenced biomass of grass and forb biomass positively. Nitrogen was found to be the most limiting factor in the influence of nutrient availability on community dynamics (Tilman, 1984 and McLendon & Redente, 1991). Results in Chapter 8 of this thesis indicated the relationship between soil ammonium and the density of legume species, especially *Chamaecrista biensis*. According to a study by Vermeer & Berendse (1983), in a series of four Netherlands grasslands, a positive correlation between ammonium and shoot biomass existed. Species richness, however, correlates negatively with shoot biomass. Fertilisation of grasslands in South Africa was found to influence biomass production (biomass increased under low levels of application), and species composition (an increase in pioneer grass and weed species and decrease in climax species with higher application of nitrogen fertilisers) (Grunow *et al.*, 1970 and Edwards & Nel, 1973).

Important aspects that came forth in the study are the significant influence of specific species on biomass production. Furthermore the standing biomass on rehabilitated sites may not also always be lower than the biomass of the natural grassland but are more variable. Critical soil chemical factors that can have a negative effect on biomass according to this study are alkalinity, salinity and bicarbonate concentrations. Ammonium and iron availability are found to be limiting factors for stimulating biomass production of both forbs and grasses.

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Chapter 10 ECOLOGICAL STATES AND TRANSITIONS ON ASH DISPOSAL SITES AT HENDRINA POWER STATION

Abstract: General trends in the vegetation dynamics on ash disposal areas are summarised in a state and transition model. Nine states with 17 transitions are recognised. Four possible endpoints are described based on the population dynamics of *Hyparrhenia hirta, Eragrostis* spp. and *Pennisetum clandestinum.* The fourth endpoint is an *Acacia mearnsii* Woodland. Transitions are based on the effect of fire, *Tatera brantsii* infestations, management, moisture conditions and secondary succession due to habitat improvement. The proposed state and transition model also relates transitions to the ability of the rehabilitated vegetation to overcome environmental constraints in order to progress to the following seral stage. A degree of directionality therefore exists, which is illustrated by the use of phases in the model. The model proposed, however, a number of major and minor thresholds in the community dynamics of ash disposal areas.

The importance of the model as a hypothesis-generating tool is indicated. Experimental studies and long-term monitoring must ultimately be conducted to test the validity of the model.

CONTENTS

10.1 INTRODUCTION

Different hypothesis and theories exist to describe vegetation change (succession). The oldest and most accepted view of succession is that of Clements (1936) who proposed that succession is a process of vegetation change through a number of intermediate stages (seral stages) to form climax vegetation. This early formulation of succession theory predicted that certain species modify their habitat in such a manner that it is less fit for themselves and more so for certain other species. Contemporary theories (Tansley, 1935 and Whalley, 1994) are, however, based on the assumption that a number of stable climaxes can exist in a climatic region (poli-climax theory).

Connel and Slatyer (1977) proposed that the process of succession can be incorporated into three alternative models, namely facilitation, inhibition and tolerance. In the **facilitation model** pioneer species or species in earlier seral stages improve the environment for the establishment of species in succeeding seral stages. This model can be related to the process of relay floristics of the Clementsian model (Pickett *et al.*, 1987). The **inhibition model** suggested that initial invaders regulate succession and prevent the establishment of other species (Connell & Slatyer, 1977). In the **tolerance model,** floristic changes may be a function of different life history characteristics. Species that appear later during succession, therefore, arrived either at the beginning or at later stages of succession. The establishment of species is determined by their tolerance to changing environmental conditions (Connell & Slatyer, 1977).

Due to the inherent instability of vegetation, the application of a stable climax theory is unattainable in many ecosystems. One of the most recent developments towards the explanation of ecosystem change is the theory of non-equilibrium ecology. Non-equilibrium ecology is based on the principles of multiple ecosystem attributes such as resistance, resilience, temporal thresholds and feedback loops and how they affect vegetation change (Brown, 1994). Successional patterns are seen as complex systems with spatial and temporal variation, historical effects and stochastic dispersal of plant propagules. The principles of the non-equilibrium ecology theory can also be applied further to models predicting certain states and transitions in vegetation (Westoby *et al.*, 1989 and Brown, 1994). An important aspect of the state, and transition model is the existence of definite thresholds (Laylock, 1991) in transitions between states and is explained in context of the "ball and cup" theory (Laylock, 1991 and Melvin *et al.*, 1992). In this context, a plant community contains a certain resistance (ability of an ecosystem to absorb change (Begon *et al.*, 1990)) and resilience (ability of an ecosystem to regain its original state (Begon *et al.*, 1990)) to pass through a threshold from one state to the next. In general, once a threshold is passed it is difficult to return to the original state (Brown, 1994).

Non-equilibrium ecology, the concept of the threshold and the application of state and transition models have become excepted ways of managing rangeland from an ecological viewpoint (Westoby *et al.*, 1989, Friedel, 1991, Melvin *et al.*, 1992, Whalley, 1994, Orr *et al.*, 1994 and Brown, 1994). Rodriguez Iglesias and Kothman (1997) also provided a summary of twenty-nine applications of the state and transition model and their structures and causes (environmental factors that were ascribed to transitions).

The state and transition concept has, however, found little acceptance outside rangeland ecology as a way to predicting change, and as a theory for successional change in plant communities. This concept was recognised three decades ago by Roux (1969) who emphasised the principle of multiple states and non-equilibrium ecology that existed in grassland on the South African Highveld through the following quote Van Rensburg (as quoted by Roux, 1969):

> "Succession cannot be regarded as a process where one define phase will forever and always give way to the next at a certain stage, and the development does not always take place along definite lines or during fixed periods of time".

This chapter attempts to catalogue the alternative vegetation states and transitions between states, occurring on ash disposal sites with different rehabilitation histories, and to relate this to ecological states in plant communities situated near the study area and to other available information. It is also the aim of the proposed state and transition model to summarise all relevant information regarding the successional patterns, community development and environmental factors influencing succession on the ash disposal sites at Hendrina Power Station.

10.1.1 Components of a State and Transition model

As indicated by the name, state and transition models consist of a number of stable states (domains) characterised by specific key species and community attributes. States are divided by transitions related to certain events (e.g. fire, drought), management practices (fertilisation, man made disturbance) or community driven factors (inhibition, facilitation and tolerance mechanism (Connel & Slatyer, 1977)). Transitions are related to thresholds that must be passed for a system to move from one state to another (Laycock, 1991). A model may also consist of a number of transient states (Westoby *et* al., 1989) from which one stable state changes to another stable state, and suspended stages in which rangelands may persist for long periods.

10.1.1.1 Identification of states

Phytosociological studies (Chapter 3) and cluster analyses (Chapter 5) were used to identify homogenous groups, which can be regarded as possible states, that change over time. To validate our observations regarding the existence of different states the results from actual surveys were used to describe the vegetation composition of states.

10.1.1.2 Identification of transitions and thresholds

Monitoring of rangeland or rehabilitated grasslands may be best served by focussing on the identification of thresholds. Thresholds can be detected by the identification of discontinuities in the relationships between sites, species composition and production (Friedel, 1991). Important methods for achieving this are multivariate ordination techniques by which major elements in ordination space can be identified (Friedel, 1991). Multivariate techniques based on Detrended Correspondence Analysis (DCA), Redundancy Analysis (RDA) and Canonical Correspondence Analysis (CCA) ordination procedures were principal data analysis methods, used during the study to determine changes and trajectories of change (Chapter 4) in the data suites. These multivariate techniques also assisted in the explanation of environmental factors (Chapter 8) which caused transitions in the vegetation.

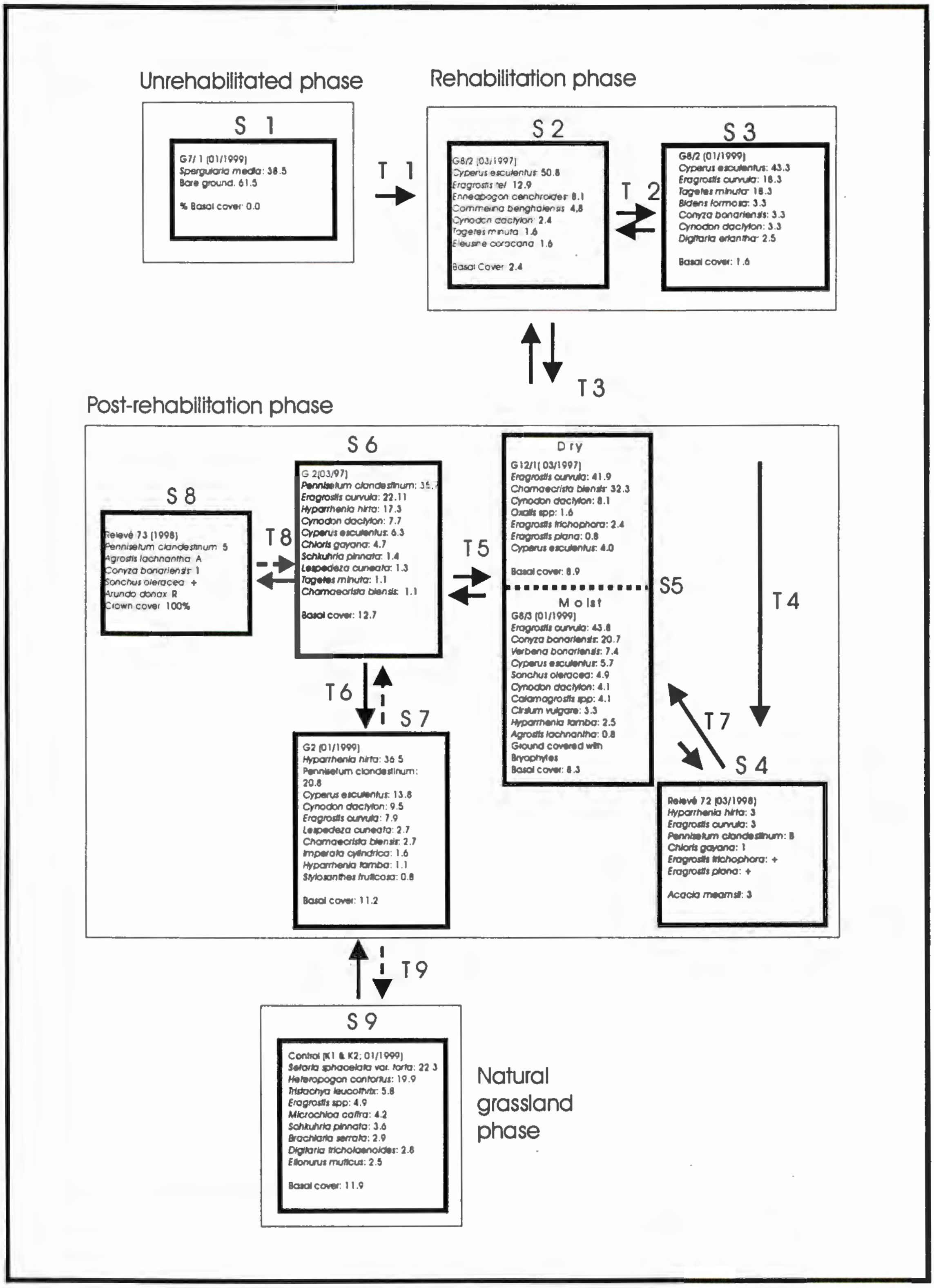

Figure 10.1: Flow diagram indicating states (S) and Transitions (T) and how they are related according to a proposed State and Transition Model of rehabilitated ash disposal areas at Hendrina Power Station.

10.2 STATE AND TRANSITION MODEL

A flow diagram indicating how states and transitions are related is given in Figure 10.1. States and transitions were also related to different phases of rehabilitation. Four phases were recognised, namely an Unrehabilitated phase, Rehabilitation phase, Post-rehabilitation phase and Natural grassland phase.

Catalogue of States

Unrehabilitated phase

State 1(S1):

The pioneer state on unrehabilitated ash disposal areas consists of the halophyte *Spergularia media.* These areas also have a high percentage of bare ground (61.5%). After sufficient ageing of ash *Chenopodium album* also started colonising these areas, especially where ash was not compacted. Vegetation cover is characteristically very low. This state was described as the *Spergularia media* Community (3) in the phytosociological study (Chapter 3).

Vegetation along transects 1 of grids 7 and 8 were found to be in State 1 (Chapter 2, Table 2.4).

Rehabilitation phase

The rehabilitation phase can be described as part of the *Amaranthus hybridus–Cyperus esculentus* Sub-community (2.2) and in particularly the *Eragrostis tef-Enneapogon cenchroides* Variant (2.2.3). If a state in the post-rehabilitated phase is severely disturbed it may revert back to the rehabilitation phase due to the invasion of annual forbs. This situation were described in the *Portulaca oleracea-Bidens formosa* variant (2.2.1).

State 2(S2):

This state can be considered a pioneer state consisting of ruderal vegetation. State 2 is characterised by a high frequency of annual forbs for example *Cyperus esculentus, Amaranthus hybridus, Datura stramonium,* the annual grass *Eleusine coracana* subsp. *africana* and annual grass species (*Eragrostis tef, Enneapogon cenchroides*) which were included in the seed mixture. Although crown cover is

Catalogue of Transitions

Transition 1 (T1)

The transition represents the rehabilitation of the ash disposal areas. A viable seed bank is added and nutrient deficiencies are corrected. Transition 1 represents the first major threshold in the state and transition model. Derelict land would take considerably longer to be colonised naturally by vegetation. By adding a seed bank by overseeding and nutrients, to improve the substrate, the threshold is overcome and the ecosystem is enhanced to a similar state as vegetation during secondary succession. A transition to the previous state (State 1) is not foreseen, except if raw ash is again deposited on top of the rehabilitated grassland.

Transition 2 (T2)

The second transition indicates the shift in vegetation composition from the first to the second step in the rehabilitation program during which annual grasses that were used as a nursing crop are replaced by perennial grass species. The annual species used may also be regarded as pioneer species, which facilitate the establishment of perennial species by being a nursery crop for seedlings and improvement of the habitat by increasing the organic content of the substrate (Jones *et al.*, 1975). This stage can therefore be associated with the facilitation model proposed by Connel and Slatyer (1977).

If perennial grass species fail to germinate due to adverse growth conditions, the vegetation will remain in State 2. Adverse conditions may include phytotoxic higher than 45% the basal cover is low (<3%).

State 3 (S3): Ruderal vegetation still dominates this state. The vegetation consists, however, of both a perennial grass and annual grass-forb component. *Eragrostis* spp. are the most dominant perennial grass species. Other perennial grass species from the seed mixture would also have colonised. A vegetation cover consisting of stoloniferous grasses (*Cynodon dactylon*, other *Cynodon* spp. and *Pennisetum clandestinum*) could have developed. *Cyperus esculentus* and *Tagetes minuta* are the dominant forbs. The basal cover remains low (<3%). A decrease in the crown cover may occur from State 2 to State 3. According to estimated values from phytosociological studies the crown cover were approximately 45-50%.

levels of nutrients, very high pH or saline conditions, or drought.

Post-rehabilitation phase

Vegetation in a post rehabilitation phase can be classified as part of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1) (see Chapter 3).

State 4 (S4): This state is a woodland community consisting of the exotic tree *Acacia mearnsii* and .was described in the phytosociological study as part of the *Acacia mearnsii* Sub-variant (2.1.2.2) (Chapter 3). The ground layer is dominated by perennial grasses such as *Eragrostis curvula* (dominant), *Hyparrhenia hirta* and stoloniferous grasses. The grass ward is in a healthy condition with a high crown (95%).

State 5 (S5): Although *Eragrostis curvula* was dominant in both the dry and most conditions, State 5 of drier environments and State 5 of higher moisture environments differ in the species that were associated with *Eragrostis curvula.*

State 5 (S5) (Moist environment): *Eragrostis curvula* is the dominant grass (frequency>40%). Forbs (*Verbena bonariensis, Cirsium vulgare, Sonchus* spp.) and grasses (*Imperata cylindrica* and *Agrostis lachnantha*) with a preference for moist environments have a high frequency. The growth medium also has a high percentage cover of bryophytes.

State 5 (S5) ((Dry environment):

Eragrostis curvula is the dominant grass species (frequency>40%). Other perennial grasses may include *Eragrostis chloromelas, Eragrostis trichophora, Eragrostis lehmanniana, Eragrostis plana* and *Digitaria eriantha.* These species were more associated with drier conditions. Due to the dense cover of *Eragrostis* spp. the cover and diversity of annual forbs may be low. Annual forbs consist of Conyza spp., *Pseudognaphalium* spp., *Chamaecrista*

Transition 3 (T3)

Ordination results and phytosociological studies also indicated this as a major threshold. If rehabilitation was not conducted correctly, the transition between the pioneer states (S2 and S3) and the development of a dominant perennial grass sward, will be retarded. This is probably more important for rehabilitated areas on slopes. The seed mixture may be washed away or topsoil can be eroded and this could mean a significant setback for the establishment of a stable vegetation cover and retrogressive succession towards state S2 or S3 can take place. Adverse soil chemical and physical conditions as described in Chapter 8 may also influence the transition from State S3 to State S5.

Large-scale disturbances may also convert the perennial grass sward of old rehabilitated ash disposal sites back to a ruderal stage as indicated by States 2 and 3. Examples of this exist on ash disposal site 3 where domestic refuse was dumped (Chapter 3).

Observations on areas heavily infested with *Tatera brantsii* indicated that retrogressive succession succession to state S3 might be possible.

Transition 4 (T4)

This transition indicates a trajectory of succession towards Acacia *mearnsii* Woodlands. The establishment of woodlands is probably due to a viable seedbank of *Acacia mearnsii* in the topsoil that was used.

Transition 5 (T5)

A dense cover of *Eragrostis* spp. (especially *E. curvula*) may inhibit the establishment of *Hyparrhenia hirta*, but after regular occurrence of fire and the invasion of

[1] The relation between State 6 and State 7 and Transition 6 was included to illustrate a tendency in the community dynamics observed at Hendrina Power Station. A site on which *Hyparrhenia hirta* would have been totally dominant with a low frequency of other perennial grasses would have been a better example of this state (for example transect 3 of grid 7; Chapter 2, Table 2.4). It was ,however, decided to use a site over a sequence of three years to illustrate the change in composition.

biensis and *Oxalis* spp. Outbreaks of *Conyza bonariensis* and *Chamaecrista biensis* may occur as was found in our study. *Cynodon dactylon* can also be an important component of the vegetation composition.

Grids 4, 12 and the bottom transect of grid 8 were found to be in this state (Chapter 2, Table 2.4). The vegetation of the first two grids were typical of the dry environment of State 5, whereas the bottom transect of grid 8 was typical of the moist environment of State 5.

State 6 (S6): [1]
State 6 represents a transitional state between *Eragrostis* spp. (such as *E. curvula*) dominated grassland and *Hyparrhenia hirta* dominated grassland. *Eragrostis* spp. and *Hyparrhenia hirta* occurred in equal proportions. The crown cover of the grass sward is in many cases lower than in State 5, which may be evident by an increase in the percentage bare ground. The basal cover, however, remains high due to the presence of large tuft-forming species. The vigour of *Eragrostis* spp. decrease and plants become moribund and in some cases break into smaller tufts or die. Grid 2 (Chapter 2, Table 2.4) which also has a high percentage of *Pennisetum clandestinum,* is used as an example.

State 7 (S7):
Hyparrhenia hirta is the dominant tufted grass and may have frequencies of over 80% (as was the case along transect 3 of grid 7 (Chapter 2, Table 2.4)). Stoloniferous grasses, for example *Cynodon dactylon* and *Pennisetum clandestinum,* may be common. A large diversity of *forbs (Bidens formosa, Conyza bonariensis, Chamaecrista biensis, Stylosanthes fruticosa, Vigna vexillata* and *Pseudognaphalium* spp.) and other grasses (*Setaria pallide-fusca, Melinis repens, Eragrostis plana, Chloris gayana, Hyparrhenia tamba* and *Pogonarthria squarrosa*) may be present, but they rarely occur with high frequencies. *Eragrostis* spp. is seldom totally absent.

