COMMUNITY DYNAMICS AND STRUCTURE OF ANT POPULATIONS ON ASH DISPOSAL SITES UNDER REHABILITATION AT HENDRINA POWER STATION, SOUTH AFRICA

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LIST OF CONTENTS

ABSTRACT

Ants can be considered as useful indicators of ecosystem recovery following the rehabilitation of ash dams, associated with power stations. However, few studies were conducted on the indicative value of ant species in disturbed industrialized areas in South Africa. This study at Hendrina Power Station (Mpumalanga, South Africa) reports on a preliminary investigation of the indicative value of ant species, changes and trends in the composition and diversity of the ant community during succession and also the habitat characteristics involved in the successional trends in the structure of the ant community on ash dams. The study was conducted over a period of three years. Pitfall trapping, sweepnetting and hand collections were used as sampling techniques. Ant fauna at Hendrina Power Station were highly diverse, with 34 species recorded on the ash dams and 38 species recorded in natural grassland.

Two successional stages were discernible on the ash dams - a pioneer stage represented by 0-3 year old ash dam grids and a second older successional stage represented by 4-9 year old rehabilitated ash dam grids. The third and most advanced successional stage was represented by the natural grassland. The pioneer stage of succession was characterized by the presence of pioneer plant species, such as *Tagetes minuta* and *Cyperus esculentus*, a low vegetation cover, a low organic matter content and a high gravel content within the soil. These areas had a low ant species diversity and was dominated by only a few opportunistic, early colonizing ant species, such as *Cardiocondyla shuckardi*, *Monomorium albopilosum* and *Monomorium* sp.2. The second stage of succession was characterized by the presence of stable plant communities such as *Hyparrhenia hirta* and *Eragrostis curvula*, a high vegetation cover, a high organic matter content and high sand content. These areas had a higher ant species diversity than the pioneer stage of succession, which were dominated by the pugnacious ant, *Anoplolepis custodiens* and other generalized ant species. Although ant species diversity on the 4-9 year old rehabilitated ash dam grids corresponds with that of the natural grassland and were also dominated by *A. custodiens*, more specialized ant species, such as *Camponotus* spp., *Cerapachys* sp., *Crematogaster* sp., *Leptogenys intermedia* etc. were caught within the natural grassland, where the diversity of the habitat is more diverse, than on the ash dams. Ant species richness as a measure of ant recolonization or resilience was significantly positively correlated with plant species diversity, percentage vegetation cover and sand content of the substrate and seemed to be enhanced by these environmental variables. Various ant species were indicative of various soil and vegetation factors, associated with different stages of succession, and could therefore be considered as useful parameters of rehabilitation success.

Ant species diversity varied significantly on a seasonal basis, being significantly lower in winter, compared with spring, summer and autumn. Ant species showed particular seasonal activities, where the majority of ant species were active during warmer months. However some ant species were active in winter, creating spatial and temporal ant diversity on the ash dams and confirmed the importance of functional diversity in ecosystems. These seasonal activities are typical for ants and reflected the effects of weather and resource availability on the activity of ant species.

Lastly it can be concluded that a diverse ant community had established on the ash dams over the short term, but the absence of specialized ant species on the ash dams emphasized the need for additional management strategies, in order to meet not only the demands of these ant species on ash dams, but also the demands of sustainability in the long term. These management strategies and other recommendations are briefly discussed.

Key words: *ants; South Africa; ash dam rehabilitation; succession; habitat characteristics; seasonality.*

OPSOMMING

Miere is suksesvolle indikatore van versteuring en is aanduidend van die herstel van ekostelsels, na die rehabilitasie van asdamme. Min Suid-Afrikaanse studies is egter gedoen op hierdie gebied. Die voorlopige studie is gedoen by Hendrina-kragstasie (Mpumalanga, Suid-Afrika), waar die gebruik van miere as indikatore van versteuring, veranderinge en patrone in die diversiteit van miergemeenskappe gedurende suksessie, asook die habitat kenmerke wat gelei het tot suksessionele patrone in die gemeenskapstruktuur van miere op asdamme ondersoek is. Die studie is gedoen oor 'n tydperk van drie jaar. Monsternemingstegnieke wat tydens die studie gebruik is, sluit in putvalle, swaainette en handversamelings.

Onderskeidelik, 34 en 38 mierspesies is gevind op asdamme en kontroles, wat aanduidend is van 'n hoë spesiediversiteit. Twee stadiums van suksessie is teenwoordig op asdamme. Die eerste stadium verteenwoordig 0-3 jaar oue persele en die tweede verteenwoordig 4-9 jaar oue persele. Die natuurlike grasveld is verteenwoordigend van die derde en mees gevorderde stadium van suksessie. 'n Lae basale bedekking en die teenwoordigheid van pionier plant spesies, soos *Tagetes minuta* en *Cyperus esculentus* is kenmerkend van die eerste stadium van suksessie. Hierdie gebiede word ook gekenmerk deur min organiese materiaal en 'n hoë gruis-inhoud in die grond. In hierdie gebiede was slegs opportunistiese mierspesies, soos *Cardiocondyla shuckardi*, *Monomorium albopilosum* and *Monomorium* sp.2 teenwoordig, gevolglik het hierdie gebiede 'n lae spesiediversiteit getoon. Die tweede en meer gevorderde stadium van sukssessie is gekenmerk deur die totstandkoming van stabiele plant gemeenskappe, soos *Hyparrhenia hirta* and *Eragrostis curvula*, 'n hoë basale bedekking, asook die teenwoordigheid van 'n hoë organiese- en sand inhoud in die grond. Hierdie gebiede het 'n hoër mierspesiediversiteit, as die eersgenoemde stadium van suksessie en word gekenmerk deur 'n hoë getal *Anoplolepis custodiens* en verskeie ander spesies. Alhoewel laasgenoemde gebiede 'n hoë spesiediversiteit het, was toestande in hierdie gebiede te ongunstig vir die

suksesvolle kolonisering deur gespesialiseerde mierspesies, soos *Camponotus* spp., *Cerapachys* sp., *Crematogaster* sp., *Leptogenys intermedia* ens. Spesierykheid is 'n maatstaf van die herkolonisering van miere en is betekenisvol gekorreleer met plantspesiediversiteit, basale bedekking, asook sand inhoud in die grond. Hierdie omgewingsveranderlikes kan daarom 'n positiewe invloed hê op die kolonisering van miere op asdamme. Gedurende suksessie op asdamme, is sommige mierspesies aanduidend van verskeie grond- en plantegroei-eienskappe en is daarom belangrike parameters van rehabilitasiesukses.

Mierspesiediversiteit varieer op 'n seisoenale basis, waartydens dit betekenisvol laer was in die winter as in enige ander seisoen. Seisoenale aktiwiteit van 'n verskeidenheid mierspesies het ook voorgekom. Alhoewel, die meerderheid mierspesies aktief was gedurende warmer maande, was sommiges ook aktief gedurende die winter maande en bevestig daarom die belangrikheid van funksionele diversiteit in ekostelsels. Hierdie seisoenale aktiwiteitspatrone is tipies van miere en dui op die invloed van klimaat en hulpbronbeskikbaarheid.

Laastens, dui die afwesigheid van gespesialiseerde mierspesies op die asdamme, op die nodigheid van alternatiewe en bykomende bestuurstrategieë, om sodoende nie net aan die voorkeure van gespesialiseerde mierspesies te voldoen nie, maar ook om te voldoen aan die vereistes van volhoubaarheid. Hierdie alternatiewe en bykomende bestuurstrategieë word in die teks bespreek.

LIST OF TABLES

CHAPTER 2

CHAPTER 3

CHAPTER 4

LIST OF FIGURES

CHAPTER 2

CHAPTER 3

CHAPTER 1

INTRODUCTION

1.1 Rehabilitation of disturbed industrial sites.

Since the turn of the century the earth has been characterized by an immense increase in the human population. This increase in the human population has lead to an increasing demand for natural resources, in order to sustain economic growth and quality of life. Nearly all known natural environments have been affected by man, through mining of coal for electricity generation and mining of minerals. South Africa is by far the most industrialized country on the African continent, with its electrical generating capacity being 60% of the whole continent, with the highveld grassland being the most heavily utilized, for coal mining (Macdonald 1989). With today's development of industrialized areas, these areas became more subjected to different man-induced actions and activities like disturbances or perturbations, which all had a detrimental impact on the ecosystem (Kelly & Harwell 1987). This is also true for man-induced disturbances such as pollution, alterations of habitats and the introduction of exotic plant and animal species, which all had a negative influence on ecosystems (Kremen 1992). Due to modern industrialized activities, areas under development became tremendously over exploited. Macdonald (1989) states that due to modern man's activities, the ecosystem has been changed to a state, which differs from the state prior to disturbance.

Disturbed industrial sites have to be rehabilitated, in order to establish a self-sustainable, self-regulating and functional ecosystem. Rehabilitation of areas transformed by mining, cultivation, or any other form of habitat modification is therefore an essential component of environmental planning and protection. Legislation regarding the rehabilitation of disturbed areas or areas under development has been interpreted by Barnard (1995) as the restoration of these areas to a "*proper condition or status that will meet the demands of sustainability*". Managing and financial aspects have to be considered in the process of restoring disturbed areas to a proper condition (Barnard 1995). The economic value of a new resource has to be at least equal to the value of the resource that will be destroyed during development, otherwise rehabilitation cannot be achieved (Barnard 1995). Here emphasis is on the economic value of the rehabilitated area, rather than sutainability. Bradshaw & Chadwick (1980) defined rehabilitation as all the actions concerned with the upgrading or recreation of disturbed areas, in such a way that the biological potential of the rehabilitated area is restored. The National Environmental Management Act (Act No. 107 of 1998), states that the disturbance of ecosystems and loss of biological diversity first of all has to be prevented, otherwise it has to be diminished and amended (Section 2; subsection 4:i-viii). Good rehabilitation requires an expanded view that includes historical, social, cultural political, aesthetic and moral aspects (Higgs 1997).

The term restoration is explained by the U.S. National Research Council (1992) as the return of a disturbed ecosystem to a condition similar to the condition before the area was subjected to disturbance. The aim of restoration is to accelerate the re-establishment of balanced natural plant communities and integrated ecosystems (Louda 1995). During the rehabilitation process, ecological damage to the resource is repaired with the objective of restoring the structure and function of the ecosystem to a condition, prior to disturbance (Higgs 1997). According to the U.S. National Research Council (NRC) committee, it is difficult to restore disturbed ecosystems to their pre-disturbance level, because climatic and biological occurrences are not the same in two different ecosystems, and also the structural and functional properties of an ecosystem before disturbance cannot be verified with certainty (Cairns 1995). Bradshaw (1995) suggests that the original ecosystem is replaced instead by another ecosystem, which differs from the original one in terms of structural and functional conditions. Cairns (1995) assumed that the successional processes would be those that would have occurred, had the ecosystem not been damaged.