The existence of this state is evident in the results of the cluster analyses conducted in Chapter 5. It was concluded that vegetation could be divided on the basis of the dominance of *Hyparrhenia hirta* and *Eragrostis* spp. in the populations of *Tatera brantsii,* the cover and vigour of *Eragrostis* spp. decrease and the establishment of *Hyparrhenia hirta* is favoured. Disturbance reduces the competitive abilities of established plant species and facilitates the seedling recruitment of *Hyparrhenia hirta,* which may result in an increase in the frequency of *Hyparrhenia hirta.* The increase in the importance values of *Hyparrhenia hirta* in relation to *Eragrostis* spp. were commonly observed on many rehabilitated areas on ash disposal sites at Hendrina Power Station (Chapter 6). The important effect of fire and *Tatera brantsii* infestations on the vegetation composition was shown in Figure 8.10 (Chapter 8) and by Van Hamburg (1999). Roux (1969), however, stated that an increase in *Hyparrhenia hirta* is part of the natural process of secondary succession. The transition from *Eragrostis-Cynodon* Grassland to a *Hyparrhenia hirta* dominated grassland may also be due to a loss of soil fertility (Roux, 1969).

According to Roux, (1969), an increase in fertility may reverse a *Hyparrhenia hirta* grassland back to *Eragrostis* spp. grassland. A shift in condition, which favours *Eragrostis* spp., may temporally halt or slow down the increase of *Hyparrhenia hirta* dominated grassland. *Eragrostis* spp. is therefore the decreaser in this system. The continuous transition toward *Hyparrhenia hirta* dominated grassland is, however, more likely as was indicated by several authors (Roux, 1969; Bredenkamp, 1975; Thatcher, 1979; Smit, 1992 and Cilliers, 1998). Figure 8.2 indicated that higher salinity and probably higher levels of Ca, K, Mg or Na may favour the establishment of a *Eragrostis* spp. dominated grassland. Higher fertility due to higher levels of ammonium can be responsible for a shift in the trajectory of development from an *Eragrostis* spp. dominated, to *Hyparrhenia hirta* dominated grassland.

Transition 6 (T6)
Transition 6 indicates the threshold from *Eragrostis* dominated grassland to *Hyparrhenia hirta* dominated grassland. Continuous burning and disturbance by *Tatera brantsii* may also be less damaging to a *Hyparrhenia hirta* population. The effect on vegetation

vegetation. Grids 2,3,9, 10 and 11 (Chapter 2, Table 2.4) were in State 6, or are in a process of developing into State 7. The only site that was convincingly in State 7 was transect 3 of grid 7. Surveys conducted in road verges in the vicinity of the ash disposal sites also indicated that these areas could be ascribed to State 7 (average frequency of *Hyparrhenia hirta*: 45%.) (Chapter 10, Section 10.3.1.3).

State 8 (S8):

Vegetation cover is dominated by *Pennisetum clandestinum.* Species preferring moist to wetland condition such as *Agrostis lachnantha, Sonchus oleraceus* and *Arundo donax* have relative high cover abundance values. The crown cover of the vegetation is 100%. No formal community was described for this vegetation type.

A community that can be associated with State 8 is the *Panicum maximum-Digitaria eriantha* variant (2.2.2) (Chapter 3) that was associated with high moisture conditions in a drainage channel on the slopes of the ash disposal sites. This variant was characterised by a high cover abundance of the species, *Pennisetum clandestinum, Cyperus esculentus* and a lush growth of *Panicum maximum* and *Digitaria eriantha.*

composition of both these influences has been documented in Chapter 8. *Pennisetum clandestinum* may also be negatively affected by regular fire occurrence. An increase in legumes is also experienced during the first or second season after burning. To illustrate this a sequence of surveys on grid 2 was used (Chapter 2, Table 2.4; see also Chapter 6, Figures 6.3 and 6.4)

The succession of the grassland back to an *Eragrostis* spp. dominated grassland is very unlikely, due to the dominant and competitive nature of *Hyparrhenia hirta.* Certain conditions will have to prevail to negatively affect the further establishment of *Hyparrhenia hirta.* As already indicated in Transition 5, a possible effect is eutrophication of the growth medium.

Transition 7 (T7)

The effect of burning on *Acacia meamsii* woodland on ash disposal sites was also recorded. Burning severely effects the establishment of these woodlands. The woodland areas are normally converted into grasslands.

It is, however, unknown if regeneration of the seed bank occurs and if left unburned if the *Acacia meamsii* woodlands will expand. This state will only sustain if a viable seed bank remains and if burning is controlled. Little is known regarding the dynamics of the *Acacia mearnsii* population on the ash disposal sites and what, except for fire, will control their establishment.

Transition 8 (T8)

An increase in moisture conditions result in an increase in the stoloniferous grass *Pennisetum clandestinum.* This can be observed in areas where sludge and waste water is pumped unto the dams. Vegetation preferring permanent water saturated condition increase at the expense of vegetation preferring well-drained conditions. Decrease of tuft forming grasses is also probably due to the formation of a dense and thick layer of *Pennisetum clandestinum.* The use of *Pennisetum clandestinum* sods during the rehabilitation process is a prerequisite for the occurrence of this transition.

A reversal of the condition will probably follow if the area is drained. Whether the vegetation will immediately return to State 6 or 5 is unknown.

Natural grassland phase

State 9 (S9):

Setaria sphacelata, Heteropogon contortus and *Tristachya leucothrix* are the dominant grasses. Species diversity is particularly high due to the occurrence of a large number of perennial forbs. Large tuft-forming grass species have lower frequencies than was encountered in state 7, but may be present. This can include *Hyparrhenia hirta, Trachypogon spicatus, Urelytrum argropyroides* and *Andropogon schirensis.* State 9 is represented in the phytosociological study (Chapter 3) as the *Brachiaria serrata-Setaria sphacelata* Community (1).

Transition 9 (T9)

The trajectory of vegetation community development on ash disposal sites is unknown. It is, however, speculated that, as in the case of old fields, vegetation of ash disposal sites will develop into so called purple veld consisting of *Heteropogon contortus, Themeda triandra, Tristachya leucothrix* and *Andropogon schirensis* (Roux, 1969). Grassland ecologists in South Africa, however, believe that the secondary "climax" vegetation on the Highveld is a *Hyparrhenia hirta* dominated grassland (Roux, 1969; Bredenkamp, 1975; Thatcher, 1979; Smit, 1992 and Cilliers, 1998).

10.3 DISCUSSION AND CONCLUSIONS

The proposed state and transition model for the rehabilitated ash disposal sites at Hendrina Power Station indicates four possible end points. The first two end points are related to the population dynamics of *Hyparrhenia hirta* and *Eragrostis* spp. on ash disposal areas (State 5 and 7). The third end point assumes the initial use of *Pennisetum clandestinum* during remediation (State 8). The fourth end point is related to the development of an *Acacia mearnsii* Woodland due to the occurrence of a viable seed bank in the topsoil (State 4). The effect of treatment was also an important factor, but it was attempted to look beyond the effect of treatment and find universal trends in the vegetation dynamics of rehabilitated vegetation.

The problem of applying the non-equilibrium theory on developing ecosystems such as rehabilitated ash disposal areas, is that a certain degree of directionality exists in the successional patterns of these areas. A number of thresholds (transitions) in the proposed state and transition model were therefore related to the ability of the rehabilitated vegetation to overcome environmental constraints in order to progress to the following seral stage. A closed system of states and transitions is therefore not possible in this study.

The application of the state and transition model in predicting states and transitions in a developing ecosystem was, however, found to be informative to indicate how environmental conditions and management options influenced plant community development. Transitions are based on the effect of fire, *Tatera brantsii* infestations, management, moisture conditions and secondary succession due to habitat improvement. The proposed model predicted fire and managed-induced changes, as well as changes brought about by secondary succession, as the most important processes governing the establishment of plant communities on ash disposal sites.

Most ecologists monitor plant species composition to a hypothetical climax. Monitoring change in species composition in relation to assumed climax might however be misleading (Brown, 1994). As already indicated by Morgenthal *et al.* (1999), using a hypothetical climax as a benchmark is also not compatible during monitoring of rehabilitated areas. The state and transition model therefore provides an alternative way under the ideology of non-equilibrium ecology.

Proposed mechanisms for transitions between states are, however, hypothetical rather than empirical (Milton & Hoffman, 1994). The final test is to follow monitoring locations through time (Friedel, 1991) to determine if theories relating to the vegetation dynamics is consistent with the state and transition model. Experimental studies and long-term monitoring are therefore necessary to test the existence of these states and transitions. Testing of the model will also increase the level of accuracy. Rejection of hypotheses relating to states and transitions should lead to further hypotheses generation (Milton & Hoffman, 1994). A state and transition model may, therefore, be regarded as a hypothesis-generating tool by which certain hypothesis can be tested and new ones created. A model can be incorporated into the management scheme, due to its ability to predict possible changes and to assist managers in making informed choices.

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Chapter 11 A PROPOSED CONDITION ASSESSMENT MODEL FOR REHABILITATED ASH DISPOSAL SITES

Abstract: Rehabilitation with vegetation is essentially an ecological problem. One of the important aspects of rehabilitation is the development of a stable and sustainable ecosystem, which is characterised by the establishment of perennial species. The ability of these species to establish are ultimately dependent on the prevailing environmental conditions. To determine if vegetation has successfully established it must be measured against some known conditions and benchmarks. It was the aim of this chapter to use species data to develop condition assessment models based on known successional gradients. Species, however, do not occur consistently at each site. A number of community attributes are therefore also investigated on which a condition model can be based.

The ISPD and CANOCO computer programs are used to analyse data and develop models. The condition assessment models are, therefore, based on multivariate ordination results. Species frequency data, percentage bare ground (winter), percentage basal cover, Shannon Diversity Indices, species richness and evenness are used for the ecological interpretation of these condition assessment models.

Two models based on species composition are presented with the newly rehabilitated sites and road verge vegetation as benchmarks in these models. These models simulate the changes in species composition along successional gradients with Gaussian response curves. A third model with community attributes incorporating the natural grassland sites, road verges and rehabilitated sites of variable ages are also presented. The model based on *Hyparrhenia hirta* and *Cyperus* spp. proved useful as species based model to indicate the condition on ash disposal sites at Hendrina Power Station. Due to the universal nature of the community attribute models it can probably be used for most rehabilitated areas on the Highveld of South Africa. These three models can be used in future in an integrated system for the condition assessment of ash disposal sites. It is proposed that condition assessment models for ash disposal sites at other power stations should also be developed to portray the specific species composition and site specific conditions of these other ash disposal sites.

CONTENTS

11.1 INTRODUCTION

The ultimate aim of every rehabilitation program is to provide a sustainable landscape (Fox & Tacey, 1994). Rehabilitation is therefore essentially an ecological problem (Bradshaw, 1996) and is a critical test of the understanding of the ecological principles that rule disturbed ecosystems (Jordan, *et al.* 1996). The question must, however, be asked what promotes and enables the self-sustainability in an ecosystem. This can possibly be answered by observing community attributes of ecosystems during progressive stages of succession. According to Barbour *et al.* (1987), vegetation of later stages of succession can be characterised by high plant species diversity, species with predominantly K-selected life history characteristics, large amounts of biomass and a lack of change (Equilibrium State). Vegetation during earlier stages of succession consists predominately of annuals that are r-selected, with short life history patterns and that occur in unpredicted habitats. Increasing environmental stability facilitates the replacement of annual ruderal species by competitive perennial species (Robinson, 1994). Succession during community development is, therefore, characterised by the constant arrival of competitive colonisers (Hulst, 1978). The ability of new colonisers to establish themselves will be highly dependent on the prevailing habitat conditions and the adaptability of colonisers to these conditions (Bradshaw, 1983, Hulst, 1978). Successional theory predicts that longer-living species will accumulate over time (Hulst, 1978). To determine if progressive ecosystem development is taking place in an area, it is imperative to assess if the theory of succession applies (Smyth, 1997 and Fox & Tacey, 1994). Except for sustainability, Ewel (1987) also proposed the use of invasibility of species, ecosystem production, nutrient retention capability and the existence of key species, to ensure biotic interactions as criteria for assessing rehabilitation success.

The most commonly employed method for assessment of rehabilitation success is the comparison of the vegetation composition between reconstructed communities and the original community (Ewel, 1987). Comparison of the community attributes of the previous climax vegetation states to the attributes of the present vegetation states, therefore, provides a practical solution to the problem of assessing ecosystem sustainability. Known successional stages in the vegetation can be used as benchmarks to assess community sustainability (Wilson, 1984). The problem of using climax vegetation as a benchmark is that it is not always the most desirable condition and it is also difficult to identify the proper climax state for rangeland management (Friedel, 1991).

Results from Morgenthal *et al* (1999) already indicated that the use of nearby natural grasslands as benchmarks in the assessment of rehabilitation success is not compatible due to the large differences in the species composition and habitat between the two regions. It was therefore decided to conduct three additional surveys on road verges in the vicinity of the ash disposal site during the summer of 1999. Although road verges have different disturbances regimes in comparison to ash disposal sites, it is a habitat that is comparable with rehabilitated sites at Hendrina Power Stations because both are dominated by *Hyparrhenia hirta*. Plant community studies by Cilliers (1998) on road verges in the Potchefstroom urban area described the *Hyparrhenia hirta* Community and regarded it as the most successionally advanced stage along the road verges that were studied. Previous studies also indicated that *Hyparrhenia hirta* dominated communities are seldom replaced by the former, natural climax community due to the persistence of *Hyparrhenia hirta* in the grass sward (Cilliers, 1998; Smit, 1992; Roux, 1969 and Bredenkamp, 1975). Grassland communities in which *Hyparrhenia hirta* dominates can therefore probably be regarded as the climax stage during secondary succession of severely disturbed grassland in the Grassland Biome.

No guidelines for the assessment of the sustainability and rehabilitation success are provided by mining legislation in South Africa. The quality of reclaimed mine land in the USA is judged by the percentage ground cover. Reclamation success for bond release is determined by achieving a certain amount of vegetation cover (Holl & Cairns, 1994).

The aims of this chapter were therefore the development of condition assessment models based on identified benchmarks, to determine critical attributes for the assessment of rehabilitation success for ash disposal areas at Hendrina Power Station, with possible application to other, similar sites, and to ecologically assess the established vegetation after rehabilitation by application of these models.

11.2 MATERIALS AND METHODS

11.2.1 Model development

Frequency data, obtained by recording the nearest plant to the sample point during descending point surveys from the 1997, 1998 and 1999 summer seasons were used. Frequency surveys were conducted along three transects at twelve permanently marked grids. The first transects from grids 7 and 8 were excluded from the data sets because they were situated on unrehabilitated ash sites and were, therefore, not applicable to this chapter. Frequency surveys conducted once annually from 1997 to 1999, as well as three frequency surveys along road verges during the summer of 1999 were used.

The condition assessment module in the ISPD (Integrated System for Plant Dynamics) computer package (Bosch *et al.*, 1992) was used in the construction of a condition assessment model based on multivariate ordination procedures. The ISPD computer package was developed as a decision support system (DSS) for the condition assessment of rangeland

(Bosch *et al.*, 1992). The use of multivariate ordination procedures is a useful way to compare monitoring points, consisting of numerous species, with each other (Friedel, 1991). Ordinations summarise data redundancy by placing similar entities in proximity in terms of a few gradients in community composition (Gauch 1982). A low dimensional ordination space is created in which similar species and samples are situated close together and dissimilar entities far apart.

The ISPD computer package facilitates the construction of a condition assessment model. An ordination module consisting of a number of ordination procedures enables the user to construct a condition assessment gradient (degradation gradient) by refinement and manipulation of the data set through the removal of outliers and reduction of noise in the data set. The final condition assessment model is then constructed based on PCA (Principal Component Analysis) or RA (Reciprocal Averaging) ordination procedures. The condition assessment model is, therefore, an ordination diagram of which the first axis represents a degradation or condition assessment gradient, from a well managed condition to a poorly managed condition, from left to right in the ordination graph The condition assessment module was developed for rangeland scientist to predict the grazing potential of the veld and therefore has a range between 115% (under utilised) to 0% (over utilised). Second and higher axes are combined into a single value, namely the residual value. Residual values less than 50% of the Euclidean length of the first axis are preferred, since this value amounts to the percentage of variation in the data set that is unexplained by the model. Sample points with a residual length of more than 50% are therefore, discarded because they do not provide a goodness of fit in the ordination model (Bosch & Gauch, 1991).

The applicability of the models constructed were verified by surveys conducted at the Kragbron Power Station in February 1997 (Van Hamburg *et al.*, 1997).

11.2.2 Identification of community attributes for the assessment of rehabilitation success on rehabilitated ash disposal sites

The CANOCO computer program (Ter Braak, 1987-1992) was used for data analysis of community attributes. Percentage bare ground, total basal cover, biomass, plant frequencies grouped according to growth form and physiognomy and species diversity were used as community attributes. The percentage bare ground was obtained from frequency surveys conducted during the winter seasons of 1997 and 1998. The percentage basal cover was calculated from the number of basal hits during frequency surveys conducted during the summers of 1997, 1998 and 1999. Species were grouped into 11 classes, which included annual Asteraceae, perennial Asteraceae, other annual forbs, other perennial forbs, legume species (Fabaceae), geophytes, trees, shrubs, perennial grasses, annual grasses and stoloniferous grasses. Species were grouped according to their growth form (trees, shrubs and herbaceous species). Herbaceous species were further divided according to the three largest families, Asteraceae, Fabaceae (legumes) and Poaceae with the rest of the herbaceous species grouped as other forbs. Species of the Poaceae were further divided into perennial grasses, annual grasses and stoloniferous grasses. Species of the Asteraceae were also distinguished according to whether they were perennial or annual. Shannon Diversity Index values, evenness and species richness were calculated from importance values (sum of the relative frequency, relative basal cover and relative density, see Chapter 7).

11.3 RESULTS AND DISCUSSION

11.3.1 Condition assessment model of species data

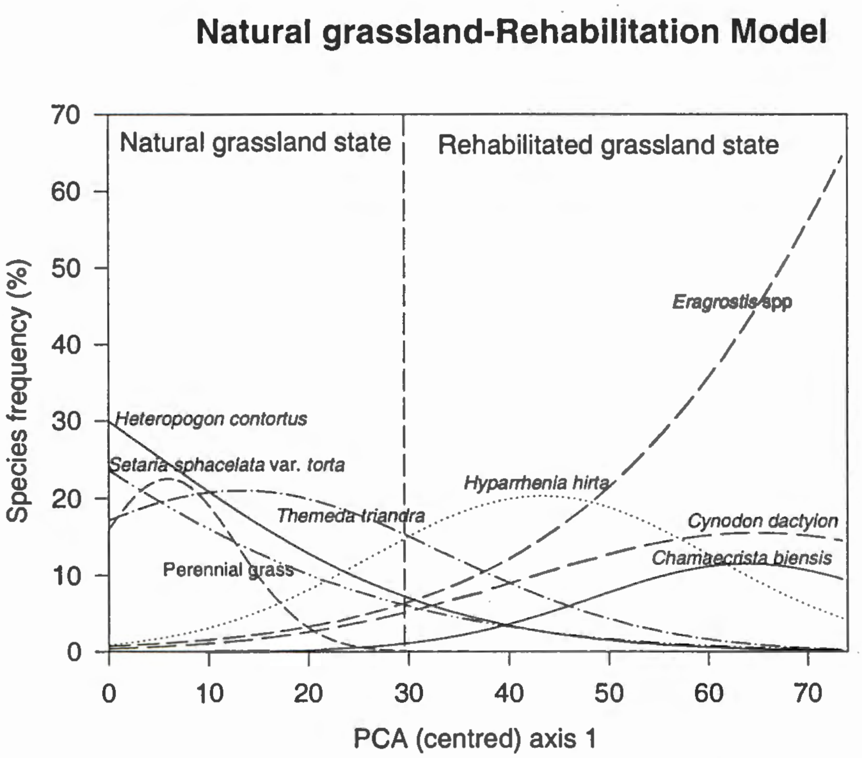
A number of benchmarks were considered for the development of the condition assessment models. Three possible models are proposed. To reduce the variation and noise in the data set, uncommon species were grouped into broad physiognomic classes. All annual forbs with a low frequency were for example grouped into one class. This made the applicability of the model on a broader scale possible.

11.3.1.1 Natural grassland–Rehabilitation Model

In the first model the natural grassland was used as a benchmark, indicative of the climax or stable condition. A PCA centred ordination procedure was used as basis for the model. The x-axis (ordination axis 1) of Figure 11.1 illustrates a hypothetical gradient in community development from left to right, from natural grassland to old rehabilitated grassland. Application of Gaussian Regression Models on *Eragrostis* spp. indicated that increases from left to right in ordination space of this species is well correlated (R^2= 0.89) with the first ordination axis (Figure 11.1). *Hyparrhenia hirta* illustrates a bell shaped regression curve (R^2= 0.294) with the application of a Gaussian curve. The highest occurrence of *Hyparrhenia hirta* is, therefore, found in the middle of the first ordination axis and decreases to the end points of ordination axis 1 indicating that this species is not found in the climax grassland taken as benchmark. A *Hyparrhenia hirta* dominated state can be observed in the middle of ordination axis. *Setaria sphacelata* var. *torta* (R^2= 0.266) and *Heteropogon contortus* (R^2= 0.0.767) represent climax species along this particular gradient and have their highest occurrence to the left of ordination axis 1. These species can be regarded as characteristic of natural grasslands of the Pretoria-Witbank-Heidelberg area, when lightly to moderately utilised by live-stock, according to Coetzee *et al.* (1995). Geophytes and many of the perennial forb species (R^2= 0.808) were exclusively associated with the natural grasslands (not shown). The model, therefore, portrays different states that can exist along ordination axis 1, from grassland dominated by *Setaria sphacelata* var. *torta* and other perennial grasses typical of natural grassland in the region, for example *Brachiaria serrata, Heteropogon contortus, Themeda triandra* and *Tristachya leucothrix,* to an

Eragrostis spp. dominated state. Figure 11.1 cannot, however, portray the condition of newly rehabilitated sites adequately, because of the dominant occurrence of *Eragrostis* spp. to the right of ordination axis 1. Dominance by *Eragrostis* spp. is, as a rehabilitation aim is desirable. *Eragrostis* spp. is, for example, an excellent perennial grass species that can be used as fodder. The assessment of a newly rehabilitated site dominated by *Cyperus* spp. and annual forbs, with a low frequency of *Eragrostis* spp., will be ordinated to the middle of the first ordination axis, which is a misinterpretation of the condition of that site. The use of this model for condition assessment is also not feasible, because the species composition of the rehabilitated grassland is not comparable to the species composition of the natural grassland. The rehabilitated grassland will probably never attain a similar level of community structure and richness due to the habitat differences and origin.

The natural grassland-Rehabilitation Model indicates a dominance by either *Hyparrhenia hirta* or *Eragrostis* spp. The state and transition model (Chapter 10) also supports the existences of these two states. In the state and transition model, State 5 indicates rehabilitated sites dominated *by Eragrostis curvula* and State 7 rehabilitated sites dominated by *Hyparrhenia hirta,* and Transitions 5 and 6 indicate the environmental and management factors responsible for the development of those states. It was therefore decided to split the data set on the basis of the frequency of *Hyparrhenia hirta* on the rehabilitated ash disposal sites, and to develop two separate models, namely the *Eragrostis-Cyperus* model for vegetation dominated by *Eragrostis* spp. or with a low *Hyparrhenia hirta* frequency (section 11.3.1.2), and the *Hyparrhenia-Cyperus* model for vegetation dominated by *Hyparrhenia hirta* (section 11.3.1.3).



Eragrostis spp: R^2=0.89
Setaria sphacelata var *torta*: R^2=0.266
Themeda triandra: R^2=0.486
Heteropogon contortus: R^2=0.767
Chamaecrista biensis: R^2=0.138
Other perennial grass: R^2=0.808
Hyparrhenia hirta: R^2=0.294

Figure 11.1: Gaussian response curves for species with the best fit along ordination axis 1 of the Natural grassland–Rehabilitation Model based on a PCA centred ordination between natural grassland sites and old rehabilitated ash disposal sites at Hendrina Power Station.

11.3.1.2 *Eragrostis-Cyperus* Condition Assessment Model

The *Eragrostis-Cyperus* Model is the first of two models that were constructed to describe the development of vegetation on rehabilitated ash disposal sites with newly rehabilitated ash disposal sites as benchmark.

The *Eragrostis-Cyperus* Model represents all areas in which *Hyparrhenia hirta* has a limited frequency (< 10%) together with newly rehabilitated sites, which consist predominantly of *Cyperus esculentus*, *Eragrostis tef*, *Enneapogon cenchroides*, *Eleusine coracana* subsp. *africana*, *Amaranthus hybridus*, as well as other annual forbs. The aim was, therefore, to create a model in which *Eragrostis* spp. were regarded as the "climax species" that increases after rehabilitation as secondary succession takes place over time. *Eragrostis* spp. includes *E. curvula*, *E. trichophora*, *E. chloromelas* and *E. lehmanniana*, as well as other *Eragrostis* spp.

A PCA centred ordination was used for the construction of the gradient. This condition model is therefore associated with the relationship between *Eragrostis* spp. and *Cyperus* spp. (particularly *Cyperus esculentus*) on rehabilitated ash disposal areas at Hendrina Power Station (Figure 11.2). Newly rehabilitated areas were associated with a high frequency of *Cyperus* spp. *Cyperus* spp. (Gaussian correlation coefficient (R^2) = 0.871) therefore increases to the right side of ordination axis 1 (Figure 11.2). *Cyperus* spp., as well as *Tagetes minuta* (R^2= 0.779) and annual grass species (R^2= 0.459) were, however, not only found to be associated with newly rehabilitated ash disposal sites, but also increased with disturbance or degradation (see Chapter 3 and Chapter 8). Community development or succession over time of the rehabilitated area is associated with an increase of *Eragrostis* spp. (R^2= 0.890) to the left side of ordination axis 1 (Figure 11.2). Ordination axis 1 can be regarded as a successional gradient, as well as probably a degradation gradient. Ordination axis 1 therefore represents a gradient from old rehabilitated sites in a less degraded and progressive stage of succession, to newly rehabilitated sites in a pioneer stage of succession or more degraded state, from left to right along ordination axis 1. *Hyparrhenia hirta* (R^2= 0.137) played a less important role and peaks to the left side of the ordination axis together with *Cynodon dactylon* (R^2= 0.126) and *Conyza* spp. (R^2= 0.199). *Eragrostis plana* is exclusively associated with the left side of the first axis (regression not shown in Figure 11.2).

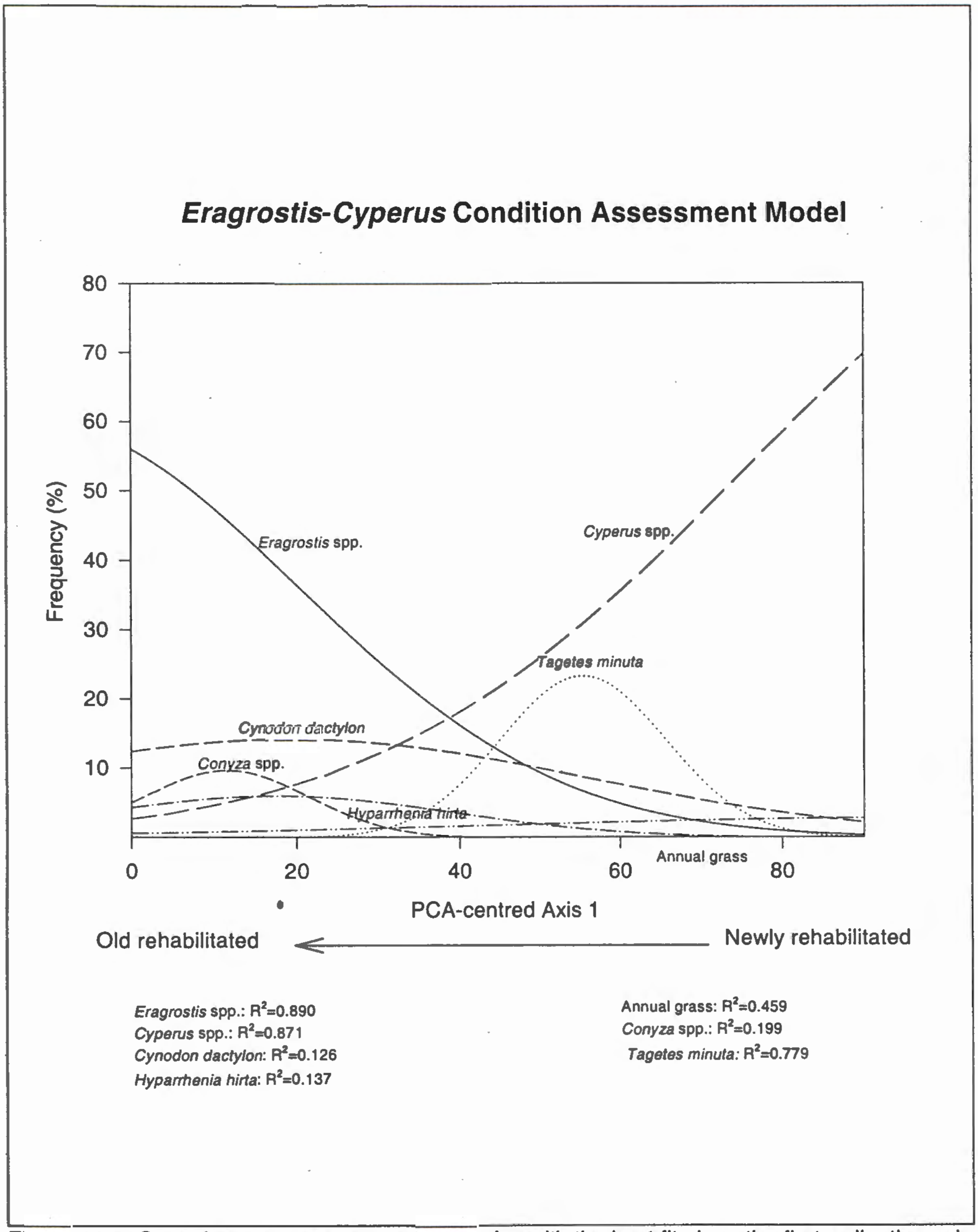


Figure 11.2: Gaussian response curves for species with the best fit along the first ordination axis of the *Eragrostis-Cyperus* Condition Assessment Model based on a PCA centred ordination between old rehabilitated sites with less than 10% *Hyparrhenia hirta* and newly rehabilitated ash disposal sites at Hendrina Power Station.

The development and persistence of an *Eragrostis curvula* dominated state is because of the ability of *Eragrostis curvula* to produce large amounts of seeds and its high regeneration and establishment rate. It is, therefore, a highly competitive grass species under favourable moisture and management conditions. The gradient along the first ordination axis of the *Eragrostis-Cyperus* Model is associated with the ability of *Eragrostis* spp., in particularly *Eragrostis curvula*, to regenerate and establish under the prevailing environmental conditions.

11.3.1.3 The *Hyparrhenia-Cyperus* Condition Assessment Model

This model was developed using samples taken from old rehabilitated areas with a *Hyparrhenia hirta* frequency higher than 10%, together with samples from newly rehabilitated sites and three road verge samples which were surveyed during the summer of 1999. Road verges were used as benchmarks because they consisted of vegetation more suitable to comparison to the rehabilitated sites than surveys conducted in an adjacent natural grassland and, as already indicated in section 11.2, established vegetation along road verges can be considered similar to secondary climax vegetation.

A PCA centred ordination was again used as basis for the model. The *Hyparrhenia-Cyperus* Condition Assessment Model was constructed on the theory that secondary succession would ultimately result in a *Hyparrhenia hirta* dominated grassland community (Roux, 1969). Figure 11.3 illustrates the distribution of sample points in the ordination space. Samples represent a gradient in rehabilitation condition from insufficiently rehabilitated to sufficiently rehabilitated from right to left along ordination axis 1. "Sufficiently rehabilitated" is defined in this study as a condition in which the rehabilitated vegetation consists of a dominant occurrence of perennial species with a closed crown cover (Barbour *et al.*, 1987 and Hulst, 1978). The residual represents the rest of the variation in species composition not accounted for by the first ordination axis. Figure 11.4 indicates the Gaussian response curves of species that best fitted the gradient along the first PCA ordination axis. Samples to the right indicate poorly or newly rehabilitated areas and are best described by an increase in *Cyperus* spp. to the right (Gaussian regression coefficient (R^2) = 0.881). The occurrence of the annual grasses, *Enneapogon cenchroides* and *Eragrostis tef*, is also confined to the right of ordination axis 1 (Figure 11.3). *Tagetes minuta* (R^2= 0.725) and percentage bare ground (Figure 11.3) peaks to the right of ordination axis 1 and, therefore, will also be associated with a degradation in the condition of the rehabilitated veld or newly rehabilitated ash disposal sites. Improvement of the rehabilitation condition over time will be associated with an increased occurrence of *Eragrostis* spp. (R^2= 0.374) and *Hyparrhenia hirta* (R^2= 0.720) (Figure 11.4). An area will be sufficiently rehabilitated if these species are well established and constituted a major proportion of the grass sward, because both are perennial grass species. Other species that also characterised this state of rehabilitation are the legume *Chamaecrista biensis* (R^2= 0.138), other legume species, *Cynodon dactylon* (R^2= 0.128) and *Eragrostis plana* (R^2=0.891). The *Hyparrhenia-Cyperus* condition assessment model predicts that *Hyparrhenia hirta* would steadily increase to become a dominant component in the grass sward, resulting in the out-competing of *Eragrostis* spp. due to regular occurrence of fire, infestations of *Tatera brantsii* or changes in the soil fertility of the growth medium (Chapter 8). The *Hyparrhenia-Cyperus* Condition Assessment Model also predicts an increase of *Hyparrhenia tamba* and *Themeda triandra* (R^2= 0.774) during later stages of succession. The gradient along ordination axis 1 of the *Hyparrhenia-Cyperus* Condition Assessment Model may be interpreted as the ability of *Hyparrhenia hirta* to outcompete *Eragrostis curvula* under certain environmental conditions such as higher fertility and high frequency of fire or continuous infestations of *Tatera brantsii* (Chapter 8) and probably also lower soil moisture conditions. The development of a *Hyparrhenia hirta* dominated community will depend on the occurrence of a large viable seed bank and the resilience of *Eragrostis curvula* to remain in a vigorous growth condition.

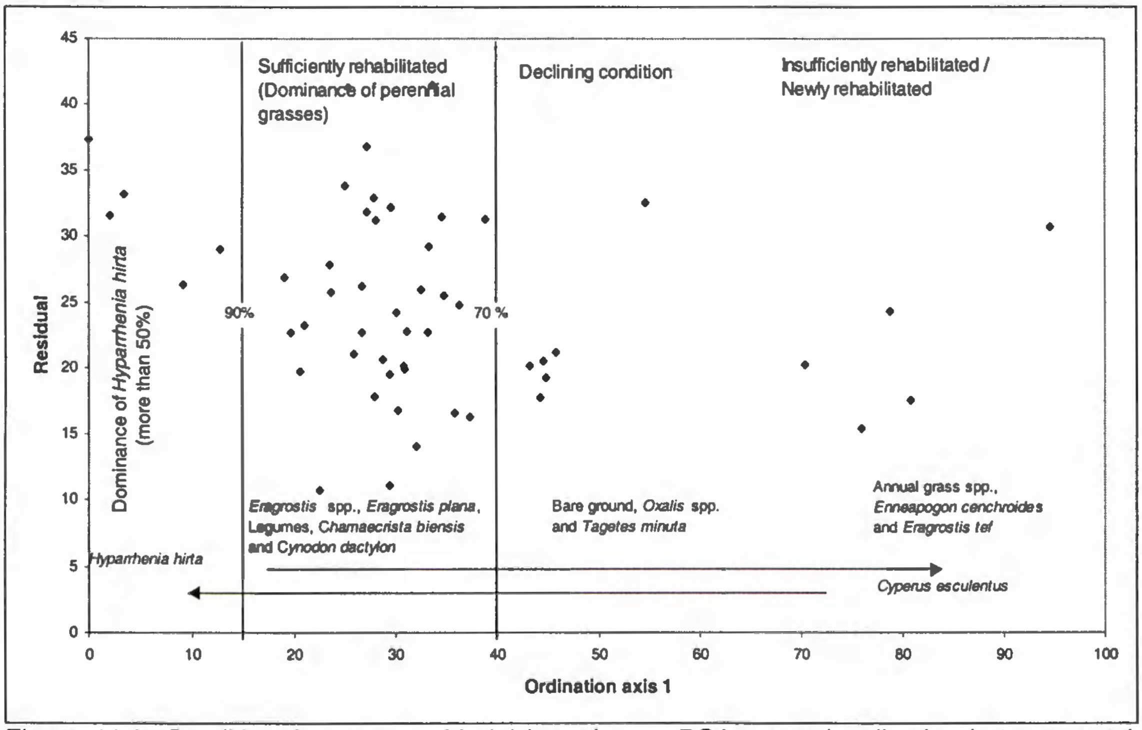


Figure 11.3: Condition Assessment Model based on a PCA centred ordination between road verges, old rehabilitated and newly rehabilitated ash disposal sites at Hendrina Power Station.

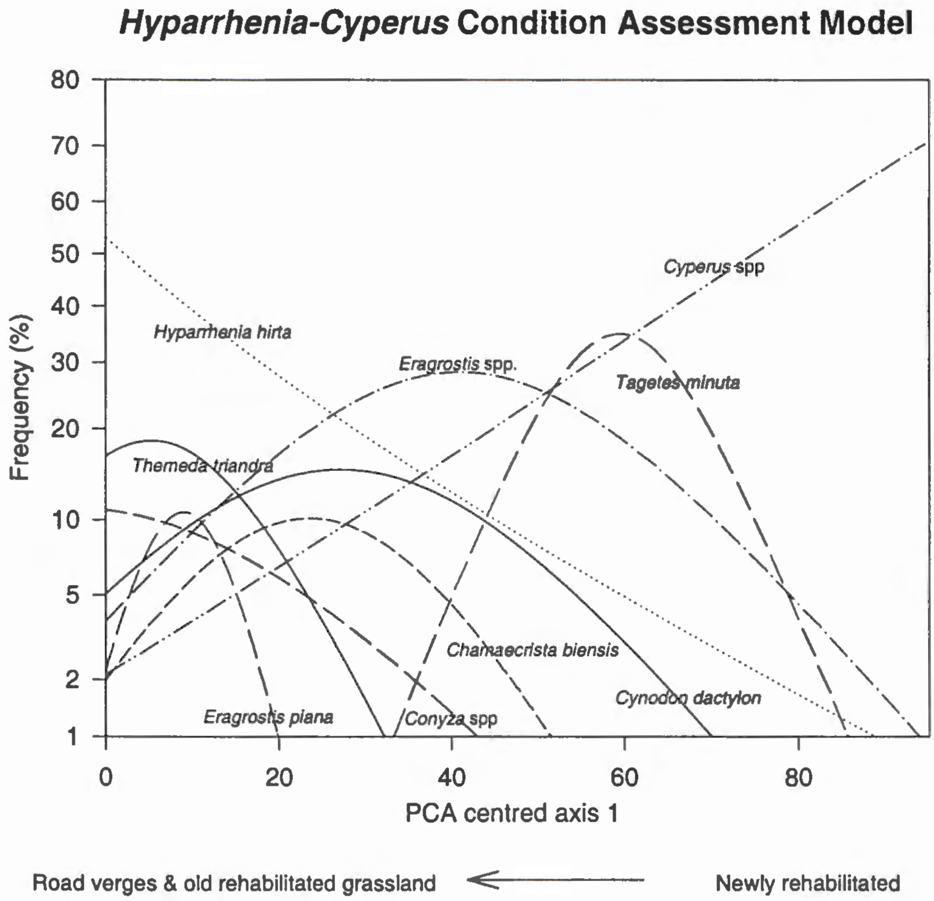
From the *Hyparrhenia-Cyperus* Condition Assessment Model condition values can be calculated. Table 11.1 provides a list of the average condition values for each grid over a period of three years (1997-1998). A condition value for transects from grids 7 and 8 are given separately. Condition values indicate that grid 1 has the lowest condition values. This is probably because the area on which grid 1 is situated was never sown with a seed mixture and was recently (1995) "disturbed" with the addition of a topsoil layer. Most other grids have condition values higher than 60%, except for grid 11, which has a condition value of 59.2 during 1998. This condition can be ascribed to infestations of *Tatera brantsii*. Transect 3 of grid 7 has the highest condition value. Transect 3 illustrates a constant increase in condition values from

91.1% to 115%, indicating a constant increase in *Hyparrhenia hirta* on that transect over the survey period. Condition values for transect 3 of grid 8 are underestimated. This is probably due to the dominant occurrence of *Eragrostis* spp. and the absence of *Hyparrhenia hirta.* The large residual on the Y-axis indicates that another model would have been more appropriate. The *Eragrostis-Cyperus* model (based on frequency data of 1997-1999 with less than 10% *Hyparrhenia hirta*) indicates a condition value of 109.9% for 1997, 97.9% for 1998 and 101.8% for 1999 data. Grid 10 shows a large improvement in its condition from 1997 to 1999 according to the *Hyparrhenia-Cyperus* model.