Restoration is mainly based upon ecological fidelity, and incorporates three principles (Higgs 1997):

- **structural/compositional replication**, where a self sustainable and functional ecosystem is established, which resemble the structure and composition of more natural ecosystems. Restoration is not the copying of natural ecosystems, but instead an imitation of it (Jordan 1995). Increasing the habitat and structural diversity of the disturbed areas by introducing large logs and rocks, are some of the ways in reaching the compositional and structural attributes of more natural ecosystems. Time is also here of great importance, in which restoration can take as little as a few years to many decades.

- **functional success** which is related to the restoration/establishment of ecological processes within the disturbed area, such as basic energy/nutrient cycles, which in turn depends on the presence and interactions of a diverse animal community. Good management procedures are essential in this regard. Neither structural/functional replication, nor functional success are possible without the other (Higgs 1997).

- **durability**, with the objective of establishing an ecosystem, where the composition, structure and function of this ecosystem is at the long-term, durable, long lasting, self-generating and self-sustainable. The resulting ecosystem must therefore be resilient enough to survive short-term unfavourable environmental conditions, such as droughts, erosion, fire etc. Majer (1990) described resilience as the speed of recovery of the ecosystem to its former pre-disturbance level, after it was disturbed.

The goal of rehabilitation is therefore to establish a durable, self-sustainable and functional ecosystem which resembles the structure and composition of more natural ecosystems. Rehabilitation is successful when these goals are accomplished in the least amount of time, with minimal costs, labor and resources (Higgs 1997).

Planning for rehabilitation is sometimes quite laborious due to the fact that there are too many interest groups involved with different viewpoints, for example ecologists want damaged ecosystems to be restored to their original state, whereas mining companies want cheap solutions with the least effort (Maguire 1995). Clear and distinct standards are needed to apply the most effective rehabilitation strategies and also to determine whether these particular rehabilitation strategies are economically and ecologically viable, in such a way that bonding requirements could be lifted (Maguire 1995). Andersen (1997a) states that desired outcomes in terms of ecological succession could be reached only if well managed practices are established.

The success of rehabilitation cannot be judged by only looking at outwardly appearance of the ecosystem, but also is it necessary to consider the appropriate functioning of the ecosystem (Andersen 1997a). Management programmes must therefore, take into consideration ecological processes involved in achieving long term stability and resilience (Andersen 1997a). Begon, Harper & Townsend (1990) describe stability as the tendency of an ecosystem to return to its original state in the presence of disturbance. Stability is enhanced by habitat diversity (Inouye 1995). Herbivore/plant interactions and sustainability of rehabilitated ecosystems depend to a large extent on the diversity of animal and plant populations (Inouye 1995).

Westman(1986) points out that four ecological components are involved in ecosystem resilience. These components are elasticity, amplitude, hysterisis and malleability. Elasticity is the rate of recovery of an ecosystem, after the introduction of disturbances. The slope of recovery is a measure of the elasticity of the ecosystem. A more elastic ecosystem is therefore one where the slope of recovery is steeper. Amplitude is the threshold level where an ecosystem cannot return to its predisturbance level, e.g. when the disturbance is large or when an area is too frequently being disturbed. Hysterisis is the level to which successional changes in a disturbed ecosystem differ from successional changes in the disturbed ecosystem, when the disturbance is removed. On the other hand the malleability of an ecosystem is described as the difference between the restored level and the predisturbance level of the ecosystem. Therefore, a more malleable ecosystem is one where the difference in the two stages of the ecosystem is larger. Fox & Fox (1986) points out that another component is involved in ecosystem resilience. Damping is described by Fox & Fox (1986) as a situation, where other forces or disturbances act upon an existing restoring force or disturbance. It is therefore the situation, where the existing restoring force is damped by the presence of other forces.

In monitoring and assessment programmes it is important to determine the reasons for ecological changes in an ecosystem, in order to make successful predictions (Rosenberg, Danks & Lehmkuhl 1986). Comparative studies are useful in predicting effects of a proposed project (Rosenberg *et al.* 1986). Rehabilitation success depends on how sustainable plant and animal communities are in any disturbed area, and is an indication of the stability of an ecosystem.

1.2 Response of the ecosystem to rehabilitation (Succession).

Miles (1979) gives a description of primary succession where he described primary succession as the gradual process, after the rehabilitation of disturbed areas, where soil releases nutrients, plants start to colonize, a diverse and more abundant animal and plant community establish, and one group of species is replaced by another, in such a way that a more complex ecosystem develops. Clements (1916) proposed that ecological succession is a process of vegetation change through a number of intermediate stages until an equilibrium is reached among the extant and the environment. Mentis & Ellery

(1994) described ecological succession as a process which occurs over time. Both the structure and function of the ecosystem are influenced by these successional changes, where the structure of the ecosystem is influenced by an increase in the habitat and structural diversity, which in return had an affect on the diversity of potential colonizing plant and animal species (Bradshaw 1995). On the other hand the function of the ecosystem is influenced by successional changes due to the increase in biomass and circulation of nutrients (Bradshaw 1995). Some ecosystems that are too frequently disturbed show no ecological development. In other words particular species cannot establish colonies in these highly disturbed areas. Severe disturbance leads to a decrease in species richness, but it increases again during ecological succession (Mentis & Ellery 1994). The climax stage of succession is not necessarily the stage where the most species are present, but it is suggested that no or little increase in the richness of plant and animal communities prove the fact that succession has not occurred immediately following disturbance (Mentis & Ellery 1994).

1.3 Importance of invertebrates in rehabilitation strategies.

Rehabilitation projects give little consideration to the faunal aspects of the ecosystem, that often control plant density and distribution of these populations, and attention is mainly paid to the physical aspects and vegetation of the rehabilitated area (Louda 1995). Salwasser & Tappeiner (1981) and Van Horne (1983) stressed that bio-monitoring studies must follow a system approach, instead of dealing only with one or a few species. Pearsall, Durham & Eager (1986) states that this system approach have to be standardized in such a way that it could be applied in a wide range of habitats.

Rehabilitation of damaged ecosystems not only involve the revegetation of these areas, but there is also a need to address the possible role of fauna in these areas. Ecological studies on the rehabilitation of industrial ecosystems is often neglected, mainly due to the complexity and difficulty of these studies. When the biological part of the rehabilitation process fails, then not only is the costs in conducting this biological survey wasted, but also the much larger expenditure on the engineering part of the operation (Bradshaw 1995). Biomonitoring is an integral part of rehabilitation attempts, to determine whether a particular area has become sustainable. During environmental assessment and monitoring programmes there is an increasing demand for the use of plant and animal species as ecological indicators (Andersen 1997b). Such indicators are used to indicate ecological changes in a disturbed ecosystem (Andersen 1997b), to monitor ecological trends over time, to provide early warning of environmental degradation, or to diagnose the cause of an existing problem (Cairns 1995). A variety of major disturbances can be monitored using indicator groups (Vanderwoude, Andersen & House 1997). Invertebrates have often been used as ecological indicators (Majer 1989; Andersen 1990; 1997b), for they: (1) are readily and easily sampled and identified (Abensperg-Traun, Arnold, Steven, Smith, Atkins, Viveen & Gutter 1996), (2) have wide distribution patterns and (3) are economically important (Noss 1990). Patchy distributions of macro invertebrates makes it difficult to successfully estimate population densities (Abensperg-Traun *et al.* 1996). In some cases invertebrates are not effective as ecological indicators, because their own diversity may vary from year to year (Abensperg-Traun *et al.* 1996). Changes in stable habitat variables are used instead as a more efficient and reliable measure of particular ecosystem conditions (Abensperg-Traun *et al.* 1996).

The bio-indicator quality of the habitat variables may be influenced by the type of disturbance or intensity of the disturbance, yet the effect of disturbance on plant and animal species may change with type of vegetation, soil type, climate or life-history principles of the target biota (Abensperg-Traun, Arnold, Steven, Smith, Atkins, Viveen & Gutter 1997). Invertebrates are better indicators of the overall state of an ecosystem, than plants (Andersen & Sparling 1997).

In the past most attention had focused on the ecological role of invertebrates as bio-indicators in aquatic ecosystems, whereas information on the role played by invertebrates in terrestrial ecosystems had been rather limited (Andersen 1997a). The importance of invertebrates in disturbed areas is often underestimated. For these areas to be self sustainable, invertebrates have to successfully colonize the disturbed habitat to aid in the development and maintenance of a good soil structure and other ecosystem functions. The sustainability of rehabilitated ash dams will depend to a large extent on the organic content of the topsoil layer (Bradshaw 1995). Invertebrates fulfil a number of essential ecosystem processes (Greenslade & Majer 1993; Majer 1984a), where they are involved in (1) soil aeration and drainage, (2) litter decomposition, (3) nutrient cycling, (4) herbivory, (5) pollination, (6) seed distribution and survival and (7) plant predation. Invertebrates also serve as food for insectivorous vertebrates (Greenslade & Majer 1993; Majer 1984a). They also satisfy in three of Noss's (1990) criteria for good biological indicators in the sense that they provide an early warning of ecological change, they have wide geographical distribution and provide a continuous measurement over a broad range of disturbances. Organic matter within the soil, together with the feeding behavior of soil animals are of utmost importance in maintaining a good soil structure (Bradshaw 1995). According to Louda (1995) insects may have detrimental impacts on the establishment of plant communities within an area, where they (1) lead to increases in the abundance of plant species (2) restrict the distribution of plant species (3) restrict the establishment of plant seedlings (4) affect plant growth (5) reduce flower and seed production. Insects also serve as providers, eliminators and facilitators across multiple trophic levels, and play an important role in the distribution, abundance and diversity of plants and vertebrates (Miller 1993). Well managed rehabilitation processes will lead to the return of invertebrates which in return play important roles in ecosystem functions such as: improving soil structure (e.g. termites and worms); nutrient cycling (e.g. springtails, mites and millipedes); stimulation of mychorrhizal activity (e.g. soil micro-arthropods); maintenance of plant community composition (e.g beetles and moth larvae); pollination (e.g. wasps and flies); seed dispersal (e.g. ants); and maintenance of the densities of other animals (e.g. spiders, predatory beetles and parasitic wasps) (Majer 1989; Majer & Nichols 1998). In addition to the measured physical and biological attributes of an area, information on invertebrate recolonization should provide important information on the overall state of various ecosystems (Majer & Nichols 1998).