A summary of species and physiognomical classes indicating their frequency values over each range of condition values are provided in Table 11.2. Table 11.2 indicates that the frequency of *Cyperus* spp. decreased and *Hyparrhenia hirta* increased with an increase in condition values, while *Eragrostis tef* and *Enneapogon cenchroides* were only present in grids with condition values lower than 40% (Figure 11.3, Table 2). The frequency of *Eragrostis* spp. increased and reached its maximum frequency between a condition of 70-89%. Another species that had a high frequency was *Pennisetum clandestinum*, which reached its maximum frequency between a condition value of 40% and 69%. An important aspect in this model is the insignificant role of bare ground. This can be attributed to the establishment of annuals in the open spaces between perennial grasses, which covered the bare patches. Another aspect of this model is the increasing role of *Cynodon dactylon* as stabiliser during the advanced stages of succession as indicated in the model. The stoloniferous species had their maximum frequencies between 90-115% (therefore later stages of "succession") and if these species were considered to be less desirable during later stages of succession the application of this model would provide undesirable results.

Table 11.1 : Average condition values for grids from 1997 to 1999 according to the *Hyparrhenia-Cyperus* Condition Assessment Model of rehabilitated ash disposal sites at Hendrina Power Station

	1997				1998				1999			
Grid	% CONDITION		RESIDUAL		% CONDITION		RESIDUAL		% CONDITION		RESIDUAL	
1	55.557	5.345	41.953	2.116	62.623	2.701	41.957	3.517	61.450	2.636	39.033	6.170
2	74.457	8.497	32.107	8.423	78.233	6.904	32.167	8.260	82.400	4.051	25.000	2.621
3	75.193	10.834	33.927	2.812	71.167	6.866	25.767	4.966	71.670	4.158	20.643	9.318
4	69.570	5.848	41.300	6.729	70.393	10.465	31.700	3.251	75.767	2.836	28.820	5.307
9	70.387	9.695	22.860	4.780	70.800	7.732	16.400	5.300	83.077	4.710	16.187	5.149
10	60.817	1.551	20.660	0.505	78.790	3.022	26.517	6.219	90.333	1.332	23.313	3.551
11	73.933	3.137	25.767	5.705	59.200	2.879	21.000	4.309	79.640	2.568	21.897	3.730
12	72.567	4.140	38.587	4.683	73.270	3.753	36.357	2.027	80.233	3.988	40.067	5.658
72	0.000	0.000	30.800	0.000	16.900	0.000	17.600	0.000	48.600	0.000	32.500	0.000
73	91.100	0.000	22.800	0.000	110.800	0.000	33.200	0.000	115.000	0.000	37.300	0.000
82	19.200	0.000	24.300	0.000	22.600	0.000	15.400	0.000	29.500	0.000	20.300	0.000
83	75.200	0.000	46.400	0.000	69.170	0.000	46.870	0.000	69.100	0.000	43.600	0.000



Hyparrhenia hirta: R^2=0.720
Cyperus spp. R^2=0.881
Eragrostis plana: R^2=0.891
Themeda triandra: R^2=0.774
Eragrostis spp: R^2=0.374

Cynodon dactylon: R^2=0.128
Tagetes minuta: R^2=0.725
Chamaecrista biensis: R^2=0.138
Conyza spp: R^2=0.158

Figure 11.4: Gaussian response curves for species with the best fit along the first ordination axis of the *Hyparrhenia-Cyperus* Condition Assessment Model, based on a PCA centred ordination between, old rehabilitated sites with higher than 10% *Hyparrhenia hirta,* and newly rehabilitated ash disposal sites at Hendrina Power Station.

Table 11.2: Summary of species average frequency values over different condition ranges at rehabilitated ash disposal sites at Hendrina Power Station (standard deviation in italics)

Species	Condition range (0-115%)							
	0-39%		40-69%		70-89%		90-115%	
Annual forbs	4.4	*2.1*	1.8	*3.5*	0.8	*1.7*	4.7	*7.9*
Annual grass	1.0	*1.5*	0.2	*0.6*	0.2	*0.6*	0.7	*0.9*
Aristida congesta	0.0	*0.0*	0.2	*0.6*	0.5	*1.4*	0.3	*0.7*
Bare ground	0.0	*0.0*	0.7	*1.3*	0.1	*0.4*	0.0	*0.0*
Brachiaria serrata	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
Chamaecrista biensis	0.3	*0.7*	4.5	*6.1*	8.2	*9.1*	9.6	*9.5*
Chloris gayana	0.3	*0.5*	0.5	*2.3*	0.9	*3.4*	1.0	*2.2*
Conyza spp.	1.2	*1.6*	3.1	*6.2*	2.5	*4.7*	4.7	*6.9*
Cynodon dactylon	5.1	*3.4*	11.0	*6.3*	14.4	*10.1*	16.7	*10.6*
Cyperus spp.	54.2	*12.1*	14.3	*8.5*	8.5	*5.5*	4.8	*1.1*
Digitaria eriantha	0.5	*1.1*	0.6	*1.3*	0.9	*1.2*	0.5	*0.7*
<u>*Enneapogon cenchroides*</u>	1.9	*3.4*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
Eragrostis echinochloidea	0.0	*0.0*	0.3	*1.1*	0.0	*0.2*	0.0	*0.0*
Eragrostis plana	0.0	*0.0*	0.5	*0.9*	0.6	*0.8*	0.3	*0.4*
<u>*Eragrostis* spp.</u>	6.3	*8.1*	28.8	*12.7*	30.9	*15.0*	9.7	*5.2*
<u>*Eragrostis tef*</u>	2.9	*5.2*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
Heteropogon contortus	0.0	*0.0*	0.1	*0.3*	0.1	*0.3*	0.0	*0.0*
<u>*Hyparrhenia hirta*</u>	0.2	*0.4*	6.8	*7.1*	17.2	*10.2*	42.3	*18.2*
Hyparrhenia tamba	0.0	*0.0*	0.2	*0.5*	0.2	*0.6*	1.3	*1.3*
Hypochaeris radicata	0.2	*0.4*	0.0	*0.2*	0.0	*0.0*	0.0	*0.0*
Other Legumes	0.0	*0.0*	0.8	*1.4*	1.2	*1.6*	0.0	*0.0*
Oxalis spp.	0.2	*0.4*	0.2	*0.4*	0.3	*0.5*	0.7	*0.7*
<u>*Pennisetum clandestinum*</u>	13.0	*10.6*	21.4	*19.5*	9.9	*13.4*	0.0	*0.0*
Perennial forbs	0.0	*0.0*	0.1	*0.2*	0.1	*0.5*	0.0	*0.0*
Perennial grass	0.0	*0.0*	0.4	*1.1*	0.3	*0.8*	0.0	*0.0*
Schkuhria pinnata	0.0	*0.0*	1.0	*1.5*	0.8	*1.6*	0.7	*1.1*
<u>*Tagetes minuta*</u>	8.1	*6.7*	2.5	*5.9*	1.3	*2.8*	2.0	*2.1*
Themeda triandra	0.2	*0.4*	0.1	*0.3*	0.1	*0.2*	0.0	*0.0*
Tree spp.	0.0	*0.0*	0.0	*0.0*	0.0	*0.1*	0.2	*0.4*

Indicator species are underlined.

11.3.2 Attributes for the ecological assessment of rehabilitated ash disposal sites

A number of community attributes can be obtained and calculated from basic ecological data. In this chapter, condition models for the evaluation of rehabilitated ash disposal sites at Hendrina Power Station, are proposed. Because of the differences in species composition (especially annual forbs) between ash disposal sites at different geographical locations of power stations and the use of different treatments, the application of previous models was found to be limited (see section 11.3.4). The use of community attributes makes it possible to apply the model to rehabilitated grasslands with different species compositions. It is, therefore, the aimed to construct a condition model based on community attributes which have a broader application value. This section of Chapter 11 is also aimed at the identification of critical community attributes with which the rehabilitated grassland community can be assessed ecologically. Species were, therefore, grouped into broad physiognomical/ growth form classes from a population level to a community level. Additional community attributes such as biomass, diversity and basal cover were also included and a PCA ordination was conducted on the data (Figure 11.5). Community attributes indicated in the correlation biplot included basal cover, perennial grass frequency and litter mass, which increased from right to left in the diagram and are also highly correlated. The percentage of bare ground and annual forb frequency increased from left to right and showed a strong antagonistic relationship to basal cover, perennial grass frequency and litter biomass. Figure 11.5 also illustrates a strong negative correlation between annual grass frequency and stoloniferous grasses on the right side, and perennial grass frequency on the left side, which means that as the one component increase, the other will decrease. Ordination axis 1 can also, in this case, be interpreted as a gradient in rehabilitation condition. From insufficiently rehabilitated (right side) to sufficiently rehabilitated (left side). No community attributes relating to diversity were correlated to the condition gradient along ordination axis 1 (can be derived by the perpendicular angle of these variables to the first axis). The following hypothesis can be derived: The correlation plot indicates that percentage bare ground together with basal cover can be a good indicator of rehabilitation condition. Plant species diversity is less successfully as an indicator of rehabilitation condition.

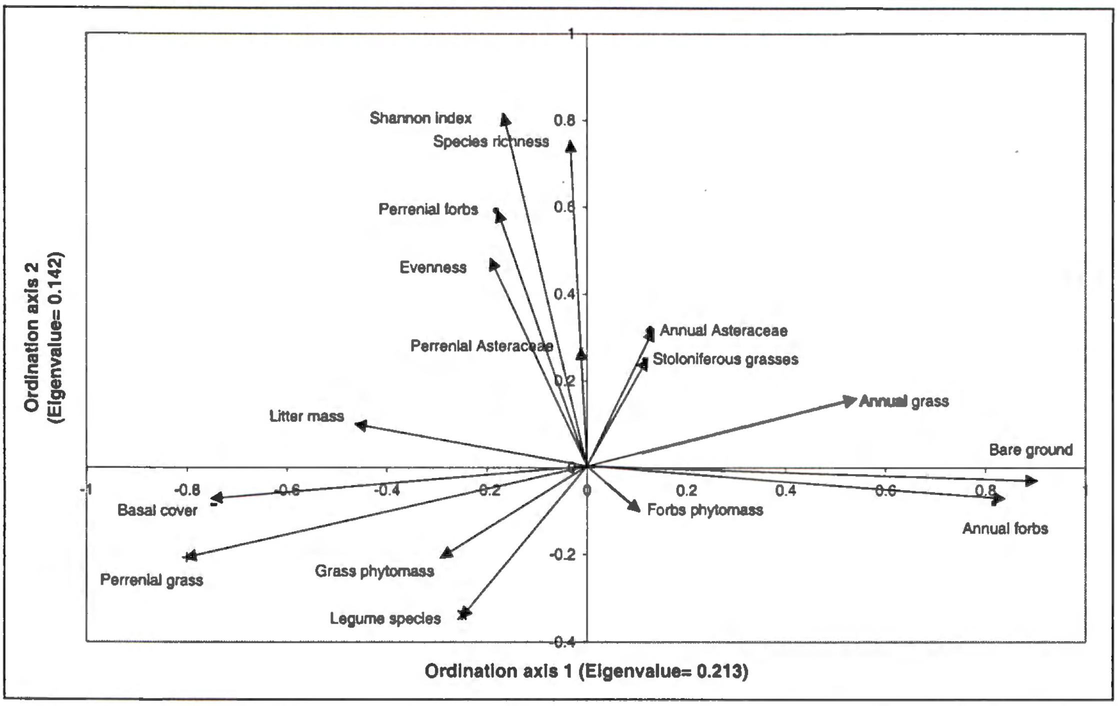


Figure 11.5: PCA correlation plot of differences in community attributes between different sites on rehabilitated ash disposal sites at Hendrina Power Station (survey years were used as covariable).

The hypothesis derived from Figure 11.5 was tested further using only old rehabilitated areas. Figure 11.6 represents the PCA correlation plot of community attributes of old rehabilitated areas. The strong effect of old against newly rehabilitated sites was, therefore, removed. Similar patterns can be observed in Figure 11.6 as in Figure 11.5. Basal cover was, for example, still strongly correlated with perennial grass frequency. Additionally, grass phytomass also showed strong correlation with basal cover. The antagonistic relationship between basal cover and percentage bare ground, however, did not feature as strongly as in Figure 11.5. Basal cover was more negatively related to frequency of stoloniferous species. An interesting aspect that can be derived from Figure 11.6, is that percentage bare ground was positively correlated to annual forb frequency and negatively correlated to frequency of annual species belonging to the family Asteraceae. It can, therefore, be deduced that other annual forbs (of which the largest portion consists of *Cyperus* spp.), excluding annual Asteraceae spp., prefer to colonise rehabilitated grasslands with more bare ground. Annual Asteraceae species preferred grasslands with a higher crown cover because they were negatively correlated with bare ground. Inspection of the data indicates that *Conyza bonariensis, Schkuhria pinnata* and *Tagetes minuta* are the annual representatives of the family Asteraceae with the highest frequency. Species diversity attributes, however, showed little correlation with basal cover or bare ground. The frequency of basal cover or the amount of bare ground, therefore, did not affect diversity. The length of the vectors representing Shannon Diversity Indices and species richness indicates that these variables are also of significant importance and considerable differences in Shannon Diversity Indices values and species richness do exist (Figure 11.6).

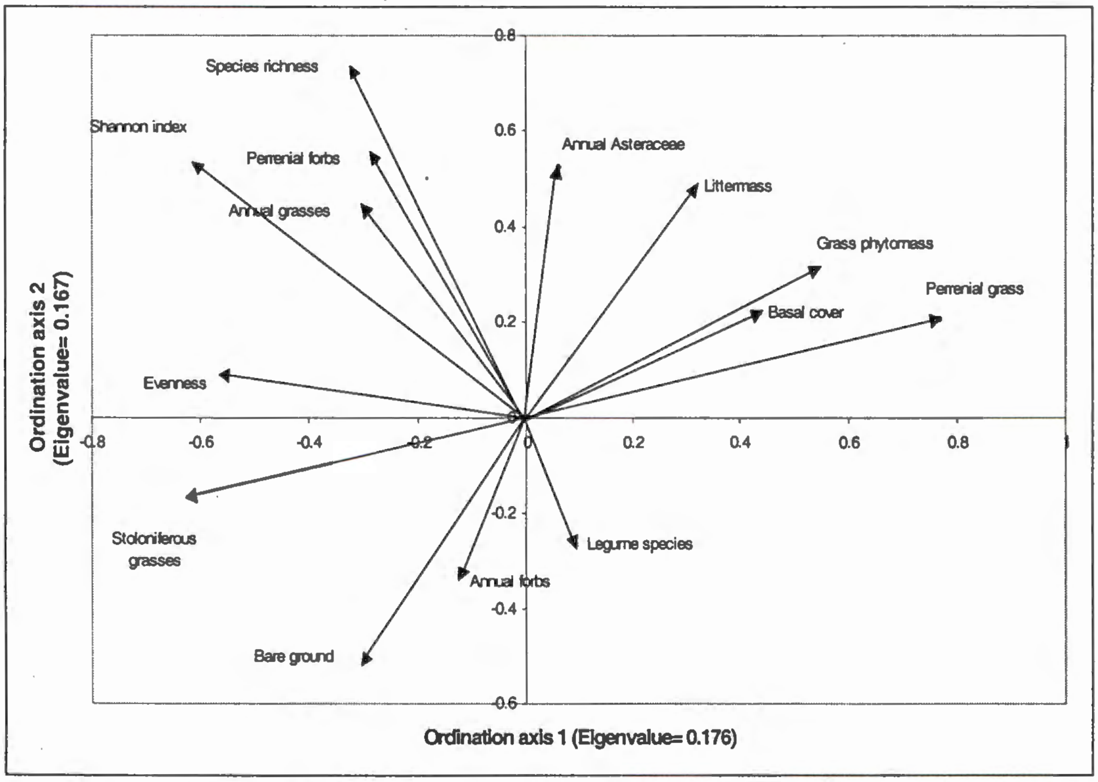


Figure 11.6: PCA ordination correlation plot to illustrate the differences in community attributes of surveys on old rehabilitated ash disposal areas at Hendrina Power Station.

Results of the PCA ordination of community attributes are similar to gradients described in the two condition assessment models with species, namely the *Eragrostis-Cyperus* Model and *Hyparrhenia-Cyperus* Model. The left side of ordination axis 1 of Figures 11.5 and the right side of Figure 11.6 portrays the same ecological condition as the left side of the two condition assessment models (Figures 11.2 and 11.4), which indicated a good or sufficiently rehabilitated condition with less disturbance. The right side of ordination axis 1 (Figure 11.5) and the left side of ordination axis 1 (Figure 11.6) are similar to the right side of the two condition assessment models (Figure 11.2 and Figures 11.4) which indicated a poor rehabilitated or more disturbed condition. The importance of a high frequency of perennial grass species is again illustrated in the PCA ordination diagrams (Figure 11.5 and 11.6) because a sufficiently or good rehabilitated conditions in the condition assessment models were related to the dominance of one or both of the perennial grass species *Hyparrhenia hirta* and *Eragrostis* spp. Dominant occurrence of perennial grasses such as *Eragrostis curvula*, *Eragrostis chloromelas*, *Eragrostis plana*, *Hyparrhenia hirta*, *Hyparrhenia tamba*, *Digitaria eriantha*, *Heteropogon contortus* and *Themeda triandra* is important for the establishment of a high basal cover. The high frequency of perennial grass species are also essential to increase the productivity and nutrient cycling of the rehabilitated sites as indicated by the strong association of litter mass and grass phytomass to higher frequency of perennial grass. Bare ground is a less important factor in the *Eragrostis-Cyperus* Model and *Hyparrhenia-Cyperus* Model because of the percentage bare ground for summer months is used.

The percentage winter bare ground and basal cover are important community attributes in Figures 11.5 and 11.6. In Figures 11.5 and 11.6 higher percentage of bare ground is strongly associated with higher frequency of annual forbs, which included *Cyperus* spp. (Figures 11.5 and 11.6), and annual grass (Figure 11.5). The species composition, therefore, determines the community attributes and the two components are highly inter-linked. The left side of ordination axis 1 (Figure 11.5) and the right side of ordination axis 1 (Figure 11.6) give an indication of what can be regarded as indicative of a sufficiently rehabilitated condition.

Basal cover and percentage bare ground can, therefore, be used as indicators of degradation in the condition of rehabilitated sites. To illustrate this, the average percentage basal cover (February-March survey) and the average percentage bare ground (September survey) are ranked and divided into arbitrary classes. These classes can, for example, be linked to erodibility to make them more informative. An **example** of how this can be used in the assessment of the condition of rehabilitated areas is explained in Table 11.3.

Table 11.3: Arbitrary condition classes based on percentage bare ground (30cm radius) and basal cover from 120 descending point surveys to give an example how percentage basal cover and bare ground can be used to assess the condition of rehabilitated areas

Class		**Survey plot**				
A		K	G8/3	G7/3	G12	
	%Bare ground (< 1%)	0.07	0.40	0.00	0.54	
	%Basal cover (> 10%)	16.12	12.74	11.11	10.47	
B		G2	G4	G9	G10	G3
	%Bare ground (< 1%)	0.00	0.14	0.28	0.94	0.14
	%Basal cover (<10%)	9.88	9.15	8.14	7.65	7.60
C		G11	G1			
	%Bare ground (1-5%)	2.83	2.73			
	%Basal cover	8.19	6.10			
D						
	%Bare ground (5-10%)					
	%Basal cover					
E		G7/2	G8/2			
	% Bare ground >10%	11.31	22.14			
	% Basal cover	0.82	1.62			

A percentage basal cover higher than 10% with less than 1 % bare ground are arbitrarily taken to represent grassland in a good condition (Class A). Most of the grids that fall into this category are visibly in a good condition with little bare open patches. Three rehabilitated sites are placed in condition class A, which included the bottom transect (transect 3) of grids 7 and 8, and grid 12 (Table 11.3). Grids with less than 1% bare ground, but with a basal cover of less than 10% are grids 2, 4, 9, 10 and 3 and are placed in condition class B (Table 11.3). Although class B indicates areas with an average basal cover of less than 10%, the basal cover of the grids that occur in the class are higher than 7% and are presumably, therefore, already in a satisfying condition. Grids that are of concern are grids 1 and 11 that fall into class C (Table 11.3). The basal cover of grid 11 was 8.19% possibly indicating the presence of large tuft grasses with the occurrence of bare patches in certain places. The *Hyparrhenia-Cyperus* model probably overestimated the condition of grid 11 for the survey years 1997 and 1999 (Table 11.1), due to the high occurrence of *Hyparrhenia hirta*. Bare ground is also a less important indicator in this model and did not fit the gradient of the *Hyparrhenia-Cyperus* model. Certain management strategies may therefore be necessary to remedy the bare patches that have developed, for example by reseeding, loosening of the substrate and fertilisation, addition of organic material to promote the recolonisation of perennial or stoloniferous grasses on the bare patches. Classes C and D indicate totally insufficient rehabilitation. Areas with a large percentage of bare ground and low basal cover, as indicated by classes C and D, may require partial or total reseeding. A reassessment of the rehabilitation technique and seed mixture that was used would also have to be considered. Transects on the newly rehabilitated areas could be placed in condition class D. Data that was used, was average data of the first two years, and the condition is consequently not comparable because rehabilitation was still in progress. If the basal cover and bare ground does not improve on the newly rehabilitated sites, the areas will have to be resown. The basal cover and percentage bare ground is especially critical for rehabilitated areas situated on slopes because of the higher risk of erosion.

11.3.3 Community attribute model

A condition assessment model was also created from selected community attributes (Figure 11.7). Percentage basal cover and bare ground were combined with species frequency data, grouped according to different growth forms and physiognomic groups. Data from newly rehabilitated, old rehabilitated and the natural grassland were used to create a successional gradient. A PCA standardised ordination was used to create the succession gradient.

Ordination axis 1 of Figure 11.7, therefore illustrates, from right to left, the changes in community attributes from newly rehabilitated areas in a pioneer stage to a climax stage (represented by surveys from a nearby natural grassland). The successional gradient may also be interpreted as a condition gradient from a preferred, sufficiently rehabilitated condition at the left to, a poorly rehabilitated or degraded condition at the right along ordination axis 1. The gradient along ordination axis 1 may therefore be interpreted in two ways, namely as a succession or as a degradation gradient. The changes in community attributes were very similar to those perceived in Figures 11.5 and 11.6. Most attributes used in this model were very well correlated to the first ordination axis. Distribution curves for basal cover (Gaussian regression coefficient (R^2)= 0.675) and perennial grass frequencies (R^2=0.907) both decrease from left to right along ordination axis 1 in the direction of poorly rehabilitated vegetation condition (pioneer stage). Degradation of the condition of the rehabilitated area is also strongly correlated to an increase in the percentage of bare ground (R^2= 0.781). Frequencies of stoloniferous grass also show a strong bell shaped curve (R^2= 0.494), peaking near the middle of ordination axis 1. Perennial forbs (R^2= 0.564) have only increased at the end of the successional gradient (climax stage) to the left of ordination axis 1.

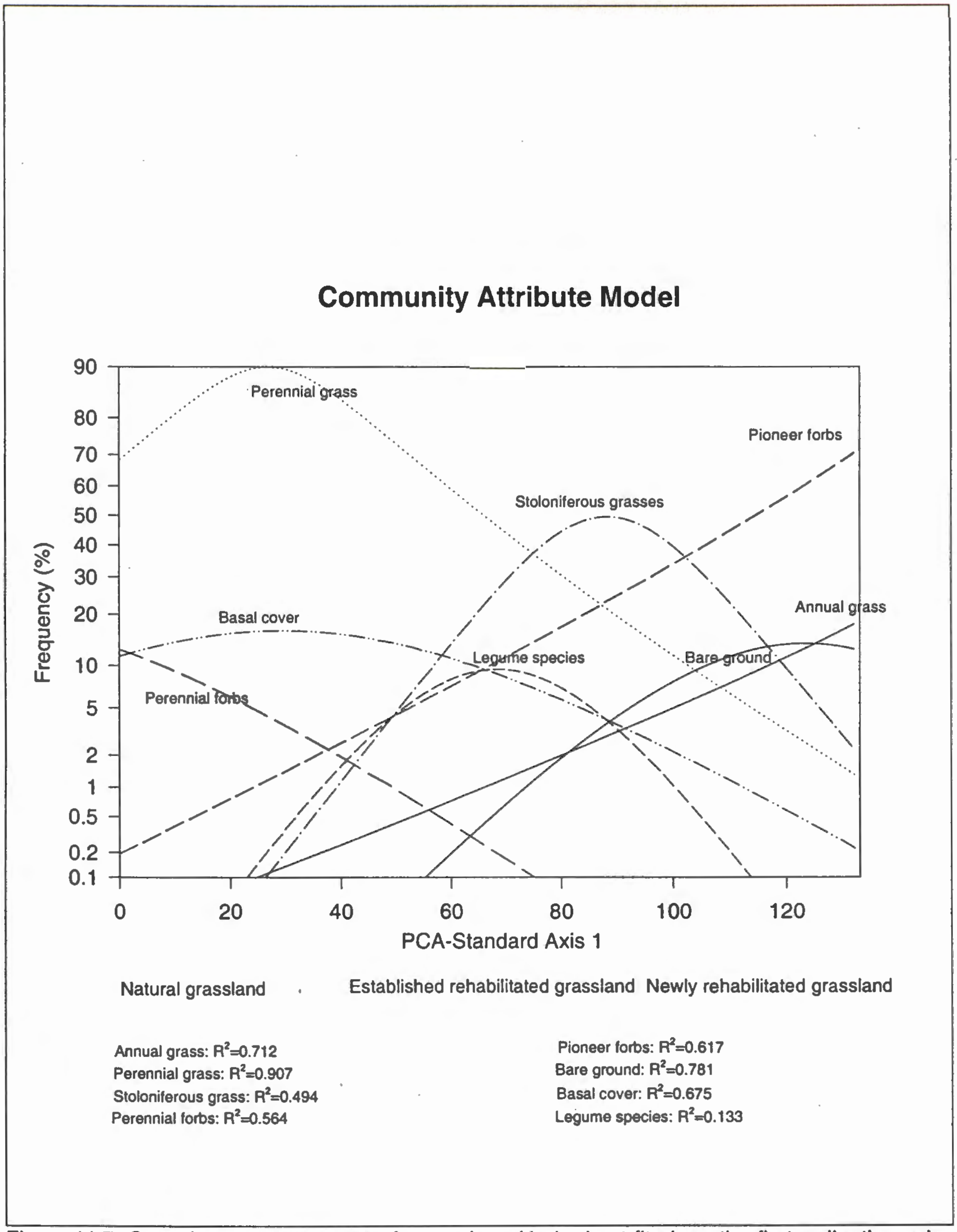


Figure 11.7: Gaussian response curves for species with the best fit along the first ordination axis of the Community Attribute Model, based on a PCA standard ordination of natural grassland sites, road verges and rehabilitated ash disposal sites at Hendrina Power Station.

11.3.4 Applicability of the condition assessment models to other ash disposal sites

Constructed models were tested on four surveys conducted at Kragbron Power Station during February 1997 (Van Hamburg, 1997). The area was surveyed with a point method and the nearest plant and basal hits were recorded. Surveys A and C at Kragbron were conducted on unrehabilitated areas and surveys B and D at Kragbron on rehabilitated areas. The following results were expected due to the species composition. It is expected that site C would have a condition value of 10% or less, due to the large percentage of bare ground and frequency of annual spp. and could be regarded as being in a very poor state. Site A would also be in a poor state but would have an expected condition value of 10-30%. This site consisted of high frequencies of *Tagetes minuta* and *Schkuhria pinnata* and *Enneapogon cenchroides* (Table 11.4). Site B and D would have average condition values higher than 50%, but the expected value of site D would be higher than B because of higher frequencies of *Digitaria eriantha* and *Eragrostis* spp. (Table 11.4).

The *Hyparrhenia-Cyperus* Model overestimated the condition of the test surveys if the amount of bare ground and frequency of annual species is considered. This was probably because data contained very little *Hyparrhenia hirta* and *Cyperus* spp. The condition of especially Kragbron C was, however, very poor due to the large percentage of bare ground and annual forbs (Table 11.4). The *Eragrostis-Cyperus* Model presented more reliable condition values, but values were still higher than expected. As expected, both models indicated site D as being in the best condition, but the *Hyparrhenia-Cyperus* Model indicated the condition of site C as being higher than that of site A.

Kragbron data were also used to test the application value of the Community Attribute Model. Table 11.4 indicates that this model was far more sensitive than the *Hyparrhenia-Cyperus* Model and depicted the rehabilitation condition more accurately. The rationale for this is by combining species in broad functional groups such as Perennial grasses, Stoloniferous grasses, pioneer forbs, and other ecological parameters for example Basal cover and % bare ground variability is reduced and areas differently rehabilitated becomes comparable. The condition values indicated by the Community Attribute Model were very similar to the predicted values. Survey C at Kragbron had a condition value of 3.9%, which is the value that was expected. Site A was also expected to be in a poor condition (10-30%) and the Community Attribute Model did indicate this condition correctly. The Community Attribute Model also accurately estimated the condition of the two rehabilitated sites, sites B and D. The expected values for site B (>50%) were higher than was indicated by the Community Attribute Model (40.8%). This model will probably be better adapted to areas of different species composition because it is less sensitive for species composition variations. Condition values obtained from the community attribute model also corresponded more to estimated condition values. Survey C is according to the Community attribute model in the worst state because of the high % of bare ground and annual forbs. Survey D has the highest condition because of the high occurrence of perennial grasses and low occurrence of annual forbs.

Table 11.4: Applicability of condition assessment models to other ash disposal areas

	KRAGBRON A	KRAGBRON B	KRAGBRON C	KRAGBRON D
Annual forbs	2.5	1.6	52.2	1.2
Annual grasses	3.6	1.4	5.2	3.1
Aristida congesta	7.0	0.3	0.0	7.7
Chamaecrista biensis	0.0	0.0	0.0	0.0
Chloris gayana	0.0	0.0	0.0	0.4
Conyza spp.	17.1	15.2	6.3	2.0
Cynodon dactylon	4.3	54.0	0.4	9.8
Cyperus spp.	8.0	0.3	0.0	0.4
Digitaria eriantha	0.0	7.1	0.0	28.2
Enneapogon cenchroides	10.1	0.0	0.0	0.0
Eragrostis echinochloidea	0.0	0.0	0.0	0.0
Eragrostis plana	0.3	0.3	0.0	0.0
Eragrostis spp.	19.1	11.3	0.0	32.3
Eragrostis tef	0.0	0.0	0.0	0.0
Bare ground	2.6	0.0	26.7	0.4
Heteropogon contortus	0.0	0.0	0.0	0.4
Hyparrhenia hirta	0.3	0.0	0.0	0.0
Hyparrhenia spp.	0.0	0.0	4.9	0.0
Legume species	0.0	2.5	0.0	0.7
Perennial forbs	0.3	0.0	0.4	0.0
Perennial grasses	2.6	1.4	0.0	10.6
Schkuhria pinnata	10.1	0.3	0.8	1.2
Setaria pallide-fusca	0.0	0.0	0.0	0.4
Tagetes minuta	11.7	4.4	2.2	0.0
Themeda triandra	0.3	0.0	0.0	0.0
Tree species	0.0	0.0	0.9	1.2
Hyparrhenia-Cyperus value	63.9	76	67.8	73.0
Hyparrhenia-Cyperus residual	34.7	53.7	56.7	43.4
Eragrostis Cyperus value	58.6	65.1	41.5	83.1
Eragrostis Cyperus residual	27.7	45.9	45.9	34.1
Community attribute value	27.5	40.8	3.9	52.1
Community attribute residual	51.5	34.5	56.6	38.5

11.4 CONCLUSIONS

Four ordination models related to the plant community condition of rehabilitated ash disposal areas were developed. Three of these models use species as indicators, while the fourth model is related to characteristics in the community itself. Although the aim was to include as many benchmarks as possible, the use of multiple benchmarks is difficult because of the presence of high β diversity. Grouping of rare species according to their growth form or physiognomy prove to be fruitful in reducing the β diversity and noise in the data. Attempts to produce a model in which both the perennial species *Eragrostis* spp. and *Hyparrhenia hirta* increased simultaneously were not successful, and it was decided to divide the data set according to the occurrence of *Hyparrhenia hirta* in the data. Condition assessment models of both species were, thereafter developed separately.

The *Eragrostis-Cyperus* and *Hyparrhenia–Cyperus* Models are based on the following assumptions:
The area was rehabilitated with a grass seed mixture consisting of *Eragrostis curvula* or related *Eragrostis* species. A list of other species that were used is included in Chapter 1 of the dissertation. A topsoil layer of at least 5cm was used, but most of the areas were covered with a topsoil layer of 10cm.
The model is restricted to the summer rainfall area with an average annual precipitation of approximately 700-900mm.
Rehabilitation was conducted on a dry land system and no irrigation was used.
The model was constructed from surveys conducted on rehabilitated lagooned ash disposal areas with rehabilitation ages of 1 to 9 years.
Data were collected during the summer months (February-March) using a descending point method at intervals of 1m along transects of 120m long.
Bare ground of the September survey was used. Basal cover increase and the percentage bare ground decrease during community development indicating that these parameters are valuable when determining the condition of a site and were important components in the models.

Figure 11.8 represents a schematic diagram for the use of the *Hyparrhenia-Cyperus* Model, *Eragrostis-Cyperus* and Community attribute models as a condition assessment tool. *Cyperus* spp. are used as indicators for newly or degraded rehabilitated areas. To make the species models applicable to other areas, the species used as indicators must be adapted to include species typical of the area under question. For the construction of condition or degradation models, indicator and other key species must be identified. *Eragrostis* spp. and *Hyparrhenia hirta* are used as indicators of well-established rehabilitated in models of this study because they are major components of most of the older rehabilitated ash disposal areas at Hendrina Power Station. *Eragrostis curvula*, which comprises a major proportion of the *Eragrostis* spp. group, is a valuable fodder species (Roux, 1969) and is of major importance for rehabilitation of most gold mine dumps in South Africa (Roux, 1966). *Hyparrhenia hirta* is, however, less palatable than the *Eragrostis* spp. and can therefore not be preferred if the area is to be used for fodder. Results from studied attributes in previous chapters indicated that *Eragrostis* spp. will be out-competed by *Hyparrhenia hirta*, especially if the area is burned regularly.

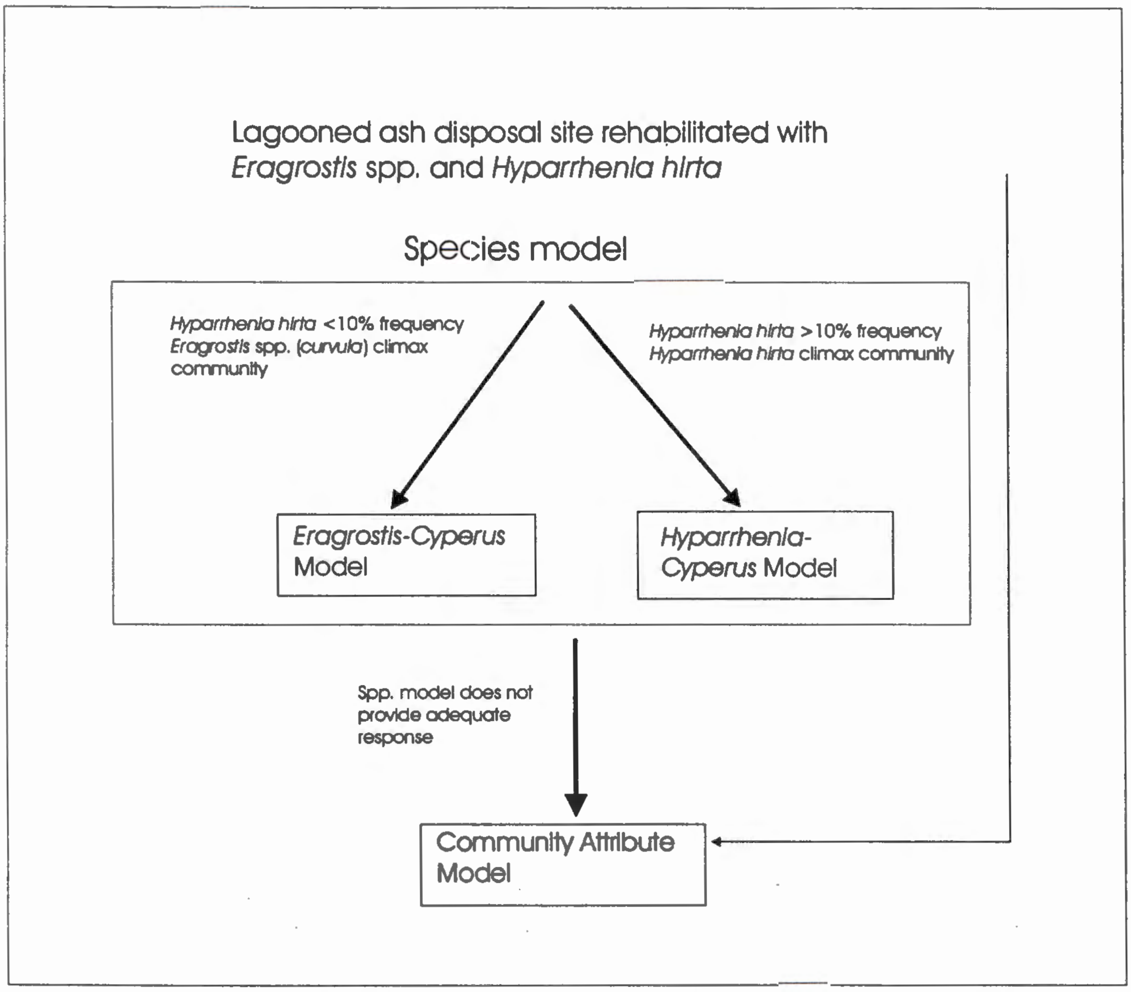


Figure 11.8: Condition assessment tool incorporating three possible models for assessment of vegetation condition of rehabilitated grasslands on ash disposal sites.

The proposed models are developed to indicate the condition of the rehabilitated state in relation to the pioneer stage. The ideal condition must be decided in relation to the final use of the area and must be applied appropriately. Benchmarks indicating the optimum rehabilitation condition must, therefore, be chosen in relation to the final use of the rehabilitated area.