1.4 Ecological role of ants in disturbed areas.

Ants are important components of terrestrial ecosystems and are in general good bio-indicators of rehabilitation success and ecosystem condition in disturbed areas (Majer 1983; 1997; Andersen 1990), because they are an abundant, diverse group of animals (Vanderwoude *et al.* 1997) with a community structure which tends to reflect the nature of the environment in which they occur and they are responsive to changing environmental conditions. Ants provide valuable information about the scale of disturbance caused, as well as the rate at which the disturbed ecosystem recover (Jackson & Fox 1996). In specialized niches ants tend to occupy the higher trophic levels, and play an important role in the functioning of an ecosystem (Majer 1984b). They are of major importance in the facilitation of primary succession (Andersen & Sparling 1997) and fulfill a number of ecosystem functions. Ants can also easily be sampled and sorted, without specialized techniques or equipment (Vanderwoude *et al.* 1997; Andersen 1990). Ants gain food from nectar, seeds, carrion, or other invertebrates, and many have specialized feeding or foraging habits. (Majer, Sartori, Stone & Perriman 1982). Ants have the capacity to exert a considerable influence on soil structure and fertility by their feeding and mixing activities (Curry 1994). They play important roles in soil turnover and soil aeration (Majer 1978a) by their movements in the soil and nest construction (Curry 1994). They also attribute to decomposition cycles within an area (Andersen 1990; Scougall, Majer & Hobbs 1993). They are involved in soil mixing and water infiltration under ponded conditions (Lobry de Bruyn & Conacher 1994). Abensperg-Traun *et al.* (1997) found that ants influence the distribution, abundance and richness of other arthropods, including vertebrates (Andersen 1990). They are able to reduce the abundance of ground-dwelling spiders and carabid beetles especially in areas where dense ant colonies are present (Hölldobler & Wilson 1990). High levels of carbon, nitrogen and phosphorus occur in patches of areas where ants transport animal and plant remains into their nests and mixing it with the substrate, and in return lead to the patchy distribution of plant species, especially during the early stages of succession (Hölldobler & Wilson 1990). Information on the distribution of ant species, relative abundance of ant species and community organization of ants can be interpreted by comparing it with various other ecological characteristics (Burbidge, Leicester, McDavitt & Majer 1992). Lastly the ant community provide valuable information about the degree of disturbance, as well as the rate at which recovery takes place in a rehabilitated area (Jackson & Fox 1996).

The composition of the ant community is highly sensitive to ecological change. Disturbance of an area can lead to an elevation in soil temperature, a decrease in the amount of litter (Lobry de Bruyn, Jenkins & Sutrisno 1997), changes in vegetation cover and changes in the composition of the plant community (Majer 1984a; 1985), which in return will lead to a reduction in the number of species and genera, and will alter the composition of the ant community (Burbidge *et al.* 1992). Andersen (1986a) states that vegetation structure is affected by disturbance. Ant community parameters provide valuable information on the plant community, physical characteristics and overall state of the environment in which they occur (Majer & De Kock 1992). Some studies have shown that plant successional patterns and the speed at which succession in the plant community occur are influenced by ants (Jackson & Fox 1996). Ants have direct effects on a wide range of plant species where they act as seed dispersal agents, seed predators (Hosking & Turner 1997), protectors of plant species and indirectly via their association with host specific prey and homopteran sap suckers (Jackson & Fox 1996). Majer & Abbott (1989) demonstrate that ants are involved in seed predation, where seeds are used as a food source, where either the kernel or the elaiosome appendages are consumed. They also found that seeds are used as a decoration in the nests, and are incorporated in the structure of the nest. Seed are benefitted by ants, where the seed are dispersed over long distances by ants, and isolated from other seed predators and wildfires (Scougall *et al.* 1993). According to Majer & Abbott (1989), ants have a greater impact on seed resources, than rodents in the Australian arid zone. Selective feeding on vegetation by ants can also promote the occurrence of specific plants, in such a way that certain plant species are associated with particular ant colonies.

Ants are therefore important in the succession on rehabilitated areas, in which they act as dispersal agents of seeds, and therefore lead to the establishment of particular plant communities within different areas. On the other hand the composition of the plant community differs during the different stages of succession, which in its turn determine the ant species which are present at different stages of succession. Some ant species will leave the succession, when they are no longer able to withstand unfavourable environmental conditions, to which they are subjected. These ant species are then replaced by other ant species better suited to the changing environmental conditions, which resulted in a progressive change in the species composition of the ant community. Replacement sequences in succession may result in coexistence between certain ant species (increased species richness) and can determine the composition and structure of ant communities. Certain habitat features such as slope, aspect, vegetation type and climatic conditions can also influence the physical and biotic environmental conditions in disturbed areas, since successional trends tend to be habitat specific.

1.4.1 Ant functional groups

Ant species can be classified into functional groups which respond differently in relation to disturbance (Majer 1983; Andersen 1990;1995; Vanderwoude *et al.* 1997), climate and vegetation type (Andersen 1990), and can simplify complex patterns of species composition (Andersen 1997a), when knowledge in the biology of species is limited (Vanderwoude *et al.* 1997). Changes in the composition of functional groups, rather than species, provide a more meaningful indication of ecological change, and changes in the composition of other invertebrate groups (Andersen 1997a). Greenslade (1978) has first proposed this functional group classification of Australian ants based on their competitive interactions, habitat requirements and evolutionary history, whereas Andersen (1990;1992) paid more attention to community dynamics than evolutionary history. The functional groups classified by Andersen (1990;1992) can be summarized as follows:

- **Dominant dolichoderinae** - *Iridomyrmex* species are the dominant ant species within this functional group, which are widespread throughout the Australian environment. *Iridomyrmex* species are highly active and aggressive, where they have major competitive influences on other Australian ants (Andersen 1995). They are particularly abundant in hot and open habitats, where the soil surface is not covered with litter (Lobry de Bruyn *et al.* 1997), which allow for high rates of foraging activity (Andersen 1995).

- **Sub-ordinate Camponotini** - This functional group is characterized by species of *Camponotus*, and are competitively sub-ordinate in the presence of *Iridomyrmex* species, but may become dominant in the absence of *Iridomyrmex* spp. They have large body sizes and usually forage during the night. They have low relative abundances in any ant community (Andersen 1995).

- **Climate Specialists** - This functional group can be sub-divided into three categories e.g. hot climate specialists, occurring in the arid zone; tropical climate specialists, occurring in the humid tropics and cold climate specialists, occurring in cool-temperate regions. Cold and tropical climate specialists are unspecialized and are very abundant in the absence of dominant dolichoderines, whereas hot climate specialists are characteristic of areas where dominant dolichoderines are most abundant. Hot climate specialists on the other hand are specialized in their foraging behaviour and usually forage during the hottest part of the day, when no other ants are active and therefore reduce their competitive interactions with other ants (Andersen 1995). Andersen (1990) and Lobry de Bruyn (1993) noted that habitat disturbance had a negative effect on *Iridomyrmex* species and therefore lead to a reduction in the dominance of these species, which lead to an increase in the number of opportunistic species and generalised myrmicines.

- **Cryptic species** - This functional group is characterized by genera such as *Solenopsis* and *Hypoponera* and other small ponerines (Andersen 1997c), and nest and forage almost exclusively within the soil, therefore reducing competition with other ant species (Andersen 1995).

- **Opportunists** - This functional group is characterized by species of the genus, *Tetramorium* and *Cardiocondyla*, where they are indicative of highly disturbed environments or other habitats supporting low ant diversity (Andersen 1997a). These species have wide climatic and habitat tolerances (Andersen 1997a). Opportunistic ant species can be abundant in cool and shady habitats, in hot and open habitats, in habitats with heavy litter, and in highly disturbed areas (Andersen 1995). They are unspecialized and poorly competitive and are therefore strongly influenced by competition from other ants (Andersen 1995; 1997a).

- **Generalized myrmicinae** - *Pheidole* spp.; *Monomorium* spp. and *Crematogaster* spp. are characteristic of this functional group and have generalized habits regarding nesting and foraging requirements. As in the case of the opportunists, these species have wide climatic and habitat tolerances (Andersen 1997a). These species are not very active nor aggressive and they have small foraging ranges (Andersen 1995). Generalized myrmicinae are abundant in a wider range of habitats, than opportunists, and are moderately sensitive to low temperature stress (Andersen 1995). Changes in the relative abundance of opportunistic and generalized myrmicine ant species are often correlated with levels of disturbance (Andersen 1990).

- **Specialist predators** - These ants are specialist predators of other arthropods and include species such as *Leptogenys* and *Cerapachys*. They are in little competition with other ants probably due to their specialized diets, large body size, small colony size and low population densities (Andersen 1995).

1.5 Studies done on the use of ants as indicators of habitat disturbance.

The role of ants as indicators of rehabilitation success following mining have successfully been used for more than 20 years in Australia (Andersen 1997a). However little information is available on the use of ants in biomonitoring studies in South Africa, except for a study done by Majer & De Kock (1992) on rehabilitated sand mines at Richards Bay. In Australia ant monitoring programmes have also been used in the forestry industry, and in monitoring grazing pressure (Andersen 1997a). In the past the majority of studies have concentrated on the effect of fire and mining on ant species composition and activity (Majer 1984a; 1985), and only recently was the effect of habitat disturbance on the activity and composition of ants in farmland environments examined (Lobry de Bruyn 1993). Yeatman & Greenslade (1980) used ants as bio-indicators in three conservation parks in South-Australia. Studies found that ant species track environmental gradients, especially in agro-ecosystems (Peck, McQuaid & Campbell 1998). A study in Costa Rica, by Roth, Perfecto & Rathcke (1994), associations between ant diversity, vegetative structure and other components of crop management were found. Delabie & Fowler (1993) found that ants were temporary correlated with different environmental factors, within Brazilian cocoa plantations. Tian, Brussaard & King (1993) found that ant populations were related to the nitrogen content of plant residues in tropical agro-ecosystems.

1.6 Environmental parameters influencing the return of ant species to rehabilitated, disturbed areas.

The successful recolonization of ant species on rehabilitated areas is influenced by environmental parameters such as: (1) rehabilitation methods, (2) climatic factors, (3) insolation of the ground, (4) presence of large logs, (5) plant growth, (6) competition between recolonizing ant species, (7) the establishment of an appropriate litter layer, (8) plant species richness and (9) vegetation structural diversity, which provide favourable micro-climates (Andersen 1997a; Majer 1984a; 1990), within the disturbed area and influence the availability of food, shelter and nest sites, which in return lead to the establishment of a richer ant fauna (Abensperg-Traun *et al.* 1996). An example of ant recolonization influenced by competition from other ant species was done at North Stradbroke Island in Queensland by Majer (1985), where recolonization was retarded by the introduction of *Pheidole megacephala*. Majer (1984a) states that rehabilitation methods and climatic factors have an overriding influence on the rate of ant species colonization throughout Australia. This corresponds with other Australian studies, where the speed of ant succession tends to be higher in areas with a more favourable rainfall distribution (Majer & De Kock 1992). Majer (1984a) suggests that the time since rehabilitation has a greater influence on ant species composition, than the rehabilitation method. Majer (1990) found that rehabilitated areas may act as an ecological "island" from the surrounding vegetation, due to differences regarding its physical and botanical structure. Majer (1990) also found that, at a particular stage of the rehabilitation process one ant species may be favoured over the other, while at a later, more mature, stage other ant species benefit from the rehabilitation process or succession, possibly due to the availability of a particular food source or nature and condition of the ecosystem at these particular stages.

Ants can therefore be used as bio-indicators of environmental conditions. (Majer 1983; 1997; Andersen 1990), but is hindered due to lack of long-term studies, which are costly (Majer & Nichols 1998). These problems could be circumvented by following the chronosequence approach, where a range of rehabilitated areas representing different ages were sampled (Majer & Nichols 1998). This provides rapid feedback, but can produce ambiguous data (Majer & Nichols 1998).