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Chapter 12 GENERAL DISCUSSION AND CONCLUSIONS

Abstract: Rehabilitated ash disposal sites at Hendrina Power Station followed a successional pattern similar to old fields on the Highveld of South Africa. Results also indicate that fires promoted the increase of *Hyparrhenia hirta* and negatively affected the regeneration and existence of *Pennisetum clandestinum* and *Eragrostis* spp. The most important factors determining the dynamics of vegetation on the ash disposal sites are the initial treatment, fire and infestations of the small mammal, *Tatera brantsii.* Bare ground and basal cover of the vegetation prove to be two of the best community attributes to determine the ecological condition of ash disposal areas. Rehabilitated areas older than three years have a certain degree of stability due to the dominance of perennial grass species. Stability can also be related to the lack of change in species composition although changes in the abundance of species did take place. No indication can be found that retrogressive succession is taking place, or that diversity is decreasing. Colonisation and expansion in the populations of rare perennial species were slow or non-existent. The vegetation dynamics and changes were based on changes in the species abundances rather than changes in the overall species composition. The only areas in which total changes in species composition could be found were the newly rehabilitated areas. The biomass of old rehabilitated areas are similar to the biomass of the natural grassland. Regular fires also had a negative effect on litter but did not influence grass biomass as such. Species densities influence biomass but no relationship exist between biomass and diversity. Chemical factors that are related to biomass production included ammonium concentrations, salinity and alkalinity.

It is postulated that vegetation stability is a function of environmental stability especially regarding soil chemical properties. Floristic characteristics that promote plant community stability are the adaptability of the species, diversity and species persistence. Only if community stability and environmental stability have been achieved will sustainability on an autotrophic level be possible.

Research questions that arose from the study include aspects of similarity between ash disposal sites at Hendrina Power Station and other ash disposal sites, the influence of legumes to improve the N-cycle in rehabilitated ecosystems, and the role of the topsoil seed bank during the rehabilitation process. The present study, although it did not investigate the seed bank, suggested that it played an important role in the vegetation dynamics. The effect of soil moisture and impermeable layers on vegetation dynamics remains unexplained. This study was descriptive and the hypotheses generated from these studies need experimental verification.

CONTENTS

12.1 GENERAL DISCUSSION OF PLANT COMMUNITY DYNAMICS ON COAL-ASH DISPOSAL SITES AT HENDRINA POWER STATION

A total of 276 species were found of which 149 species occurred on the ash disposal sites and 163 species were found in the natural grassland. The gamma diversity between the natural grassland and ash disposal sites was therefore similar. Of all the species 35 were found to occur in both areas of which most were annual pioneer species. The species composition and life form spectra of the two areas were, however, considerably different. Therophytes and hemicryptophytes were the most important survival strategies for species growing on the ash disposal sites whereas a hemicryptophytic life form was the most important strategy in the natural grassland. A study of the different life forms can convey a number of characteristics of the species that occur in a community for example species with a therophyte life form is of a annual nature, survive unfavourable conditions through seeds, is mostly herbaceous and will have stochastic population sizes over time. Therophytes are mostly associated with pioneer communities and due to their stochastic occurrence in pioneer communities contributes little to long-term stability. Hemicryptophyte species survive through growth points situated near the ground, and are associated with herbaceous species with a perennial growth form, but which normally die back to ground level during unfavourable seasons. Climax species in climatic regions with a dry and cold season have mostly such a hemicryptophyte life form. Such species will promote stability because they will have a longer presence in a community and, therefore, promote a lack of change. The life form spectra not only indicate the survival strategies of species but indicate the potential for species change in communities. In both areas the largest represented families were those of the Poaceae, Asteraceae and Fabaceae (subfamily Papilionoideae).

12.1.1 Plant community dynamics

Plant communities were differentiated according to differences in species composition of the natural grassland, rehabilitated areas and unrehabilitated areas (Chapter 3). Differences in species composition at a sub-community level were based on differences in established and newly/disturbed-rehabilitated areas. The three variants that were described were differentiated mainly by the effect of treatments. Different treatments were used on the slopes and plateau's and, therefore, the effect of topography must also be considered. The vegetation of the established or old rehabilitated areas were, however, found to be relatively homogenous. The majority of the plant cover consisted of the perennial grass species, *Eragrostis curvula*, *Cynodon dactylon* and *Hyparrhenia hirta*, while *Cyperus esculentus* and *Chamaecrista biensis* were the most abundant forbs occurring on the ash disposal sites. Species differentiation was based on the absence of certain species or differences in the dominance of species, for example *Chamaecrista biensis*, which occurred more abundantly in the *Chamaecrista biensis*

Variant (2.1.1) of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community. Differences in diversity were also found to be important in distinguishing variants of the *Hyparrhenia hirta-Eragrostis curvula* Sub-community (2.1). The *Panicum maximum-Digitaria eriantha* Variant (2.2.2) of the *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2) was the only variant based on habitat conditions, while the most of the other communities were more based on rehabilitation age or rehabilitation treatment. The *Amaranthus hybridus-Cyperus esculentus* Sub-community (2.2) was associated with a drainage area on a slope of the ash disposal areas.

Cluster analysis was performed using importance values of species from each year over a three-year period on rehabilitated ash disposal areas (Chapter 5). The species groups formed during cluster analysis, were less associated with treatments, and differentiated the vegetation on the basis of the dominance of selected species. The most significant changes over the study period were in the vegetation composition of newly rehabilitated areas. Changes in the cluster properties were associated with decreases in the abundances of *Eragrostis* spp. (*Eragrostis curvula* and *Eragrostis trichophora*) and *Pennisetum clandestinum,* and an increase in the abundance of *Hyparrhenia hirta*. During the first year (1997), most of the old rehabilitated areas were grouped together, with the *Eragrostis* spp. as the most important species. Vegetation of the plateau and two of the slopes on ash disposal site 1 were associated together. During the following two years, the newly rehabilitated areas became more similar to the older rehabilitated areas. Convergence in species composition was found towards the community composition of older rehabilitated vegetation. Convergence in the vegetation of older rehabilitated areas occurred because of changes in the abundance of perennial grass species. Some survey grids (G8/3, G12, and G4), however, remained grouped together, indicating that little differentiation occurred in the vegetation of that association. Grids that formed other associations and clusters were G2, G3 and G9 (Chapter 5). A possible reason for this is a decrease in the importance of *Pennisetum clandestinum* and increases in large tuft forming species such as *Hyparrhenia hirta*. The changes in species composition at grids G2 and G3 can be linked to regular and intense fires that swept through these areas during the study period. G7/3 remained a separate association throughout the survey period. The association of G10 and G11 remained the same but diverge from the rest of the old rehabilitated areas. A cluster analysis of only old rehabilitated areas of 1997 indicated that sampling grids G10 and 11 were already dissimilar to the rest of the older rehabilitated areas in the first year of survey. At the end of the third survey year (1999) five groups could be distinguished.

The following species were the most dominant in these groups:

Hyparrhenia hirta-Conyza bonariensis Group

Eragrostis curvula-Cyperus esculentus Group

Eragrostis curvula-Cynodon dactylon Group

Hyparrhenia hirta-Eragrostis curvula Group

Pennisetum clandestinum-Eragrostis curvula Group

The stability of the vegetation was investigated by comparing the changes in species importance values over the three-year period.

Statistically significant changes in species composition were found in Grids 2, 10, 11 and 12 during RDA ordinations (Chapter 6). Changes in species composition/ abundances were found in vegetation of some of the older rehabilitated areas. Box and whisker graphs and RDA biplots indicated consistent trends in importance value changes of dominant species. In areas where *Pennisetum clandestinum* was used, a consistent trend in the decrease of that species was indicated. On the plateau of ash disposal site 1, this decrease in *Pennisetum clandestinum* was followed by increases in *Eragrostis* spp. On the slopes of ash disposal site 1, decreases in *Pennisetum clandestinum* was accompanied by decreases in *Eragrostis* spp., but with marked increases in *Hyparrhenia hirta*. These tendencies were especially evident in grids 2 and 3. Decreases in *Eragrostis* spp. were less conspicuous in grid 4 on the eastern slope of ash disposal site 1. All these areas (grids 2, 3 and 4) were burned annually during the survey period. The other grid (grid 9), that was situated on a slope, experienced less drastic changes in species composition and most of the changes were in the importance values of annual species. The only perennial species that illustrated changes on grid 9 were *Pennisetum clandestinum,* which decreased considerably during the first year of survey (1997), and *Eragrostis* spp. and *Hyparrhenia hirta,* which increased simultaneously in importance values over the survey period. Outbreaks of the annual forbs *Bidens pilosa*, *Bidens bipinnata* and *Schkuhria pinnata* during 1999 on the bottom (transect 3) and upper (transect 1) transects were also experienced on grid 9.

Plateaus of ash disposal sites on which grids 10, 11 and 12 were situated, illustrated statistically significant changes in species importance values (Chapter 6). A similar trend to that experienced on the slopes of ash disposal site 1 occurred in grid 11. The importance value of *Hyparrhenia hirta* increased considerably with a reduction in the importance value of *Eragrostis* spp., which resulted in *Hyparrhenia hirta* replacing the *Eragrostis* spp. as the most important species after three years. These tendencies were, however, less significant in grid 10 and did not occur at all in the vegetation of grid 12. A consistent trend in the data at the three grids were the sharp increase in the importance values of *Chamaecrista biensis* during 1999 and a decrease in the importance values of *Cyperus* spp. during this period. Grid 11 was the only site on which bare ground has increased, accompanied by decreases in the importance values of the annual forb species *Tagetes minuta* and *Schkuhria pinnata*. The increase in importance values of *Chamaecrista biensis* on the plateau of ash disposal area 3 was more prominent than on other areas, except for grid 1 on the plateau of ash disposal area 1, which also showed an increased in *Chamaecrista biensis* during the 1999 season.

Vegetation changes on the slopes of ash disposal area 1 were probably due to regular fires during the survey period, and changes in the vegetation of grid 11 due to past fires followed by infestations of *Tatera brantsii* (Highveld Gerbil). Factors influencing vegetation changes in grids 10 and 12 are less evident. Recovery in the vegetation condition after previous fires (1996-1997) may be a reason for changes in species composition on grids 10 and 12. Although the vegetation of grid 12 was also burned and thereafter infested with *Tatera brantsii,* it did not affect the importance values of *Eragrostis* spp., as was the case on grids 10 and 11. This probably indicated that other environmental factors made these areas more resistant to the effect of burning, and burrowing activities of *Tatera brantsii.* A possible explanation for this higher resistance of *Eragrostis* spp. is the higher moisture conditions due to the position of grid 12 on a lower terrace which, therefore, promotes the accumulation of runoff water from the surrounding slopes. The effect of the slope was visible on grid 11. Part of the third transect was on top of a division wall of a lagoon. The topsoil was especially compacted in these areas and the habitat was visually drier than in the middle of the original lagoon itself.

After investigating the changes in importance values of species, the rate of vegetation change was determined using similarity/dissimilarity coefficients (Chapter 7). It was found that, although statistically significant changes or certain trends in the average values of species importance values could be observed, the rate at which they occurred was not consistently statistically significant. The rate of change between old rehabilitated sites with different rehabilitation ages did not vary statistically significantly. The rate of change on newly rehabilitated areas was the highest in comparison to older rehabilitated areas. These areas also illustrated the highest rate of change between all sites investigated. The results are consistent with most studies, which found that the initial changes in a community were high but decreased to a stable level during the following years (Facelli & D'Angela, 1990 and Myster & Picket, 1994). Due to the short duration of three years of survey, only two periods (1997-1998, 1998-1999) could be used and therefore no long-term trends could be established. Changes in community composition were investigated further by comparing the diversities of the sites sampled over consecutive years. No consistent decreases in species richness or Shannon Diversity Index Values could be found. Correlations between survey years and diversity indicates that diversity either increased statistically significantly or remained unchanged. The diversity was statistically significantly higher in the natural grassland than on rehabilitated ash disposal sites. No significant differences in species diversity could be found between newly rehabilitated and older rehabilitated sites. This is also consistent with results from the phytosociological study (Chapter 3). The highest diversity (Shannon Diversity Index and species richness) was found in an area rehabilitated during 1992 with a road transecting the site and an eastern facing slope (Chapter 7). A similar site rehabilitated during 1994, also with a road transecting the site and with an eastern facing slope, however, had a statistically significantly lower diversity than the other site with the similar topography. Species richness and evenness were also not consistently related, for example vegetation on the plateau of ash disposal site 3 had a low diversity and species richness but the highest evenness values of all the rehabilitated areas. If the relationship between diversity and stability is used to determine the ecological success of rehabilitated areas, then it must be concluded that the vegetation cannot be regarded as stable or sustainable. It is, however, argued that grasslands on the South African Highveld are characterised by the dominance of a few representatives of the family Poaceae. Diversity is, therefore, not always a good indicator of the condition of the veld. It is, however, realised that a higher diversity of perennial grass species with a high degree of evenness, will increase the stability of a community by increasing the inherent tolerance in the community.

After describing the changes and differences in the vegetation based on their species compositions, the effect of soil chemical and physical, as well as biological and management factors on the vegetation were investigated. It was found that most of the variation in soil chemical and soil particle size characteristics could be attributed to the initial topsoil used. Boron, pH and salinity were initially high on the newly rehabilitated areas, but were considerably lower in the older rehabilitated areas (Chapter 8). Soil chemicals associated with old rehabilitated ash disposal areas, which are considered limiting factors for plant growth, were found to be in acceptable limits in comparison to the natural grassland. Rehabilitation, in which a topsoil layer was used, resulted in an improvement of the growth medium. Soil chemical analysis also indicated that no saline or alkaline conditions existed. Soil chemical characteristics could, therefore, not be considered the most important limiting factor. Treatments used in the rehabilitation process explained variations in the vegetation composition better. Factors that had an influence on plant community development were effects of fire and the small mammal, *Tatera brantsii,* on plant species composition. N. Wright[1] (pers. comm.) and A. Vermaak[2] (pers. comm.) investigated these relationships between small mammals and vegetation in more detail in separate studies conducted on the dynamics and impacts of small mammals on the ash disposal sites (Van Hamburg, 1999). The effect of fire and disturbances due to *Tatera brantsii* activities were of special importance. Fire was found to be an important factor controlling the dynamics of the vegetation after rehabilitation. Regular effects of fire promoted an increase in the importance values of *Hyparrhenia hirta* with a subsequent reduction in the importance values of *Eragrostis* spp. and *Pennisetum clandestinum*. It was also found that fire and *Tatera brantsii* activities might promote the establishment of *Chamaecrista biensis* and *Cyperus* spp. These observations were also confirmed by experimental studies on the effect of *Tatera brantsii* colonies on vegetation in rehabilitated areas at Hendrina Power Station (Van Hamburg, 1999). The initial treatment and the frequency of fire can be regarded as some of the most important driving forces behind plant community development on ash disposal areas, together with the effect of *Tatera brantsii* colonisation patterns. The effect of fire

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was generally greater on slopes due to its higher frequency on slopes, whereas the effect of small mammal disturbances was more intense on plateaus. Some slopes however also had extensive *Tatera brantsii* colonies (no sampling grid was situated on a slope with extensive *Tatera brantsii* infestations). Extensive *Tatera brantsii* colonies was always visually associated with a low crown cover of grasses.

Biomass production between the natural grassland and old rehabilitated vegetation was not statistically significantly different (Chapter 9). This can be because of the dominance of large pioneer grasses on older rehabilitated areas. No correlation could be found between species diversity and biomass production, which is inconsistent with results from previously published data (Grubb, 1977 and Silvertown, 1980). Grass biomass and also litter mass were positively influenced by higher levels of soil nitrate but was negatively influenced by increase salinity and alkalinity. Fire were found to cause a reduction in the accumulated litter mass. Although the grass biomass of the rehabilitated areas was similar to the natural grassland the accumulated litter mass of the natural grassland was higher. The accumulation ratio of litter was more effective in the natural grassland than on rehabilitated ash disposal sites but was more susceptible to fire. The densities of a number of species were significantly correlated with biomass production. Grass biomass was mostly influenced by the density of *Hyparrhenia hirta,* while *Chamaecrista biensis* mainly influenced forb biomass. A higher grass biomass also in positive association with Hyparrhenia hirta encourage the establishment of *Hyparrhenia hirta seedlings.* Because *Pennisetum clandestinum* was negatively associated with increased grass biomass the possibility exists that this species is outcompeted by species with a higher biomass production.

12.1.2 Condition assessment and monitoring of vegetation

From the literature it is clear that monitoring approaches in general are based on two successional theories in plant ecology. The first is based on the original climax concept first described by Tansley (1935), Clements (1936), Dykershuis (1949), Whittaker (1953) and Egler (1954). Monitoring is then conducted in relation to a known threshold that can be identified in a successional sere. The threshold that is used, is normally a perceived climax condition. The second successional theory was created on the principle of non–equilibrium ecology (Westoby *et al.*, 1989). This explained the dynamics of rangelands on the basis of a number of stable states which are linked by transitions based on the effect of management strategies (burning programs, grazing intensities, etc.) and environmental conditions (e.g. drought or moisture regime changes). No defined climax is therefore indicated.

A State and Transition Model (Chapter 10) was developed as a method of summarising the results of the study. In this model the dynamics of the rehabilitated vegetation was explained in terms of changes in the abundance of the three dominant species *Hyparrhenia hirta*, *Eragrostis* spp. and *Pennisetum clandestinum* and the occurrence of *Acacia mearnsii.* The model also indicated possible driving forces that may cause the Transitions between States. The model portrays how rehabilitated vegetation may develop where the species composition is similar to this case study. The state and transition model was also developed as a hypothesis-generating tool that can be used in other similar case studies.

Condition assessment models were developed to determine the ecological condition of the vegetation of rehabilitated ash disposal sites at Hendrina Power Station (Chapter 11). It was difficult to indicate the condition based on only one possible "climax condition" with species as entities. Results also indicated that more than one climax condition may develop, depending on the trajectory of development (Chapter 10). After applying the *Hyparrhenia-Cyperus* Condition Assessment Model developed in this study (Chapter 11) to surveys conducted on ash disposal areas at Kragbron Power Station, it was realised that the use of species as entities to determine the condition of rehabilitated areas is limited. It was, therefore, attempted to unify the entities in a condition assessment model by grouping species together in functional groups, and by incorporating community characteristics. The percentage of bare ground and basal cover were found to be valuable community characteristics. Shannon Diversity Index values and species richness were, however, not associated with bare ground and basal cover if only rehabilitated sites were compared. Results indicated that, if the natural grassland were incorporated in the model, then diversity would be associated with basal cover and percentage bare ground. It must, however, be asked whether the diversity of the rehabilitated grassland is comparable to the natural grassland. The composition according to life forms, basal cover and bare ground was used to construct a community attribute model. All areas, including natural grassland and newly rehabilitated areas, were incorporated to provide a condition gradient based on a successional gradient, from a pioneer stage typical of newly rehabilitated sites, to a hypothetical climax stage dominated by perennial grass and forb species.

No single condition assessment model (Chapter 11) could be constructed to determine the ecological condition of the rehabilitated areas, and therefore the state and transition model (Chapter 10), which incorporated four different endpoints and how they are related to each other was a better method to explain the dynamics of the vegetation. Both models (Chapters 10 and 11) were based on the interaction of the perennial grass species *Eragrostis* spp. and *Hyparrhenia hirta*, which were the two most dominant tuft grasses. *Cyperus* spp. was used as an indication of deteriorating or insufficiently vegetation establishment. The state and transition model presented a number of conditions, which were not incorporated in the condition assessment models. A good example of this is the occurrence of *Pennisetum clandestinum*-dominated grassland and *Acacia mearnsii* Woodland states, which were possible trajectories, but which were not incorporated in the condition assessment model. The *Eragrostis-Cyperus* and *Hyparrhenia-Cyperus* condition assessment models, however, also recognised the occurrence of an *Eragrostis* spp. dominated state and a *Hyparrhenia hirta* dominated state.

These two condition assessment models can, therefore, be incorporated in a state and transition model to increase the power of the model. To quantitatively assess the vegetation in a state and transition model is difficult and the use of a gradient analysis method to assess the vegetation will be more informative.

12.2 CONCLUSIONS

12.2.1 Plant community characteristics and dynamics

Similar conclusions on the dynamics of developing vegetation found in other case studies could be identified on rehabilitated ash disposal sites at Hendrina Power Station.

These include the initial site conditions as a common factor influencing community development (Myster & Picket, 1990 and Dzwonko & Loster 1998), which were also found to be an important driving force on rehabilitated ash disposal sites. Results and observations indicated that the species composition on rehabilitated areas were a function of the seed mixture and topsoil seed bank.

The dynamics of the rehabilitated grasslands showed predominantly a unidirectional change towards a community structure consisting of similar perennial grass species (*Eragrostis curvula, Hyparrhenia hirta* and *Cynodon dactylon*) on a species compositional level indicating that vegetation will converge towards a vegetation type predominantly characterised by *Eragrostis curvula, Hyparrhenia hirta* and *Cynodon dactylon*. According to Glenn-Lewin & Van der Maarel (1992) convergence is also more probable in systems with a low diversity or where one or few species dominate.

To conclude that only one state exists and that all vegetation will converge towards a species composition dominated by above species is, however, oversimplified. Results have indicated that four different endpoints could be reached under different scenarios. These four end points included a state dominated by *Pennisetum clandestinum*, an *Eragrostis curvula* dominated state, a *Hyparrhenia hirta* dominated state and an *Acacia mearnsii* woodland state. Some areas have developed into other communities as a result of specific site conditions for example areas dominated by *Pennisetum clandestinum* in high moisture areas. Even if all the above species may be dominant differences in species composition of low occurrence species (*Chloris gayana, Stylosanthes fruticosa* and *Lespedeza cuneata*) did exist and remained for the duration of the study. Homogenisation between areas regarding lower occurring (transient) species did, therefore, not occur even after nine years of community development. Results of the current study related well to successional models proposed by a number of authors. The initial succession on rehabilitated areas follows the successional model (**monoclimax theory**) as proposed by Clements (1936). Two processes described by Connel & Slatyer (1977) can be predominantly observed in succession on rehabilitated vegetation. Facilitation plays an important role during the first two years after rehabilitation because of the role of annual species as soil stabilisers. The inhibition model may, after the establishment of a perennial grass sward, take over as regulating process due to the increasing competitiveness of existing species. This may partially explain the continual dominance of particular species.

Older rehabilitated vegetation may develop into a number of endpoints **(multiple climax theory-** Whittaker, 1953 and Whalley, 1994) depending on the initial conditions and regulating environmental factors (moisture, fire, small mammal disturbance or continual human management). The existence of a true climax condition is also questioned because vegetation illustrated continuous changes particularly due to annual species changes (**non- equilibrium ecology** – Hulst 1978, Begon *et al.*, 1990 and Whalley, 1994).

The first, most adapted perennial species with a high competitive ability will determine the community dynamics because other less adapted species (for example *Digitaria eriantha*) will be outcompeted. *Eragrostis curvula* and *Hyparrhenia hirta* determined the dynamics of the vegetation in this study of rehabilitated ash disposal sites, as the first species with a high competitive ability. It may therefore be necessary to manipulate the initial composition if other species are favoured more (Dobson *et al.*, 1997). Species that are most suited to the local habitat will survive due to competition and environmental conditions acting as a selection sieve (Hulst, 1978). This is shown by the number of grass species used in the rehabilitation of ash disposal sites, but only a few (for example *Chloris gayana, Cynodon dactylon, Eragrostis curvula* and *Digitaria eriantha*) established successfully (Morgenthal *et al.*, 1999).

Roberts *et al.* (1981) indicated that diversity on rehabilitated areas was in most case studies low and this was no exception at Hendrina Power Station. Dzwonko & Loster (1998) attributed the low colonisation of grass species to the restricted dispersal abilities of grassland species. Results at Hendrina Power Station indicated that the species in the seed mixture and the viable soil seedbank largely determined diversity on rehabilitated areas. Changes in diversity were also more due to increases in evenness than to increases in species richness. A high diversity is regarded as important because higher diversity increases the resilience in the community (Barbour *et al.*, 1987) and increase the number of key species (Robinson, 1994). Higher species richness also ensures a source of available potential dominant species and exerts a selective effect on regenerating dominants (Grime 1998). This is probably true but is difficult to put into practice on rehabilitated areas because environmental rather than community process (competition) will act as selection sieve during community development.

Figure 12.1 is a schematic illustration of the influence of plant community characteristics and environmental characteristics on plant community and environmental stability. Although only plant community characteristics have been considered, faunal components can be added to improve the legitimacy of the model. It is postulated that in the presence of a stable environment and good plant cover, sustainability will be possible at an autotrophic level. Plant community stability is expressed as a function of the environmental stability. Critical environmental characteristics include amongst others the growth medium (of considerable importance is soil fertility and toxicities), climate (drought periods can have a negative effect during the initial rehabilitation period) and disturbance (results indicated in this study that fire may be detrimental to rehabilitated vegetation). The characteristics of the vegetation are also ultimately linked to the nature of the growth medium (Iverson & Wali, 1992).

A number of floristic characteristics are indicative of a stable vegetation cover, that can be summarised in relation to the species composition, diversity and life history characteristics (Figure 12.1).

12.2.1.1 Species composition

Plant species composition (including the presence of specific ecotypes) indicates the availability of key species adapted to the specific environment. Hooper (1998) showed that the species composition present could be as important as the richness in species. Figure 12.1 also suggest that environmental stability is partially determined by the species composition because the adaptability of the species must be considered if reference is made to environmental stability (Kelly, 1989). Examples of certain species that have shown adaptability to environmental conditions on rehabilitated ash disposal sites at Hendrina Power Station, because they regenerated and illustrated an increased occurrence, are *Chamaecrista biensis*, *Cynodon dactylon*, *Eragrostis plana*, *Hyparrhenia hirta* and *Lespedeza cuneata*.

The species composition can also be related to the life-form spectra (e.g. Chamaephytes, epiphytes) and functional groups (stoloniferous graminoids) that may be present. Certain life-forms or functional groups can be regarded as being indicative of a stable ecosystem. The species composition will also influence the biomass production and life history characteristics of the plant communities.

12.2.1.2 Species diversity

According to examples in the literature, species diversity is one of the community characteristics that may be linked to higher community stability due to increase resilience against disturbance (Begon *et al.*, 1990). A low species diversity is a common problem in rehabilitated areas due to the use of limited numbers of species for rehabilitation (Roberts *et al.*, 1981 and Iverson & Wali, 1992). A problem with present seed mixtures used during rehabilitation is the use of species with a low adaptability for rehabilitation purposes. A limited local species pool for colonisation on rehabilitated areas also contributes to the problem of low diversity (Pärtel *et al.*, 1996).

Questions should be asked about the relationship between stability and diversity in grassland ecosystems, because a common characteristic of grasslands is the dominance of one or two species. Examples of this are the occurrence of *Hyparrhenia hirta* dominated grasslands along road verges, the dominance of *Eragrostis plana* on flood plains and the occurrence of pure stands of *Imperata cylindrica* on waterlogged soils in the region.

Conventional philosophy regarding the Pop Rivet Theory however proposed that a diverse number of components are necessary for sustainability to persist (Begon *et al.*, 1990 and Leaky & Lewin, 1995). Theoretically ecosystem stability will, therefore, be improved by higher diversity of species.

Grime (1998) however suggested an alternative view of diversity; the Mass Ratio Hypothesis that is probably more suited to grasslands and rehabilitated grasslands. Following the Mass Ratio Hypothesis the ecosystem properties should be determined to a large extent by the characteristics of the dominant species. Considering the higher importance of dominants, ecosystem properties will be less sensitive to changes in species richness in sub-dominant and less common (transient) species. Results from this study (Morgenthal *et al.*, 2000) indicated that the grass species with the highest biomass (*Eragrostis* spp. and *Hyparrhenia hirta*) mostly dominated the vegetation on rehabilitated areas and illustrated the highest increase in occurrence (*Hyparrhenia hirta*). The occurrence of *Hyparrhenia hirta* and *Chamaecrista biensis* were best associated with increases in grass and forb biomass respectively. Both these species were dominant species, which further support the mass ratio hypothesis. According to Grime (1998) a high diversity of species is beneficial. Sub-dominant species and transient species (as used by Grime, 1998) may play an important role in niche development and may influence the regeneration of dominant species. It is also recognised that a high richness of sub-dominant and transient species increased the capacity of vegetation not to deteriorate after disturbance because adapted sub-dominant species may replace the dominant species.

A number of studies indicated that biomass could be negatively related to species diversity (Vermeer & Berendse, 1983) especially under high fertility. Results from this study however failed to indicate any relationship between these two community characteristics because the growth medium is only of low to moderate fertility and therefore the ability of the ecosystem to maintain a high species diversity is not possible.

12.2.1.3 Life history characteristics

A third important aspect in plant community stability is a lack of species change due to the persistence of long-lived species (K-selecting species) (Barbour *et al.*, 1987 and Begon *et al.*, 1990). Persistence therefore is determined by the life history characteristics of the dominant species and continual regeneration of long-lived species will enhance stability.

Another component in ecosystem stability is the presence of the microbiological and faunal component in the soil (Figure 12.1), which were investigated in other studies as part of the research conducted at Hendrina Power Station (Van Hamburg, 1999). Microbiological activity is an important ecosystem aspect because it promotes mineral recycling. During this study biological activity in the form of soil fauna has been considered as an important aspect of ecosystem development.

Results indicate that *Hyparrhenia hirta* or *Eragrostis* spp. will probably dominate most areas if stability is reached. Due to the slow colonisation rate no drastic change in species composition will occur in the short term. The species diversity will remain low if no additional inputs are made such as diversification of the habitats and the use of a larger number of species in seed mixtures.

The long-term stability of the vegetation will ultimately depend on the soil fertility of the growth medium. Possible causes for deteriorating soil fertility is a continual drop in pH, which may increase the solubility of microelements and heavy metals. According to Bradshaw (1984) it has been found that if no adverse habitat conditions exist, the present vegetation cover will improve the habitat and stimulate other slower ecosystem processes such as nutrient cycling and soil microbiological activities. According to present soil chemical analyses no adverse toxicity problems exist in the topsoil and ash of the study area (Chapter 8). At present, disturbances by small mammal populations and frequent fires are the most important factors contributing to environmental instability. Other factors contributing to environmental instability are soil physical properties (formation of impermeable layers) and nutrient deficiencies. It may be argued that the effects of these disturbances may only be short term and form part of the natural ecosystem processes.

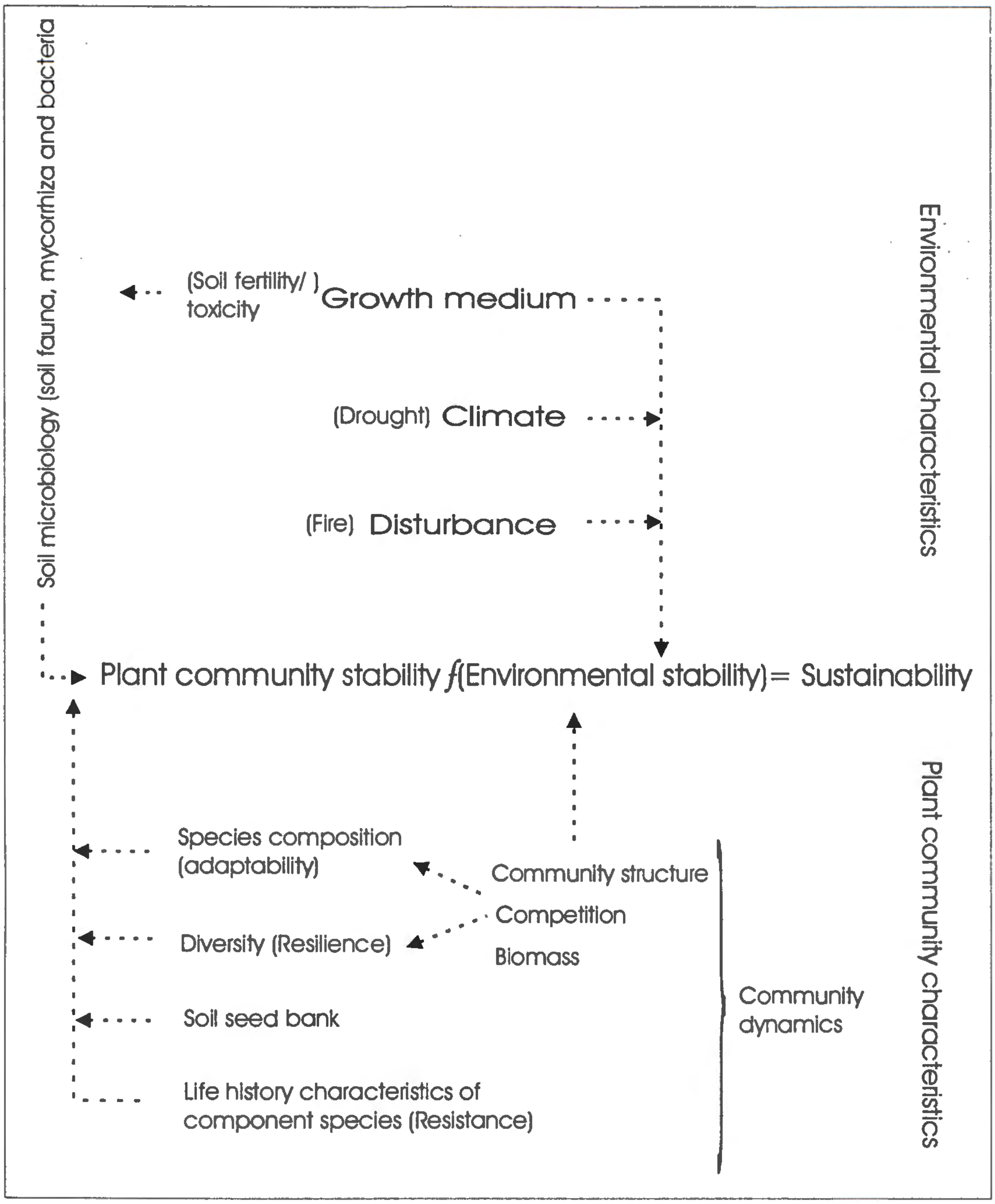

Figure12.1: A schematic diagram indicating possible factors relating to plant community stability and environmental stability to ensure sustainability at an autotrophic level on rehabilitated mine areas.

12.2.2 Vegetation stability

The most important question of this study is whether stability has been reached after nine years of rehabilitation? This will depend on the references point which is used to define stability.

If the natural grassland is used as reference point, then rehabilitation has failed because no successional development in rehabilitated ash disposal sites towards the community characteristics of the natural grassland has taken place. Except for a similar biomass (Chapter

9) and a small number of species occurring in both areas (Chapter 4) no other similarities were found between the natural grassland and older rehabilitated areas. It is believe that to compare the two areas, and to expect that the vegetation of the rehabilitated ash disposal sites will develop into a similar species composition and community characteristics as the nearby natural grassland is unrealistic and highly unlikely due to habitat differences and slow colonisation patterns (Morgenthal *et al.,* 1999).

If a lack of change in the abundance of key species is considered to reflect a stable state, then stability has not been reached on most sites because results indicated that changes in the abundance of key species (e.g. *Pennisetum clandestinum* and *Eragrostis* spp.) are still taking place. The only site which probably applies to this definition of stability is the bottom transect of G7 situated on the lower slope of a five year old rehabilitated slope (Figure 5.10). Both Chapters 5 and 6 indicate that changes in the abundance of key/dominant species are significant in a number of areas. Some of these changes could also be regarded as unidirectional (Table 6.1).

From a species compositional viewpoint stability has been reached because little evidence of any compositional changes could be observed on older rehabilitated areas. This is also confirmed by studies on changes in species richness, which were not statistically significant if a sequence of nine years are used (Chapter 7). Results indicate that stability due to a lack of species compositional changes could be possible within 3-4 years after rehabilitation depending on the time of seeding, soil seed bank and climatological conditions.

It is concluded that vegetation stability has been reached from a compositional viewpoint and within the time frame of the study and will probably remain stable if, as explained in Figure 12.1, the environment remains stable.

12.3 OVERALL CONDITION OF ASH DISPOSAL AREAS AT HENDRINA POWER STATION

The overall condition of areas rehabilitated before 1996 were satisfactory. The only vegetation in a deteriorated condition was on the plateau of ash disposal site 3, in the area on which grid 11 was situated, due to low moisture regimes, frequent fires and extensive infestations of *Tatera brantsii.* Most of the slopes investigated had a higher crown and basal cover than the plateaus. The rehabilitation can however, be regarded as successful in the establishment of a perennial grass cover. The dominance of perennial grass species is beneficial for rehabilitation success, because species longevity, renewal and management are of interest for rehabilitation success (Fox & Tacey, 1994).

The diversity of the sites was far lower in comparison to the adjacent natural grassland area (Figure 2.1). Little habitat diversity exists and the prevalent vegetation was found to be relatively homogenous in composition. The plateau of ash disposal site 1, which was covered by a soil layer but never sown, had a higher species diversity than surrounding areas sown with a seed mixture. This may indicate that if a higher species diversity is required after rehabilitation, then competitive grasses such as *Eragrostis curvula* must be excluded, or the use of a seed mixture of any sort should be reconsidered. The species that will establish will then be from the soil seed bank of the topsoil and will consists of a large diversity of annual forbs (especially during the first few years) and grass species that originally grew on the area from where the topsoil was taken. The origin of the topsoil will also influence the type of vegetation that will establish on the rehabilitated sites. The rehabilitated areas will then be left to colonise itself from the available seed bank and natural succession will be the ultimate goal. The question must, however, be asked whether a high diversity due to a large number of annual forbs in the short term is desirable in rehabilitated systems that are left unsown? During rehabilitation it is more important to establish a dense vegetation cover over the long term using perennial species. A permanent vegetation cover is more desirable to control dust pollution, water runoff and erosion on disposal sites. The only way that a permanent vegetation cover can be established, is if the vegetation consist of perennial species and regeneration of those species occurs. Because of the above reasons such studies on the natural colonisation from the topsoil layer on dumps have not been conducted in South Africa. Examples however exist of studies conducted on the natural colonisation of open cast coal mines in the USA (Holl & Cairns, 1994 and Skousen *et al.* 1994).

12.4 PROPOSALS FOR FUTURE VEGETATION MONITORING PROGRAMS

Based on experience gained from the current study, the following proposals are made for other vegetation monitoring studies on ash disposal areas.

12.4.1 A phytosociological approach must be considered as a prerequisite for future monitoring studies. Although it is a qualitative method, a phytosociological approach will provide a detailed floristic account of all vegetation. Secondly, a phytosociological approach identifies homogenous areas on which quantitative survey plots can be laid out. The level of "homogeneity" must, however, be decided, for example on a community, sub-community or variant level. The extent of the homogenous areas will become known after a phytosociological study which will determine the specific method that should be used in further quantitative surveys. Through phytosociological studies "states" in the vegetation can be identified that can be incorporated into a state and transition model or management plan. A phytosociological study can also identify critical sites that can be incorporated into a preliminary condition assessment model. The relationship between survey sites in homogenous areas (communities), by comparing the number of species shared between survey sites in homogenous areas (communities), will also become known after a phytosociological study is completed.

12.4.2 In the current study quantitative surveys were conducted over a three-year period, using a descending point survey method and a quadrat method was used to determine the frequency, basal cover, density and biomass of the species. These survey methods proved sufficient to indicate species changes on a macro scale over consecutive years. A descending point method along a 120 m long transect will, however, not be adequate or accurate enough to indicate small variations in the vegetation composition. Because the study was descriptive rather than experimental, it was difficult to relate environmental variables to species data. The CANOCO program, however, proved useful to detect environmental effects. Although surveys were conducted seasonally, only annual results over the three years were included in the study. The best time for surveys was found to be during February and March (Van Hamburg, 1999) and seasonal surveys seemed to be unnecessary, because little or no winter annuals were found. A late winter survey is proposed if the remaining vegetation, which is left from the previous growing season, needs to be known. Descending point surveys will provide adequate information about the species composition and basal cover of the area. In smaller areas a bridge point/point frame apparatus should be used for surveys on a smaller scale and for small homogenous areas (Brown, 1954).