1.7 Effects of fire on the recolonization abilities of invertebrates and ants.

Fire is an important land management tool in many ecosystems throughout the world (Andersen 1991). Burning of vegetation is a natural process, occurring most often as a result of lightning (Kern 1981), and is sometimes man-induced for example to drive animals towards hunters and more recently, for the production and maintenance of grazing (Kern 1981). The effect of fire on fauna is often underestimated. Too frequent burning or a total absence of burning are likely to result in a loss of species (Greenslade 1997). Greenslade (1997) also found that total absence of fire can lead to a decrease in the diversity of the plant community. Greenslade (1997) noted that burning frequency and intensity influence the functional and structural recovery rate of an area undergoing burning. Vegetation structure, level of insolation of the ground (Andersen 1986a), decomposition processes (Greenslade 1997) are all affected by fire. Burning also has a negative impact on invertebrates, where burning reduces the number of plants, needed for food and shelter, although in some studies this effect was found to be short-term and insignificant, and studies have shown that the responses of invertebrates to season and environmental conditions were higher than to fire itself (Greenslade 1997).

Fire has little direct effect on ground foraging ant species due to the sheltering of these ants in nests, where these nests protect against the scorching heat of veld fires (Andersen 1991). Ground foraging ant species are also incapable of dispersing away from the fire (Andersen 1991). However, burning indirectly affect ants, due to modification of the habitat, decrease in food supplies and interspecific competition by other ants (Andersen 1991). Burning may affect the community structure and the species composition of ants and some studies indicate that ant species abundances increase after burning (Hosking & Turner 1997). Many studies have shown that ants have a preference for open habitats and high temperatures, and therefore benefit from burning (Greenslade 1997). Other benefits include seed rain, mobilization of nutrients and clearing of foraging obstructions (Jackson & Fox 1996). An increase in the activity of ants, after burning, may have positive effects on seed foraging rate and seed dispersal by ants (Hosking & Turner 1997). Shea, McCormick & Portlock (1979) proved that the burrowing of seed in the soil by ants should ensure the survival and germination of seed following burning. Vanderwoude *et al.* (1997) found that burning frequency may affect the dominance of functional groups. Humidity, light and temperature of the ground surface were found by Greenslade (1997) to be more important factors determining ant species composition than fire, whereas Jackson & Fox (1996) states that the impact of clearing and mining is much more severe. Andersen (1991) found that it is quite difficult to interpret ant response to fire at the species level, due to their high diversity and poor knowledge of their biology. Andersen (1991), states that when the response of ants to fire is investigated it is preferable to divide ant species into functional groups, according to their habitat requirements and competitive interactions. Jackson & Fox (1996) found that burning leads to the establishment of new habitats, which are preferred by opportunistic and thermophilic ant species. Specialized ant species, dependent on a high vegetation cover and specialized food and habitat requirements are not favoured by burning. Competition for food by other, more competitive ant species also lead to the unfavourability of these burnt sites for specialized ant species.

1.8 Parameters of ecological status.

Available literature demonstrates that certain ant parameters can be used, indicative of ecological status (Majer 1983) e.g.

- **Species richness (*S*)**

  Total number of ant species (S) per transect or survey grid. Ant species richness is however dependent on the sample size. Margalef's richness index could be used instead, as a more reliable parameter.

- **Shannon-Wiener diversity index (*H'*)**

$$H' = -\sum_{i=1}^{S} \left(\frac{n_i}{N}\right) \ln\left(\frac{n_i}{N}\right)$$

S = total number of species within a sample

n_i = total number of individuals belonging to the ith species within a sample

N = total number of individuals within a sample

The Shannon-Wiener diversity index gives more value to scarce species, whereas the Simpson diversity index only gives value to dominant species.

- **Ant species equitability (J')**

  Ant species equitability is an indication, on how evenly the number of individuals were distributed between the ant species.

$$J' = \frac{H'}{\ln S}$$

H' = Shannon-Wiener diversity index

$\ln S$ = natural log of the number of species

- **Indicator species**

  Individual species whose presence, absence or abundance is indicative of a particular factor.

- **Indicator groups**

  Groups of ants indicative of specific disturbances and perturbations.

Majer, Day, Kabay & Perriman (1984) consider ant species diversity and species richness as the most representative parameters of the ant community. Species richness as an ecological parameter can be examined at two levels. At the first level, a change in the number of genera and families are used as ecological parameters. At the second level, a change in the richness of species within particular genera are used as an ecological parameter (Andersen 1997b). These taxa are not necessarily good indicators of habitat change after disturbance (Andersen 1997b). Ant species richness, species evenness and similarity indices not only provide valuable information into the species composition of an area, but also the degree of disturbance (Majer 1983). Changes in the species richness and composition of indicator taxa, can be indicative of the extent of ecological change (Andersen 1997a).

The use of indicator species as parameters of ecological status depend on the availability of long-term data sets, to determine which species populations are relatively stable within undisturbed ecosystems (Inouye 1995). Likens (1983) pointed out that these long term data sets could provide valuable information in future studies. When the role of ants as indicators of ecological change are investigated, one must firstly consider overall changes in the pattern of the organization of the ant community, and secondly focus on individual species with specific habitat preferences (Andersen 1986b). Lastly Andersen (1986b) also concentrated on the use of opportunistic ant species as bio-indicators, known for their exploitation of disturbed habitats. The disturbance of ecosystems results in a reduction of specialized ant species and therefore, trends in ant species diversity, species evenness, and number of ant species within an area, at a particular time can be indicative of the status of the ecosystem.

1.9 Objectives and motivation for the study.

Eskom (Electricity Supply Commission of South Africa) has instituted rehabilitation programmes on ash dams to minimize the ecological impacts of their power stations on the environment and in particular to minimize erosion and dust pollution. Rehabilitation success and the factors involved in effective rehabilitation, depend ultimately on the sustainability of the plant and animal communities in these areas, and ants can clearly exert a casual influence in this regard. Ecological stability is enhanced by habitat and structural diversity. The increase in habitat and structural diversity on the ash dams must be part of Eskom's rehabilitation goal, in order to establish a diversity of invertebrates to colonize these disturbed areas effectively. The establishment of stable plant communities therefore provide certain habitat and niche requirements for specific invertebrates, especially ants, to fulfil essential functions within the ecosystem, such as seed distribution, herbivory, nutrient cycling and decomposition processes. The rehabilitation attempt will therefore fail if the necessary invertebrates are unable to colonize these disturbed areas successfully.

The hypothesis is that, rehabilitation will be optimal and successful when ant species diversity, number of ant species (species richness), species composition and the number of specialized ant species tend to be the same as in the adjoining natural grassland. The success of Eskom's rehabilitation program can be measured by comparing rehabilitated sites with stable and sustainable plant and animal communities which are resilient and resistant to extreme environmental conditions, such as fire and droughts.

A good ecological basis for rehabilitation and the identification of biological indicators and parameters should enable Eskom to improve its rehabilitation techniques. This should also enable Eskom to reach the demands of ecological stability and sustainability in the least amount of time at minimum cost.

The objectives of this study were (1) to determine whether changes in the number of ant species (species richness), species diversity and community structure could be used as parameters of rehabilitation success and (2) to identify ant species indicative of environmental change due to rehabilitation success. These indicators would be valuable tools in future rehabilitation studies. Other objectives of this study were (3) to determine the various aspects of the rehabilitated ecosystem which possibly play a role in the successful recolonization of ants, (4) to measure interactive environmental parameters, by way of multivariate analyses and ordination techniques, (5) to investigate seasonal activity in the abundance of various ant species and (6) to investigate seasonal patterns in the diversity of the ant community on ash dams, in order to determine the best time for doing ant surveys.

CHAPTER 2

STUDY SITES & GENERAL METHODOLOGY

2.1 Study area

2.1.1 Location

The study was conducted at Hendrina Power Station (26°03'S; 29°35'E), Mpumalanga, South Africa, approximately 200km east of Johannesburg. This part of Mpumalanga is very rich in sub-surface coal, making this area suitable for open-cast mining and the establishment of coal-fired power stations.

This region belongs to the Grassland biome of South Africa (Rutherford & Westfall 1986). Acocks (1988) described the vegetation of this particular region as part of the eastern variation of the Bankenveld (veldtype #61) and is characterized by species such as *Tristachya leucothrix*, *Eragrostis racemosa*, *Heteropogon contortus*, *Trachypogon spicatus*, *Digitaria tricholaenoides*, *Themeda triandra*, *Brachiaria serrata* and *Elionurus muticus*. The recent vegetation map of southern Africa by Bredenkamp & Van Rooyen (1996) classifies the vegetation of this region as part of the Moist Sandy Highveld Grassland. According to the Weather Bureau of South Africa, the mean annual rainfall for this region is approximately 750 mm annually, falling between October and March.

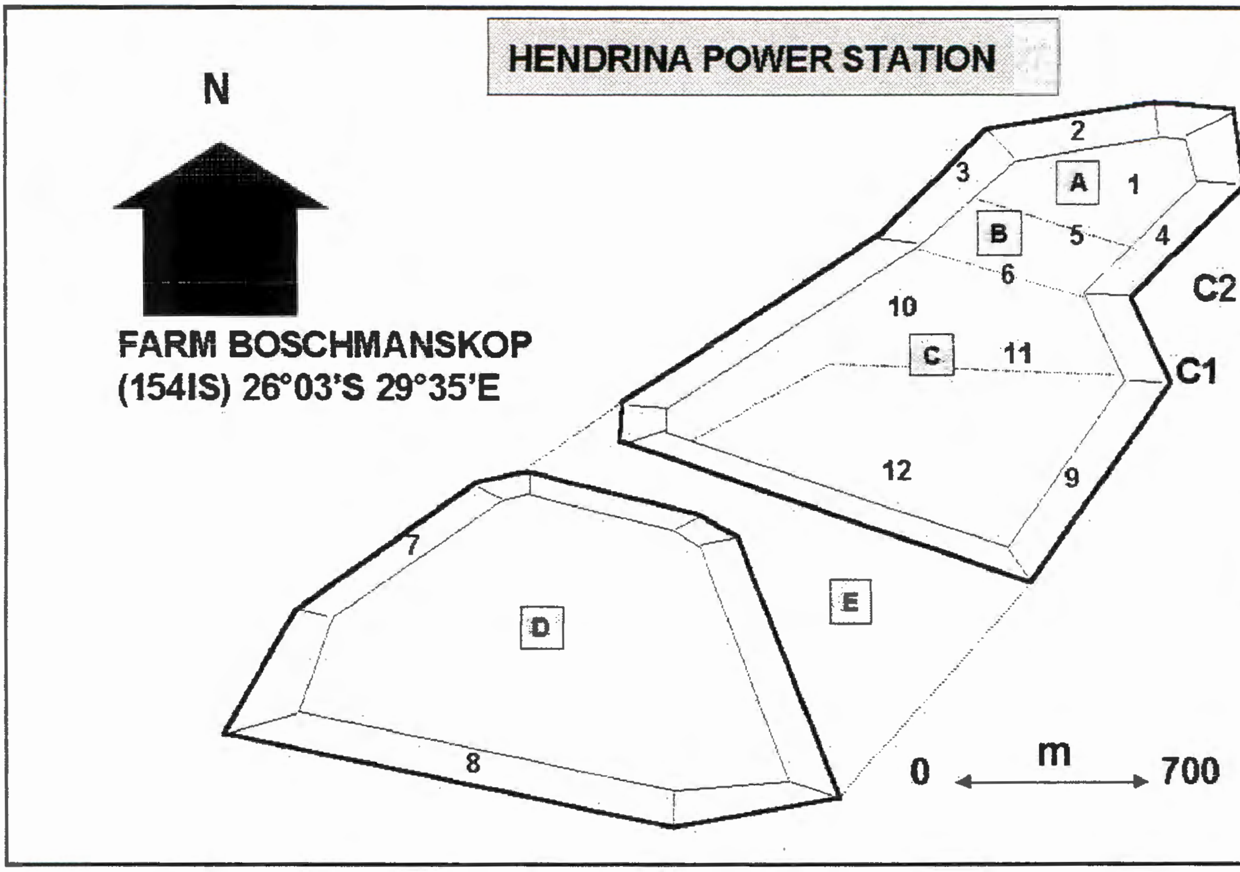

Figure 2.1: Map of ash dams (A-E) at Hendrina Power Station, showing the location of the survey grids (1-12) and of the control grids (C1 & C2).