12.4.3 Multivariate statistical analysis in the form of ordinations was the best way of analysing the data, because the visual presentation of analysed data made it easier to interpret results. A community approach was used, and it was, therefore, possible to investigate sites as part of a community with species as entities. It was seldom necessary to analyse data at a population level. The value of CANOCO has been discussed in previous chapters as a direct ordination method and CCA and RDA ordinations were capable of indicating the most important gradients. Although it was necessary to divide environmental variables into smaller groups to prevent collinearity, the most important gradients could still be extracted.

12.4.4 It is suggested that monitoring programs must be instated from the beginning of a rehabilitation program. It was difficult to determine the development of the vegetation of old rehabilitated sites because these sites were rehabilitated more than three years at the start of this study and perennial grasses already formed a dominant component of the vegetation at these sites. Questions that arose include the following: How did the vegetation develop? What were the initial species that established? Was *Hyparrhenia hirta* a major component from the start? Detailed seed bank analyses are necessary if the soil seed bank is important (as is suspected in this case), and it would be desirable to determine the plant species composition of the areas from where the topsoil was excavated, which was used in the rehabilitation process.

12.4.5 Monitoring studies should be done over a longer period of time than three years, to give adequate results (Inouye & Tilman, 1988). Examples of long term studies conducted in Europe and the USA include those of Smyth (1997), who investigated early successional patterns of vegetation on amended and unamended coal mine soils for a period of five years, and Myster & Pickett (1994), who did an annual study on 10 contrasting old fields for a period of 18 years. The longest study was that of Dodd *et al.* (1995) who used data gathered over a period of sixty years to examine the trends and outbreaks of species as part of the Park Grass Experiment. Another approach is the use of sites with different rehabilitation ages, thereby obtaining a sequence of sites with differences in rehabilitation age, for example Ursic *et al.,* (1997) who investigated revegetation dynamics of quarry walls over a chronosequence from 17 to 92 years old. This approach is only possible if the habitat and treatment of the sites are similar and the climate has remained relatively uniform.

12.4.6 The grid concept should not be applied too strictly, because it could result in transects of one grid situated on three different vegetation types that were differently treated during rehabilitation. The design of the grids on areas with different treatments close to each other, or without sufficient space for a fixed grid system, should be adapted to make provision for such areas. Transects of grids could be placed one behind the other instead of side by side. This would ensure replicability of the sample plots, which are important for statistical analyses.

12.4.7 Too little emphasis is usually placed on soil physical properties and how they influence vegetation establishment. During excavation of root systems of the most dominant species it was found on numerous occasions that roots only developed in the top 15-20 cm layer of growth medium. Mat-formation of roots occurred commonly, and many plants were probably "pot bound" by the impermeable layers in the ash that formed because of the pozzolanic properties of coal ash. This probably had large implications on soil moisture conditions and root penetration. It must, however, be said that the emphasis of the current study was more related to botanical diversity, as well as investigations into the plant community development of rehabilitated ash disposal sites, than the impact of growth medium conditions on plant growth. The subject of soil physical conditions on rehabilitated areas has also been investigated thoroughly by Hodgson & Holliday (1966), Townsend & Hodgson (1973), Bradshaw & Chadwick and (1980) El-Mogazi *et al.* (1988).

12.4.8 Surveys in the current study were not fixed to precisely the same place or line, but were conducted approximately along the same line because continuous trampling by a research team of six to eight persons using the same transect could have a substantial impact on the vegetation. Surveys on mesofauna, insects and small mammals which formed part of the greater multidisciplinary study were all conducted along the same transects. The line of survey was therefore not consistently used along the transect, but often next to the transect.

12.5 PROPOSALS FOR FUTURE REHABILITATION

Results from this study and a study from Morgenthal *et al.* (1999) indicated that only a small percentage of the species that were sown actually germinated. Unfortunately the quality of the seeds used were not tested beforehand. The seeds from certain species were from commercial seed companies, which are enforced by law to control the quality of their seed. A number of species represented in the seed mixture were harvested in the veld and were not quality guaranteed. The seed mixtures that were used, therefore, were shown to be ineffective. The only species used in the seed mixture that were frequently found or recorded are *Eragrostis curvula, Eragrostis chloromelas, Chloris gayana, Heteropogon contortus, Themeda triandra, Digitaria eriantha, Hyparrhenia hirta* and *Cynodon dactylon.*

Grasses that dominated the vegetation were *Eragrostis curvula* and *Hyparrhenia hirta,* as well as the two stoloniferous grasses, *Pennisetum clandestinum* and *Cynodon dactylon*, which were also dominant in more moist areas. *Chloris gayana* established especially well along the upper slopes of ash disposal area 1. *Digitaria eriantha* was relatively frequent on the plateau of ash disposal area 3 and on the slope where grid 4 was situated. The highest occurrence of *Heteropogon contortus* and *Themeda triandra* was found on the eastern slope of ash disposal site 3, on which grid 9 occurred. Results from Chapter 8 indicated that these species preferred less saline conditions and were also associated with higher levels of ammonium and manganese. The grasses *Cenchrus ciliaris* and *Panicum maximum* were only found once on ash disposal areas. Annual species (*Eragrostis tef* and *Enneapogon cenchroides*) acting as pioneers were established relatively successfully. The regeneration of these pioneer species is, however, not critical and there absence during later stages are less important.

The role of the soil seedbank of the topsoil must not be underestimated. Strong evidence exists that the *Acacia mearnsii* Woodland originated from a viable seed bank. The question must also be asked what is the role of the seed bank in establishing dominant or co-dominant stands of *Hyparrhenia hirta*? Most of the secondary climax vegetation in and around the disposal areas (for example road verges) are dominated by stands of *Hyparrhenia hirta*, but only a small percentage of the seed sown was that of *Hyparrhenia hirta*. Little evidence exists that further colonisation of species from surrounding areas have occurred. The topsoil is, therefore, important in increasing the diversity of the ash disposal sites. Smyth (1997) also found the use of native soil beneficial, due to the additional input of seed bank species to the system, thereby increasing the species richness of the rehabilitated area. This can be seen from the lack of increase in the species richness of the ash disposal area. The other possibility for no increase in species richness is because the number of species colonising the area is equal to the extinction rate of species (Hulst, 1978). The input from external sources like other remaining natural and semi-natural areas must also be considered to be low, because no natural area directly bordered any of the ash disposal sites. Most of the surrounding areas are cultivated maize fields. Species that colonise from these areas are therefore minimal and are ruderal annual weeds e.g. *Conyza bonariensis, Tagetes minima* and *Bidens formosa.*

12.5.1 Selection of species for revegetation

From this studies a seed mixture of the following species is recommended for future use on ash disposal sites at Hendrina Power Station and other stations in the region.

Pioneers: *Eragrostis tef, Enneapogon cenchroides, Pogonarthria squarrosa, Aristida congesta* subsp. *congesta* and *Eleusine coracana subsp. africana.*
Perennials: *Eragrostis curvula, E. chloromelas, E. trichophora, E. plana, Chloris gayana, Heteropogon contortus, Themeda triandra, Digitaria eriantha* (stoloniferous variety), *Hyparrhenia hirta* and *Cynodon dactylon* (sods). It is recommended that, if mowing for fodder is intended, then *Hyparrhenia hirta* must be excluded from the seed mixture. The use of *Hyparrhenia tamba* and *Imperata cylindrica* (rhizomes) (especially in damp areas) may be considered, although both are not appropriate as fodder. It is further recommended that *Setaria sphacelata* var. *torta* be tested and screened for possible inclusion in the mixture (this species was, however, not found on the ash disposal areas, but occurred abundantly in the natural grassland). The grasses *Panicum maximum, Chloris virgata, Cenchrus ciliaris, Fingerhuthia africana* and *Eragrostis echinochloidea* that were used in previous seed mixtures, were found to be unsuccessful to establish (Morgenthal *et al.,* 1999). The further use of these species is therefore not recommended.

The use of legumes is very important in many rehabilitation schemes in overseas countries, due to their symbiotic relationship with nitrogen fixing bacteria (Bradshaw, 1980). The legume species *Chamaecrista biensis, Stylosanthes fruticosa* and *Vigna vexillata* are proposed for inclusion in the seed mixture. It is strongly suggested that proposed legume species must still be tested for nitrogen fixing properties, and the correct strain of bacteria must be identified for inoculation. These plants are only listed due to their <u>possible</u> fixing properties and due to their high frequency on the ash disposal areas at Hendrina Power Station.

12.5.2 Identification of possible species for rehabilitation

No evaluation of species success was performed to test the viability and suitability of the species to the habitat. Restoration and rehabilitation of mine spoils in Europe and USA usually undergo screening tests to determine the viability of the species and germination success. The following levels of species selection for rehabilitation can be distinguished:

12.5.2.1 Ecological selection

The first step is to identify species that form part of earlier and later successional stages. Species are selected based on their ability to colonise and persist in similar conditions, by looking at species growing on the type of surface that are to be rehabilitated, or in habitats with similar conditions. Jusaitis & Pillman (1997) collected species that grow in and around overburden heaps, edges of fly ash ponds and salt flats in southern Australia. These species were already considered to be halo or xerophytic (Jusaites & Pillman, 1997).

12.5.2.2 Germination test

The viability of the seeds are tested by germination of the species in petri dishes (Salo *et al.*, 1996) or by using diaphanoscope or X-ray machines (Smyth, 1997). The germination test is used to determine the viability.

12.5.2.3 Glasshouse trials/pot trials

The first screening takes place in a controlled environment in glasshouses by testing the tolerance of the species. Tests could also be conducted to determine which nutrients would possibly be missing by using the tailings/ash as growth medium. The seedling emergence and growth of the plant in the waste material are also evaluated (Jusaitis & Pillman, 1997).

12.5.2.4 Field trials

The following step is to use the species under a number of possible amelioration practices to determine the best amelioration method for the specific species. The regeneration and survival of the species is also investigated.

Species are screened at each trial level and thereby the suitability of the species and amelioration practices for rehabilitation onto the waste disposal area are ensured.

If an ecosystem which is characterised by a higher species diversity is required, then the present inputs must be adjusted. This will mean experimental studies that are aimed at identifying perennial forbs and other grasses to increase diversity. Additional amelioration practices of a higher standard (landscaping, addressing nutrient deficiencies and toxicities and increasing seed input) and long-term management will be required. This will ultimately increase financial inputs to attain this level of output.

12.5.3 Aftercare and management

Bradshaw and Chadwick (1980) indicated aftercare as a crucial component (Chapter 1, Figure 1.1). Ecosystem development can be improved by a continued input of nutrients or application of organic material; especially in areas were retrocession occurred. The areas where vegetation did not establish sufficiently can also be resown to improve the condition. The loosening of the topsoil on plateaus, where compaction is a frequent problem, to improve seedling establishment and water infiltration can also be recommended. An area on top of ash disposal site 3 was characterised by surface crusts and compaction.

Results indicated that the most important environmental factors regulating community change are regular fire occurrence and infestations of *Tatera brantsii*. These two factors are, however, associated with each other. It is proposed that fire frequency be controlled on the ash disposal areas. It is realised that uncontrolled veld fires are a problem that are difficult to solve. Regular veld fires have a negative effect on the crown cover and species composition and, therefore, possibly on the stability of the vegetation. Promotion of a vigorous crown cover by excluding regular fires may also control the problem of *Tatera brantsii* infestations, due to the habitat preference of the small mammal to bare areas. The condition assessment models can be used to evaluate the rehabilitated areas to indicate where possible reseeding and fertilisation are needed to improve the condition.

Other factors that probably influence vegetation condition are soil physical conditions for example crust formation, soil moisture and presence of impermeable layers. These factors were, however, not thoroughly investigated and further studies are necessary to look at these impacts. In comparison with other ash disposal areas, the soil chemical conditions of ash disposal sites at Hendrina Power Station were more favourable for plant growth.

12.6 FINAL COMMENTS

12.6.1 Rehabilitated ash disposal sites at Hendrina Power Station followed a successional pattern typical of old fields in the Highveld.

12.6.2 Fires promoted the increase in the abundances of *Hyparrhenia hirta* and negatively affected the regeneration and existence of *Pennisetum clandestinum* and *Eragrostis* spp.

12.6.3 The most important factors determining the dynamics of vegetation are the initial treatments, fire and infestations of *Tatera brantsii.*

12.6.4 Bare ground and basal cover, together with life form classes, were successfully used to determine the plant condition after rehabilitation.

12.6.5 Vegetation stability has been reach on old rehabilitated areas from a compositional veiwpoint if data are considered within the time frame of this study. No indication can be found that the vegetation of the older rehabilitated areas is in a retrocessional state or that diversity of the ecosystem is decreasing. The diversity of the rehabilitated ash disposal sites are, however, much lower than that of the natural grassland.

12.6.6 Colonisation and expansion in the populations of rare perennial species are slow or non-existent.

12.6.7 The vegetation dynamics are based on changes in species abundances rather than changes in the overall species composition. The only areas on which total changes in species composition are the newly rehabilitated areas.

12.6.8 The vegetation on ash disposal areas will probably never achieve the same floristic composition and life form characteristics that prevail in the adjacent natural grasslands, due to the drastic environmental differences between the two areas.

12.7 RESEARCH ISSUES THAT CAN BE DERIVED FROM THE STUDY

12.7.1 Are the dynamics of rehabilitated grasslands on ash disposal sites at Hendrina Power Station similar to other rehabilitated areas of ash disposal sites?

12.7.2 Legumes are the most dominant forbs especially on older rehabilitated areas. What are the influences of these legumes in the improvement of the nitrogen cycle in rehabilitated ecosystems?

12.7.3 What is the role of the topsoil seed bank and soil of the sods of stoloniferous species? Although the present study does not investigate the soil seed bank it is suggested that it played an important role in vegetation dynamics.

12.7.4 What is the effect of soil moisture and impermeable layers on vegetation dynamics?

12.7.5 This study is purely descriptive and the conclusion generated from this study needs experimental verification.

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Appendix A

Paper published in SA Tydsrif vir Natuurwetenskappe en Tegnologie, 18(4): 106-115

THE USE OF ORDINATION TECHNIQUES FOR THE EVALUATION OF REHABILITATION SUCCESS OF ASH DAMS ASSOCIATED WITH COAL-DRIVEN POWER STATIONS (Afr.)

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Abstract

The use of plant species during rehabilitation is in essence an ecological problem. The aim of vegetation rehabilitation program must, therefore, be to obtain a stable and sustainable ecosystem. The characteristics of these ecosystems do not have to be similar to the original systems but must be of the same value to satisfy the aim of rehabilitation and sustainable development. The South African Bill of rights demand that development must be ecological self-sustainable to ensure a healthy environment for the people of this country. The rehabilitation of ash dams at ESKOM power station sites is an important aspect of the strategy to minimise the impact of these power stations on the environment, to facilitate the wise utilisation of these rehabilitated areas and to acquire future closure certificates. Monitoring rehabilitated areas must be regarded as an important aspect of a rehabilitation program because it is an important aid during the selection of treatments to improve the growth medium and therefore stimulate species establishment. Monitoring also serves to identify problems and to improve aftercare. During this study a multivariate technique was used as monitoring tool to identify pattern of species establishment. A Detrended Correspondence Analysis (DCA) ordination technique was employed to analyse frequency data from surveys being done during the summers 1997 and 1998. The significance of the first ordination axis was derived from the length of the axis and it's eigenvalue, which gives an indication of the amount of dissimilarity along the axis. An eigenvalue larger than 0.3 can be used as a rule of thump as an indication of a significant gradient. The success of the rehabilitation program was tested against three possible benchmarks.

a) Frequency data of rehabilitated slopes and surfaces were compared with frequency data of a adjacent natural grassland. The colonisation of species from this natural area was tested. Scatter diagrams of ordinations could also indicate the amount of dissimilarity between the two areas.

b) Frequency data of grids where seed mixtures A and B were used were analysed together with the seed ratios of different grass species that were used in the seed mixtures. Seed mixtures were employed as extra sample plots.

c) An ordination was also performed on frequency data of slopes to obtain an age-gradient of one to six years of rehabilitation.

Results showed that species composition of the rehabilitated areas had little in common with the natural grassland. It must, therefore, be accepted that colonisation from the natural grassland did not take place. The comparative study between species of the seed mixtures and the species composition of the old rehabilitated areas showed that few species from the seed mixture colonise successfully. Only three species, *Eragrostis curvula*, *Hyparrhenia hirta* and *Cynodon dactylon* colonised successfully and occur as dominant grass species in rehabilitated areas. It could therefore be ask where the other grasses and forbs occurring in abundance on old rehabilitated areas originated? Possible sources include the topsoil layer that were used as amelioration method, contamination of the seed mixtures and natural colonisation from bordering areas that also has a ruderal origin. Species from the seed mixtures also showed a successional relationship. Annual grass species from the seed mixtures establish first after revegetation. During the consecutive year perennial grasses increased in abundance with a sharp decrease in annual grass species of the seed mixture. The annual grass species of the seed mixture were not able to establish a regenerating population. Ordination of the plots of different ages showed that little change in species composition along the first ordination axis exists after three years of rehabilitation and that environmental conditions associated with the second ordination axis played an increasing importance. Although both recent and old rehabilitated areas were characterised by annual forbs the species composition between the two areas was significantly different. If the different benchmarks were a measurement of rehabilitation success it must be concluded that the rehabilitation program was successful to establish a relative stable perennial grassland.

Appendix B
Paper presented at 2000 annual congress of the SA Akademie vir Wtenskap en Kuns: Biologie held at the Technikon SA

ABOVE GROUND BIOMASS PRODUCTION OF A SELECTED NUMBER OF GRASS SPECIES GROWING ON REHABILITATED ASH DAMS (Afr.)

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Abstract

Little is known concerning the contribution of individual species biomass in rehabilitated grasslands on tailings such as ash disposal dams. Species biomass can however be a good indicator of the nutrient status and general condition of rehabilitated vegetation. During this study a number of dominant species contribution to the biomass of the total community were investigated. The individual biomass production of *Hyparrhenia hirta* (Thatch grass) and *Eragrostis* spp (Love grass) between a nearby natural grassland and old rehabilitated ash disposal sites were compared. The study was conducted on rehabilitated ash disposal sites at the Hendrina Power Station during 1997 until 1999. A garden fork was used to excavate 707 plants of 11 species on rehabilitated areas and a adjacent natural grassland. Plants were air dried at room temperature for six months where after the roots and aboveground parts were separated. Natural logarithmic transformed data were analysed with ANOVA and Tukey's test for unequal populations.

Plants of *Hyparrhenia hirta* had the highest biomass (197.13 g/plant) of all species investigated. *Eragrostis* spp., *Eragrostis plana* and *Digitaria eriantha* plants had a similar (70-112 g/plant) but smaller biomass than *Hyparrhenia hirta*. The plant biomass of the annual grass *Enneapogon cenchroides* (27.96 g/plant) was similar to the plant biomass of *Chloris gayana* (27.07 g/plant). The plant biomass of the three pioneer grass species, *Aristida congesta, Eragrostis tef* and *Eleusine coracana* were smaller than 20 g/plant. The plant biomass of the grass species *Eragrostis* spp and *Hyparrhenia hirta* were higher on rehabilitated ash disposal sites in comparison to the same two grass species in the natural grassland

The plant with the highest contribution to grass biomass was *Hyparrhenia hirta* and therefore was the most competitive species in vegetation of rehabilitated ash disposal sites. The dominant occurrence of this species may therefore greatly influence successional development of vegetation.

A possible explanation for the differences in the plant biomass of the two species *Eragrostis* spp and *Hyparrhenia hirta* in the two different areas can be accounted to the smaller niche space due to higher species richness, plant density and a lower overall nutrient status of the natural grassland, which were situated on shallow rocky soils.