The study area consists of four different ash dams (A-D) covering a surface area of approximately 215 ha (Figure 2.1). Ash dam A covers the area situated nearest to the power station, while ash dam B and C were built to the south of ash dam A. The construction of ash dam B was never finished, because the stockpiles collapsed. Ash dam D is the most recent rehabilitated area, and is separated from the other ash dams. Disposal of ash on ash dam D is still in progress. The construction of the fifth ash dam (ash dam E) commenced in late 1997.

The ash dams are bordered by land with a number of different land uses. They were constructed to the south of the power station, thus the northern boundary of the area is formed by the power station, while the north-western boundary consist of a railway line and a coal loading station. Maize fields form the south-western, southern and eastern part of the ash dams. The area is also bordered to the north- east by a number of open cast coal mines. The ash dams are therefore partly surrounded by severely disturbed areas, because of mining and ash disposal activities.

2.1.2 Rehabilitation techniques used at Hendrina Power Station.

The control of dust, erosion and pollution of water bodies is the main objective of Eskom's rehabilitation policy. Mechanical preparation and establishment of vegetation of these areas is therefore essential (Michael 1991). Effective revegetation will control dust blow-off under windy conditions (Michael 1991). Unmanaged ash dams lead to dust blow-off, which has an effect on the visibility in the area, poses a health hazard and leads to water pollution (Van Rensburg, De Sousa Correia, Booysen & Ginster 1998). Several substances and grass species have been used for rehabilitation purposes (Michael 1991). These substances include topsoil, compost, sewage sludge, grass mulch and organic fertilizers. One aim of this study was to evaluate the cost-effectiveness and sustainability of the rehabilitation method used (Michael 1991). However, each ash dam has some unique characteristics which should influence the rehabilitation success (Michael 1991). The different grass species sown during different years of rehabilitation are shown in Table 2.1 (Michael 1991).

Ash dams A and C have been rehabilitated with different indigenous grass species, whereas small areas of *Acacia mearnsii* woodland have also established over the years. Ash dam B is characterized by dense stands of *Arundo donax* and *Pennisetum clandestinum,* and can be regarded as a semi-wetland.

The first revegetation was undertaken in November 1986 on top of ash dam A (Table 2.1).

Seeds were sown by hand in rows running north-south and then lightly rotavated with a tractor mounted rotavator. Different grass species were planted along experimental strips on top of ash dam A, but few of these species were able to establish over the years. The top of ash dam A was revegetated in the early 1980's with *Cortaderia* sp. and *Pennisetum clandestinum* (Table 2.1). The *Cortaderia* sp. was removed during 1995 and a 50mm layer of topsoil was added.

Table 2.1: Seed mixtures applied on various grids of the ash dams at Hendrina Power Station.

Mixture used in 1986 (Plateaux area of ash dam A - Grid 1)	Mixture used in 1990 (Plateaux area of ash dam C - Grid 12)	Mixture used in 1992 & 1994 (Slopes of ash dam A, C & D & plateaux of ash dam C - Grids 7, 8, 9, 10 & 11)	Mixture used in 1996-1997 (Middle parts of the slopes of ash dam D - Grids 7 & 8)
Cortaderia sp.	*Cenchrus ciliaris*	*Chloris gayana*	*Chloris gayana*
Pennisetum clandestinum	*Chloris gayana*	*Chloris virgata*	*Cynodon dactylon*
	Chloris virgata	*Cynodon dactylon*	*Digitaria eriantha*
	Cynodon dactylon	*Digitaria eriantha*	*Enneapogon cenchroides*
	Digitaria eriantha	*Enneapogon cenchroides*	*Eragrostis curvula*
	Enneapogon cenchroides	*Eragrostis chloromelas*	*Eragrostis echinocloidea*
	Eragrostis chloromelas	*Eragrostis curvula*	*Eragrostis lehmanniana*
	Eragrostis curvula	*Eragrostis echinocloidea*	*Eragrostis teff*
	Eragrostis echinocloidea	*Eragrostis lehmanniana*	*Panicum maximum*
	Eragrostis lehmanniana	*Eragrostis teff*	*Pennisetum clandestinum*
	Eragrostis teff	*Hyparrhenia hirta*	*Pogonarthria squarrosa*
	Fingerhutia africana	*Pennisetum clandestinum*	*Themeda triandra*
	Heteropogon contortus	*Themeda triandra*	
	Hyparrhenia hirta		
	Panicum maximum		
	Themeda triandra		

A mixture of topsoil and sub-soil from different soil depths were used during this rehabilitation attempt. The soil was probably from a soil form with a plinthic horizon, because of the high iron and manganese concretions within the soil layer. Topsoil contains organic matter, seed store, and is the area where microbial activity takes place and therefore act as the plant growth medium (Easton 1995). Sub-soil is described by Easton (1995) as those layers below the topsoil which lack the fertility of the topsoil and are especially important in root anchorage, which also serves as a moisture reservoir. Thin layers of topsoil provide both favourable physical and chemical conditions for plant growth, which in return lead to the successful establishment of vegetation (Adriano, Page, Elseewi, Chang & Straughan 1980).

Parts of the plateaux on ash dam C (Grid 12) were revegetated at the beginning of the 1990 growing season (Michael 1991; Table 2.1). The ash was ameliorated with a 50 cm layer of topsoil, stripped from selected areas, and fertilized with 250kg/ha superphosphate and 200kg/ha of 4:3:4 zinc fertilizer, and limited water was applied (Michael 1991). An area of 15 ha was planted with a mixture of more than 16 species of grass (Michael 1991).

An evaluation of the revegetated area was undertaken in July 1991 (Michael 1991). Above-ground biomass was collected in ten, 0.5 m^2 areas at a height of 30mm, where it was dried at 70°C for 24 hours (Michael 1991). The biomass was then calculated in kg/ha. The average above-ground biomass of the revegetated area after one season was 956kg/ha (Michael 1991). Basal cover was determined using the "wheel point" method (Michael 1991). The total basal cover of the revegetated area was 8.4% (Michael 1991). A total number of 25 species were recorded along transects of 500 points (Michael 1991).

The slopes of ash dam A were rehabilitated during 1994 (Grids 2, 3 & 4), while the bottom parts of the slopes of ash dam D (Grids 7 & 8), as well as the slope and some plateaux areas on ash dam C were rehabilitated in 1992 (Grid 9, 10 & 11 Table 2.1). On all the areas, rehabilitated in 1992 and 1994, the same rehabilitation method was applied, with a topsoil-layer of 8-10 cm and a seed mixture of 14 species of grass. This seed mixture was similar to the seed mixture used during the 1990 rehabilitation initiative. The topsoil used originated from soil of the Clovely and Westleigh soil forms. Slopes were stabilized by planting 450 mm wide strips of *Pennisetum clandestinum* and *Cynodon dactylon* at regular intervals of 4m. This technique was also implemented for erosion control purposes. *Cynodon* species were found by Easton (1995) as the most appropriate species of grass to prevent erosion.

The middle parts of the slopes of ash dam D were vegetated during the 1996/1997 growing season (Table 2.1), where similar rehabilitation techniques were used as on the slopes of ash dam A and C. The topsoil originated from a maize field from a Hutton soil form. The bottom parts of the slopes of ash dam D were vegetated in 1992, where a slightly different mixture of grass species and topsoil were used, than those used for the middle parts. No topsoil was returned to the top parts of the slopes of ash dam D and has therefore not been revegetated at all. The construction of these part of the slopes was still in progress at the time the study was conducted and rehabilitation of these areas will be initiated in the near future.

2.2 Survey grids used in the sampling of ants.

Twelve grids, which differ in terms of aspect, topography, time since rehabilitation, adjoining areas, and other habitat characteristics, were selected for the study (Figure 2.1; Table 2.2). Ten homogenous grids (Grids 1-12), according to homogenous plant communities were established on the four different ash dams, and two control grids (C1 & C2) in the adjoining natural grassland (Figure 2.1). Homogenous areas were selected to reduce variation in the data and to determine the effect of different environmental factors on rehabilitation success.

Grids on the ash dams represented both plateaux (Grids 1, 10, 11 & 12) and slopes (Grids 2, 3, 4, 7, 8 & 9; Figure 2.1). Grid 1 was established on top of ash dam A, and three grids on the slopes (Grids 2, 3 & 4; Figure 2.1). Grids 2 & 3 were situated near the power station and were rehabilitated at the same time, with similar rehabilitation techniques. These two grids only differ from Grid 4 in terms of aspect and adjoining area. Grids 5 & 6 were only used during one pilot study in 1996.

Table 2.2: Description of grids at Hendrina Power Station, showing the differences in terms of year of rehabilitation, aspect, topography, status of adjoining areas, as well as, vegetation classification. (See text below for the explanation of vegetation classification).

Grid	Ash dam	Year of rehabilitation	Aspect	Topography	Adjoining area*	Vegetation classification
C1	Natural grassland	/	/	/	/	/
C2	Natural grassland	/	/	/	/	/
1	A	1995	/	Plateaux	/	2.1.3
2	A	1994	North	Slope	1	2.1.2
3	A	1994	West	Slope	1	2.1.2
4	A	1994	East	Slope	2	2.1.2
7 Top	D	Unrehabilitated	West	Slope	1	/
7 Middle	D	1996	West	Slope	1	2.2.3
7 Bottom	D	1992	West	Slope	1	2.1.2
8 Top	D	Unrehabilitated	South	Slope	1	/
8 Middle	D	1996	South	Slope	1	2.2.3
8 Bottom	D	1992	South	Slope	1	2.1.2
9	C	1992	East	Slope	2	2.1.2
10	C	1992	/	Plateaux	/	2.1.1
11	C	1992	/	Plateaux	/	2.1.1
12	C	1990	/	Plateaux	/	2.1.1

*** The codes for the adjoining areas are as follows:**

1 - Disturbed areas; 2 - Natural grassland

2.3 Vegetation, associated with ash dam grids at Hendrina Power Station.

The ash dam grids were classified into three plant communities, two sub-communities and six variants (Morgenthal 1999; Table 2.2).

Community 1: *Brachiaria serrata-Setaria sphacelata* var. *torta*

The adjoining natural grassland (C1 & C2; Table 2.2) is characterized by this plant community. Diagnostic species of grass, which form part of this community include the following: *Brachiaria serrata*, *Setaria sphacelata* var. *torta*, *Tristachya leucothrix*, *Elionurus muticus* and *Heteropogon contortus*. The community also includes a rich variety of forbs e.g. *Vernonia oligocephala*, *Hermannia transvaalensis*, *Acrotome hispida* and *Pentanisia angustifolia*. This particular area is known for its occasional veld fires and no grazing activities in this area could be detected.

Community 2: *Eragrostis curvula-Cynodon dactylon*

Species indicative of this community include the grass species, *Eragrostis curvula* and *Cynodon dactylon* and the forb species, *Cyperus esculentus* and *Chamaecrista biensis*. All the rehabilitated grids on the ash dams belong to this community, and this community can be divided into two sub-communities and six variants.

Sub-community 2.1: *Hyparrhenia hirta-Eragrostis curvula*

The two dominant grass species in this sub-community are *Hyparrhenia hirta* and *Eragrostis curvula*. This sub-community includes rehabilitated grids, rehabilitated before 1996. Three plant variants occur in this sub-community.

Variant 2.1.1: *Chamaecrista biensis*

Grass species associated with this variant include, *Pennisetum clandestinum*, *Eragrostis curvula*, *Hyparrhenia hirta*, *Cynodon dactylon* and the forb *Chamaecrista biensis*. This variant was found on top of ash dam C (Grids 10,11 & 12).

Variant 2.1.2: *Lespedeza cuneata-Hyparrhenia hirta*

Diagnostic species occurring within this variant include species such as the forb *Lespedeza cuneata* and the grasses, *Chloris gayana* and *Eragrostis plana*, while the dominant species within this variant include, *Hyparrhenia hirta*, *Eragrostis curvula* and *Pennisetum clandestinum*. Most of the slopes, rehabilitated between 1992-1994, were part of this variant, except the top and middle transects of grids 7 & 8 (Table 2.2).

Variant 2.1.3: *Lepidium bonariense-Eragrostis trichophora*

This variant is characterized by a high dominance of *Pennisetum clandestinum* with low abundance of *Hyparrhenia hirta*, while *Digitaria eriantha* is absent from these variant. Dominant species include the forbs, *Conyza bonariensis* and *Tagetes minuta*. The habitat associated with this variant is very similar to the *Chamaecrista biensis* variant. This plant variant was never revegetated with a seed mixture, but instead planted with *Pennisetum clandestinum* and *Cortaderia* sp., whereafter the *Cortaderia* sp. was removed in 1995 due to health risks. During this period a layer of topsoil was added with a large amount of gravel. This variant is found on the plateaux of ash dam A (Grid 1; Figure 2.1; Table 2.2).

Sub-community 2.2: *Amaranthus hybridus-Cyperus esculentus*

The forbs, *Amaranthus hybridus* and *Chenopodium album*, are indicative of this sub-community, with a dominant occurrence of forbs, such as *Cyperus esculentus* and *Tagetes minuta*. This sub-community is found on the middle parts of grids 7 & 8, which were rehabilitated in 1996 (Table 2.2), and could be subdivided into three variants.

Variant 2.2.1: *Portulaca oleracea-Bidens formosa*

This variant is characterized by dominant species such as, *Tagetes minuta* and *Bidens formosa* and some garden plants such as *Gladiolus* sp., *Iris* sp., *Canna* sp. and *Mirabilis jalapa*, possibly due to the dumping of domestic refuge on already rehabilitated areas on ash dam C. Ruderal plant species such as *Portulaca oleracea*, *Bidens formosa*, *Cyperus esculentus* and *Tagetes minuta*, garden plants and perennial grasses like *Eragrostis* *curvula*, *Cynodon dactylon*, *Eragrostis chloromelas* and *Hyparrhenia hirta* can all be found in this variant.

Variant 2.2.2: *Panicum maximum-Digitaria eriantha*

This variant occupies a small area in a drainage line on the north-eastern slope of ash dam A (Figure 2.1), and is characterized by grass species such as, *Panicum maximum*, *Pennisetum clandestinum*, *Digitaria eriantha* and the sedge *Cyperus esculentus*.

Variant 2.2.3: *Eragrostis teff-Enneapogon cenchroides*

Both *Enneapogon cenchroides* and *Eragrostis teff* are pioneer species, which best describe this variant. Other species indicative of these variant include *Eleusine coracana* subsp. *africana*, *Zea mays*, *Cyperus esculentus*, and the forbs, *Amaranthus hybridus*, *Tagetes minuta* and *Commelina benghalensis*. This variant represents newly rehabilitated areas, less than one year old.

Community 3: *Spergularia media*

The forbs, *Spergularia media* and *Chenopodium album* are found on the unrehabilitated transects of ash dam D (Top parts of grids 7 & 8; Figure 2.1). This community will eventually be destroyed during the rehabilitation process and will be replaced by other species, found in the seed mixtures or in the topsoil.

2.4 Data collection: Ant survey.

Each grid consisted of three transects (30m apart) of 120m with a total of five pitfall traps per transect, spaced at 30m intervals (Figure 2.2). Pitfall traps were placed in holes dug into the ground, with the openings flush with the surrounding soil, without disturbing the surrounding soil and vegetation too much. Pitfall traps were marked with wooden stakes to facilitate finding them. Plastic specimen jars, 120mm deep and 50mm in diameter, were used during the ant survey. Andersen (1990) consider the ideal trap diameter to be about

40mm. At the beginning of the study, pitfall traps were quarter filled with antifreeze, but later on, a mix of dishwashing liquid and water was used. As preservative, 70% ethanol, was added to the pitfall traps on removal from the soil.

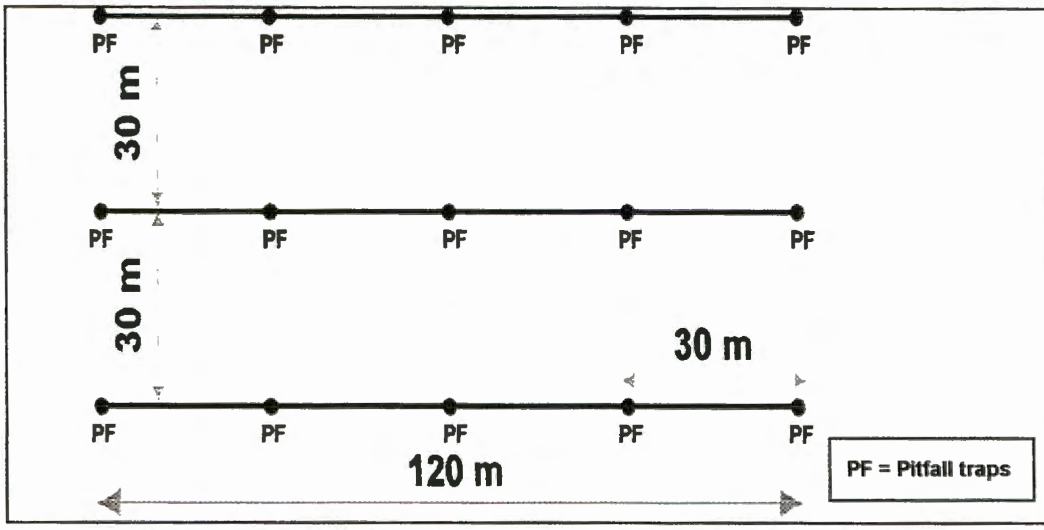

Figure 2.2: Grid layout showing the three transects and position of the pitfall traps

Ants were sampled by operating the traps for 48-hours, bimonthly, from March 1997 to January 1999. Sufficient samples can be obtained after 24-hours in hotter regions, while one week of sampling is appropriate in colder regions (Andersen 1990). The time period to leave pitfall traps in operation is constrained by the time available for fieldwork (Andersen 1990). After each collection of pitfall samples, a fresh set of pitfall traps were immediately returned to the holes in the soil for the next survey. This enabled pitfall traps to settle within the soil and also to avoid the disturbing, digging-in effect of traps (Greenslade 1973).

Pitfall trapping has been widely used in quantitative studies of Australian ant communities (Andersen 1995; Andersen & Sparling 1997) and has been shown to provide reliable estimates of species composition (Andersen & Sparling 1997) and relative abundance of species foraging on the ground (Andersen 1991). Pitfall trapping is also likely to provide a good indication of patterns of community composition (Andersen 1986b). Pitfall traps are easy to operate, require little work in the field and do not require field identification (Andersen 1997c). Pitfall trap catches are however, influenced by the structure of the ground, vegetation and litter (Andersen 1991) as well as the locomotory behaviour of ant species (Andersen 1997c), where it is suggested that fast-moving ant species are more likely to be caught and are therefore more "trapable" (Andersen 1990). Marsh (1984) found that pitfall trapping did not provide an accurate representation of the epigaeic ant community in the Namib desert and suggested that this was caused by differences in the susceptibility of some ants being trapped.

Pitfall trap data alone gives an underestimation of the total ant faunal diversity in any particular area, and it is therefore necessary to perform some additional survey techniques, such as hand collections and vegetation sweeping, if a more complete community census is required. Ant species associated with plants were collected using a 300mm in diameter sweepnet. Vegetation sweeping was done between 10h00 and 14h00. Five vigorous sweeps were taken between each pitfall trap. Sweepnet contents were emptied in tight-sealing glass jars, filled with 70% ethanol. Trapping was also supplemented by daytime hand collections to obtain species which were not recorded in the pitfall traps. Ant nests were also excavated at random locations within the survey grids. Different castes of different species were collected using this technique. Ants were identified with the help of Dr. Hamish Robertson of the South African Museum in Cape Town. Ants from each pitfall trap, sweepnet and hand collected samples were sorted to species level. Voucher specimens and a reference collection are held at the Potchefstroom University for CHE and the South African Museum in Cape Town.

Vegetation surveys were done by Mr. Theunis Morgenthal from the Botany Department at the Potchefstroom University for CHE, where these measurements include percentage bare ground, percentage plant cover, plant frequency of each species, vegetation structure and density, plant species richness and plant species composition, which were also taken along each transect. Other physical surveys, such as taking of soil samples, were taken by myself and other ecologists from the Zoology Department at the Potchefstroom University for CHE. Ten cm-deep soil cores were taken with a soil-auger in the middle of each transect, put into plastic bags, marked, sealed and sent to Ekorehab in Potchefstroom for analyses of minerals, pH, conductivity, organic matter and percentage sand, silt, gravel and clay content. These soil samples were taken during a winter survey of 1997. Litter in rehabilitated areas consisted largely of dead grass and forbs.

2.5 Data analysis

Relative abundances (%) of ant species, were calculated by dividing the number of individuals of each ant species by the total number of individuals (n/Nx100), for each transect. Seasonal abundance values of ant species were calculated over twelve surveys from 1997-1999 (Table 2.3).

Table 2.3: Different seasons in which the different samples were taken.

Sampling period	Season
March 1997	Autumn
May 1997	Autumn
July 1997	Winter
September 1997	Spring
December 1997	Summer
January 1998	Summer
March 1998	Autumn
May 1998	Autumn
July 1998	Winter
September 1998	Spring
December 1998	Summer
January 1999	Summer

Total abundance values of the different ant species in each transects, were used to calculate the Shannon-Wiener diversity index (I_n), ant species equitability and ant species richness, using the computer software package MVSP (Multivariate Statistical Package). The Shannon-Wiener diversity index was used, because it gives more weight to scarce ant species, in comparison with the Simpson diversity index which gives more weight to abundant ant species (Hellawell 1986).

Further statistical analysis was undertaken using STATISTICA 5.1. Normality in the species composition, Shannon diversity index values, equitability and richness data were tested by means of a Shapiro-Wilk test. Parametric tests were used when the data was normally distributed. These parametric tests include, analysis of variance (ANOVA) and Pearson's correlation tests. Analysis of variance was applied to the pitfall trap data to investigate possible significant seasonal patterns in the mean number of ant species (ant species richness) on ash dams and in the natural grassland. Pearson's correlation test was used to investigate possible significant correlations between the one component of ant species diversity (ant species richness) and plant and structural variables, such as plant species diversity, vegetation and soil characteristics. Any correlation with, $p<0.05$, was regarded as statistically significant. Significant differences in normally distributed data were tested by means of Tukey's test for significance. Tukey's test for significance was used to determine if there was significant seasonal variation in the mean ant species richness, caught on ash dams and in the natural grassland.

Where the data was not normally distributed, non-parametric tests such as Kruskal-Wallis ANOVA and Spearmann's correlation test were used. A Kruskal-Wallis ANOVA was used to determine if there was significant seasonal variation in the mean Shannon diversity index values and mean species equitability on the ash dams and in the natural grassland. Spearmann's correlation test was used to investigate possible significant correlations between mean Shannon diversity index values, mean species equitability and different ant species and plant and structural variables, such as plant species diversity, vegetation and soil characteristics. Any correlation with $p<0.05$ was regarded as statistically significant. Significant differences in non-parametric data were tested by means of a significance test, described by Miller (1981). The equation is as follows:

$$\left|\overline{R}_i - \right|\overline{R}_j \leq \sqrt{C_{(n-1;0,05)} \cdot \frac{N(N+1)}{12} \cdot \left(\frac{1}{n_i} + \frac{1}{n_j}\right)}$$

Miller's test for significance was used to investigate significant differences in the mean Shannon diversity index values and mean species equitability on ash dam grids in relation to different seasons. For both Tukey's and Miller's test, the 95% level ($p<0.05$) was regarded as statistically significant.

When differences in the ant species composition, ant species diversity, species equitability and ant species richness on ash dam grids, in relation to time since rehabilitation, were investigated, data for grids, rehabilitated at the same time, were combined. Mean Shannon diversity index values, mean equitability values and mean ant species richness in each, bimonthly survey, from 1997-1999, were treated as repeated measures, due to the interdependent influence of age of rehabilitation on the mean Shannon diversity index values, mean species equitability and mean ant species richness. These repeated measures were then compared between grids which were rehabilitated at different timescales. A two-way ANOVA was then applied to the data to determine if time since rehabilitation had a significant influence on the mean Shannon diversity index, mean species equitability and mean ant species richness. Tukey's test for significance at the 95% confidence level was then further applied to determine if there were any significant differences in the mean Shannon diversity index values, mean equitability, and mean ant species richness on ash dam grids, which were rehabilitated at different timescales. Differences in the ant species composition, ant species diversity, species equitability and ant species richness on ash dam grids, in relation to time since rehabilitation were also investigated by rank-abundance curves. The log-normal model appear to be widely applicable (Preston 1962; Williams 1964), and may often fit complex communities with large numbers of species, being mostly of intermediate abundance (May 1975; Whittaker 1975). The mean Shannon diversity index values, mean species equitability and mean ant species richness on the ash dam grids, rehabilitated in different years, were compared with that of the natural grassland.

Ant species which are characteristic of unrehabilitated, young and older rehabilitated ash dam grids, as well as specialized ant species, which normally occurred only in the natural grassland and were therefore characteristic of areas with a high habitat and structural diversity were also determined. Shannon diversity index values, species equitability, species richness and species composition data in the adjoining natural grassland were used throughout the study as a benchmark for comparing ant data on the ash dam grids.

Multivariate ordination techniques were used to determine possible ant-plant relationships on various ash dam grids. For these analyses, ash dam grids, which were rehabilitated in different years, characterized by different aspect, adjoining areas, topography, plant communities and plant variants were used. Multivariate ordination techniques arrange survey areas along axes in terms of the species which are present within these areas, in which these survey areas are represented by points arranged along two major ordination axes (Ter Braak 1995). Survey areas with a similar species composition group close together, while survey areas with a different species composition occur far apart (Ter Braak 1995). In an ordination much more taxa can be included, and is useful when information on the biology of species is unknown (Kremen 1992). Kremen (1992) also states that the distribution of many species and their relationships to environmental parameters could be assessed simultaneously by means of ordination techniques. Indicator properties of various animal and plant species can also be assessed by means of ordination techniques (Kremen 1992).

Multivariate analyses were performed using the multivariate statistical package, CANOCO (Ter Braak 1988). Species abundance matrices for ant or plant data were analyzed by an ordination, using a Detrended Correspondence Analysis (DCA; detrended by polynomials, CANOCO program; Ter Braak 1988). DCA is an unimodal method of ordination (Ter Braak & Šmilauer 1998). A Detrended Correspondence Analysis (indirect gradient analysis) was applied to vegetation data, to determine possible relationships between ant species and various plant species on various rehabilitated and unrehabilitated ash dam grids, using ant species abundances as supplementary data. No down weighting of rare species was attempted. Ordination diagrams were redrawn from the solution file obtained from the CANOCO program. The co-variation in the distribution of species is displayed by a DCA to just a few ordination axes, in which the dimensionality of *N* species among *M* samples are reduced (Kremen 1992). The variation in the dispersion and arrangement of samples or species along different axes could be explained by the eigenvalues associated with each particular axis (Gauch 1982; Kremen 1992). Gauch (1982) and Kremen (1992) suggest that a DCA is more effective than other ordination techniques because: (1) it removes the arch effect and compression of gradients at ends, (2) it ordinates sites and species simultaneously within the same ordination space, and (3) it requires no assumptions about directions of environmental gradients or weighting of species or sites. In a DCA, analysis is based only on the distribution of species abundance values (Kremen 1992). Kremen (1992) proved that a DCA is an important ordination technique for assessing the ability of plant and animal distributional data to indicate a particular environmental pattern, when other information is not available.

Correlation analyses were used to investigate the possible influence of plant species diversity, plant species richness and other habitat characteristics, such as vegetation and soil characteristics on the diversity, equitability, richness and composition of the ant community on rehabilitated ash dam grids. The association between ant species and various plant species on rehabilitated ash dam grids has also been tested by various correlation matrices.

In order to provide further information on the relationship between ant species distribution and associated environmental parameters, a Canonical Correspondence Analysis (CCA) was used, where environmental data was superimposed on the ordination plots to look for patterns and correlations (Kent & Coker 1992). In a CCA ordination, species are distributed along easily measured environmental gradients (Gauch 1982), in which the species axes are constrained to be linear combinations of the environmental data (Kent & Coker 1992). The significance of a particular environmental variable can be assessed through Monte Carlo testing of the axis, associated with that variable, using the axis eigenvalue as the test statistic ($p<0.05$) (Kremen 1992). Both the variability of the environmental data and species data is described in a CCA ordination (Kent & Coker 1992). In a CCA one could therefore test the influence of various environmental variables in establishing the ordination pattern (Kremen 1992). The CCA ordination techniques were considered for the analysis due to long gradients and heterogeneity in the composition of the ant community. Analyses were performed with symmetric biplot scaling, where ant species data were not transformed. Environmental variables included in the CCA analysis of ant data were percentage sand, silt, clay, gravel, percentage organic carbon, pH and conductivity. Floristic data used in the CCA included plant species abundances and percentage vegetation cover.

The effect of these environmental variables on the composition of the ant community was further assessed by using simple linear regressions. Regression analyses can be used to determine possible relationships between species and the associated environment, by looking at species and environmental variables at a number of survey areas (Ter Braak & Looman 1995). To investigate a situation where one ant species respond to more than one environmental variable, a multiple stepwise regression is used. In a multiple regression, the variation in a particular dependent variable is explained by two, or more independent variables. Using multiple regressions together with various forms of correspondence analysis, an integrated ordination of species together with associated environmental data is obtained (Kent & Coker 1992).

The aims of canonical ordination techniques were therefore to detect relationships between ant species and various plant species on different ash dam grids. Another objective of ordination techniques was to determine the possible influence of various environmental variables on the composition and distribution of the ant community in various grids on rehabilitated ash dams. The resulting ordination diagram therefore, not only expresses the variation in the distribution and composition of the ant and plant community, but also determine the environmental variables which are responsible for the variation in the composition of the ant community.

CHAPTER 3

RESULTS

3.1 Ant community structure in succession studies of ash dam rehabilitation.

3.1.1 Ant species composition on the ash dams and in the adjoining natural grassland.

A total of 34 ant species, from 12 genera, were collected during the twelve survey periods on rehabilitated and unrehabilitated ash dams grids (Figure 3.1), compared to 38 species in 18 genera in the adjoining natural grassland (Figure 3.2). Ant species were divided into those that were dominant (5% - 100% relative abundance), sub-dominant (0.5% - 5% relative abundance) and sub-ordinate (0.05% - 0.5% relative abundance). The names of the dominant, sub-dominant and sub-ordinate ant species on the ash dams and in the natural grassland, represented by each number on the x-axis of Figure 3.1 and Figure 3.2, as well as the relative abundance values of the dominant, sub-dominant and sub-ordinate ant species on the ash dams and in the natural grassland are given in Table 3.1.

Both the ash dams and the natural grassland had *Anoplolepis custodiens*, *Solenopsis punctaticeps*, *Monomorium albopilosum*, and *Monomorium* sp.2 as dominant ant species, with *A. custodiens* being the most abundant of all (Figures 3.1, 3.2). *Crematogaster* sp.1 and *Pheidole* sp.2 were dominant in the natural grassland, but only sub-ordinate on the ash dam grids. *Tetramorium setuliferum* was dominant in the natural grassland and sub-dominant on the ash dams. *Lepisiota capensis* and *Lepisiota laevis* were dominant on the ash dams, but sub-dominant and sub-ordinate, respectively in the natural grassland (Figures 3.1, 3.2).

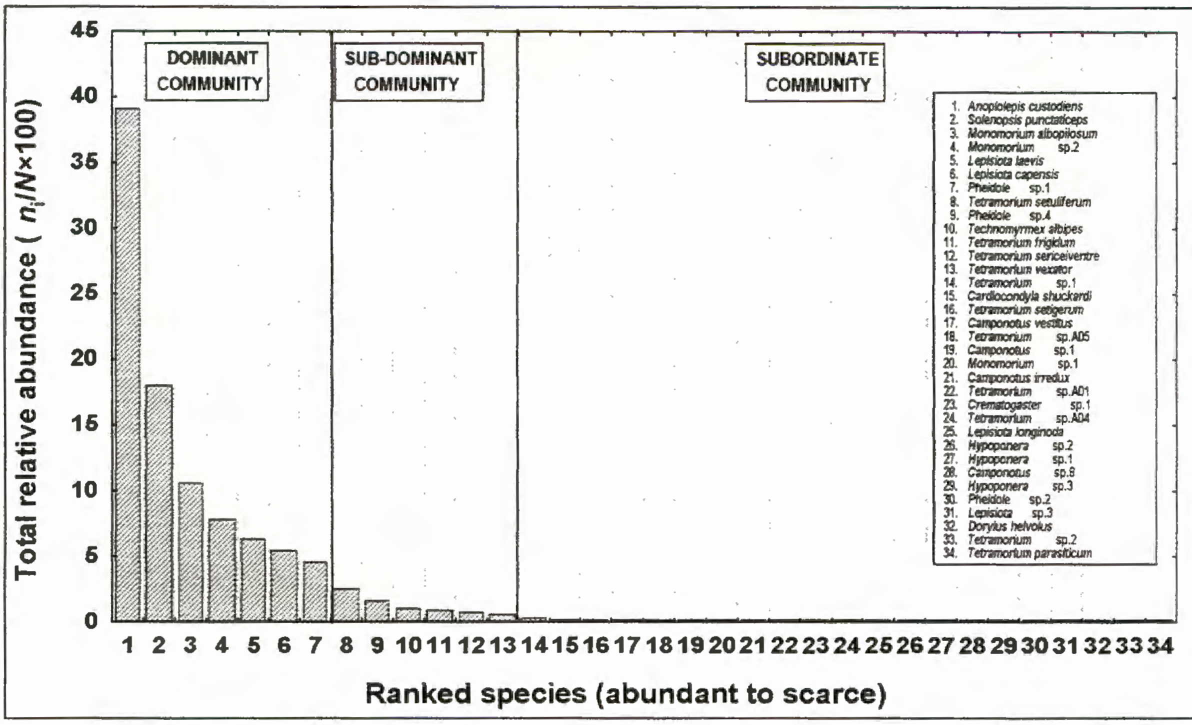

Figure 3.1: Total relative abundances of dominant, sub-dominant and subordinate ant species, collected on rehabilitated and unrehabilitated ash dam grids.

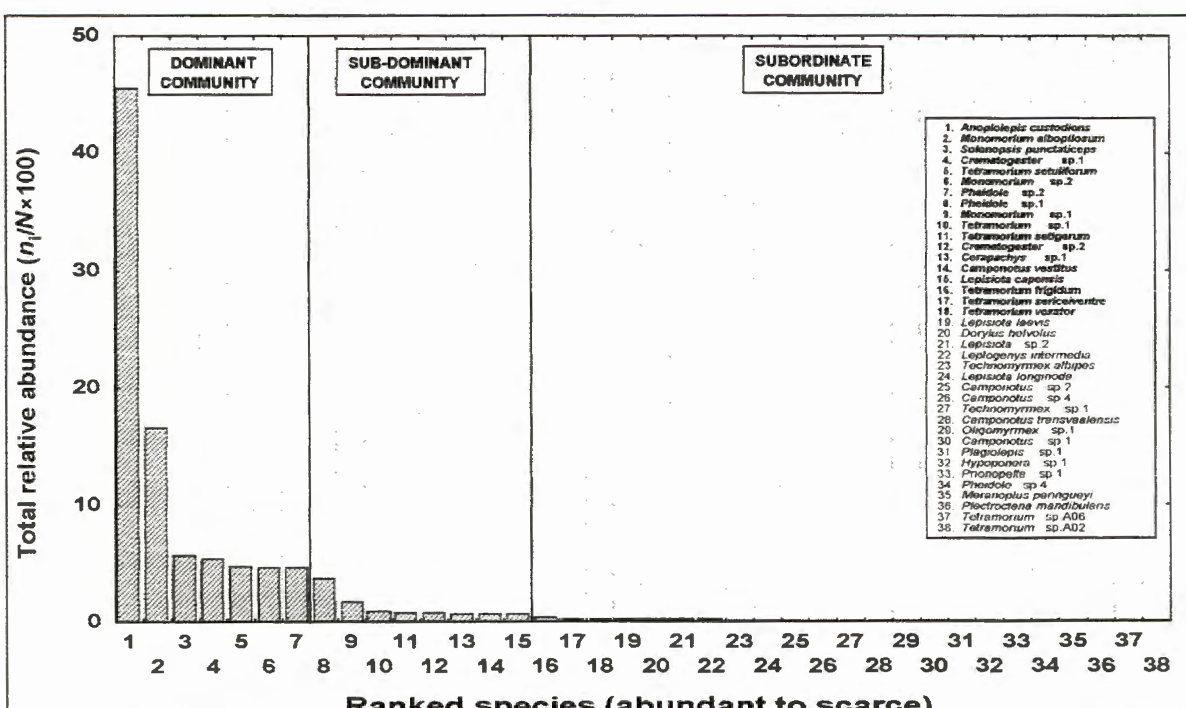

Figure 3.2: Total relative abundances of dominant, sub-dominant and subordinate ant species, collected in the adjoining natural grassland.

Table 3.1: Relative abundance values of the dominant, sub-dominant and sub-ordinate ant species on rehabilitated and unrehabilitated ash dam grids and in the natural grassland from Fig. 3.1 & Fig. 3.2. Ant species are ranked from abundant to scarce. The numbers in the table represent the dominant, sub-dominant and sub-ordinate ant species, which were also given on the x-axis.

REHABILITATED & UNREHABILITATED ASH DAM GRIDS

		Species	Relative abundance
Dominant	1	*Anoplolepis custodiens*	39.053
	2	*Solenopsis punctaticeps*	17.962
	3	*Monomorium albopilosum*	10.570
	4	*Monomorium* sp.2	7.818
	5	*Lepisiota laevis*	6.330
	6	*Lepisiota capensis*	5.392
	7	*Pheidole* sp.1	4.537
Sub-dominant	8	*Tetramorium setuliferum*	2.458
	9	*Pheidole* sp.4	1.637
	10	*Technomyrmex albipes*	1.004
	11	*Tetramorium frigidum*	0.852
	12	*Tetramorium sericeiventre*	0.706
	13	*Tetramorium vexator*	0.647
Sub-ordinate	14	*Tetramorium* sp.1	0.361
	15	*Cardiocondyla shuckardi*	0.192
	16	*Tetramorium setigerum*	0.162
	17	*Camponotus vestitus*	0.097
	18	*Tetramorium* sp.A05	0.044
	19	*Camponotus* sp.1	0.034
	20	*Monomorium* sp.1	0.027
	21	*Camponotus irredux*	0.026
	22	*Tetramorium* sp.A01	0.025
	23	*Crematogaster* sp.1	0.023
	24	*Tetramorium* sp.A04	0.009
	25	*Lepisiota longinoda*	0.008
	26	*Hypoponera* sp.2	0.008
	27	*Hypoponera* sp.1	0.005
	28	*Camponotus* sp.8	0.004
	29	*Hypoponera* sp.3	0.003
	30	*Pheidole* sp.2	0.001
	31	*Lepisiota* sp.3	0.001
	32	*Dorylus helvolus*	0.001
	33	*Tetramorium* sp.2	0.001
	34	*Tetramorium parasiticum*	0.001

NATURAL GRASSLAND

		Species	Relative abundance
Dominant	1	*Anoplolepis custodiens*	45.561
	2	*Monomorium albopilosum*	16.648
	3	*Solenopsis punctaticeps*	5.699
	4	*Crematogaster* sp.1	5.419
	5	*Tetramorium setuliferum*	4.803
	6	*Monomorium* sp.2	4.607
	7	*Pheidole* sp.2	4.565
Sub-dominant	8	*Pheidole* sp.1	3.710
	9	*Monomorium* sp.1	1.778
	10	*Tetramorium* sp.1	0.910
	11	*Tetramorium setigerum*	0.826
	12	*Crematogaster* sp.2	0.812
	13	*Cerapachys* sp.1	0.658
	14	*Camponotus vestitus*	0.644
	15	*Lepisiota capensis*	0.644
Sub-ordinate	16	*Tetramorium frigidum*	0.378
	17	*Tetramorium sericeiventre*	0.322
	18	*Tetramorium vexator*	0.294
	19	*Lepisiota laevis*	0.294
	20	*Dorylus helvolus*	0.280
	21	*Lepisiota* sp.2	0.280
	22	*Leptogenys intermedia*	0.252
	23	*Technomyrmex albipes*	0.182
	24	*Lepisiota longinoda*	0.154
	25	*Camponotus* sp.2	0.056
	26	*Camponotus* sp.4	0.028
	27	*Technomyrmex* sp.1	0.028
	28	*Camponotus transvaalensis*	0.028
	29	*Oligomyrmex* sp.1	0.014
	30	*Camponotus* sp.1	0.014
	31	*Plagiolepis* sp.1	0.014
	32	*Hypoponera* sp.1	0.014
	33	*Prionopelta* sp.1	0.014
	34	*Pheidole* sp.4	0.014
	35	*Meranoplus peringueyi*	0.014
	36	*Plectroctena mandibularis*	0.014
	37	*Tetramorium* sp.A06	0.014
	38	*Tetramorium* sp.A02	0.014

3.1.2 Ant species as indicators of ecosystem change, due to rehabilitation success (Qualitative analyses).

The approach in this section was (1) to identify pioneer ant species which are characteristic of unrehabilitated areas and early stages of succession, (2) to identify ant species which are characteristic of later stages of succession, and (3) to investigate if specialized ant species, which under normal circumstances only occurred within the natural grassland, colonized the ash dams.

Grids laid on the ash dams represent areas, rehabilitated in different years, and therefore characterize different stages of succession. Mean abundance values per transect of ant species which were present during the different stages of succession on ash dam grids, in comparison with the adjoining natural grassland are summarized in Table 3.2. Table 3.2 also shows a progressive change in the number of ant species during different stages of succession.

3.1.2.1 Early successional ant species.

The best example of an early successional ant species is *Cardiocondyla shuckardi* which was caught in high numbers on the ash dam grids before rehabilitation and during an early stage of succession (rehabilitated in 1996), but was not caught on the oldest rehabilitated ash dam grid (Grid 12) and in the adjoining natural grassland (Table 3.2; Figure 3.3).

The other nine ant species found in the unrehabilitated grids (Table 3.2) were also encountered in all the later stages of succession and hence are species with broad habitat tolerances, that are able to colonize an area moderately quickly. These ant species were also present in the natural grassland.

Table 3.2: Mean number of ants, caught per transect, during different stages of succession. Ants are arranged according to their order in the succession.

	Ash dam grids rehabilitated at different stages						
	Unrehabilitated areas	Rehabilitated in 1996	Rehabilitated in 1995	Rehabilitated in 1994	Rehabilitated in 1992	Rehabilitated in 1990	Natural grassland
	Grids 7 & 8 Top	Grids 7 & 8 Middle	Grid 1	Grids 2, 3 & 4	Grids 7 & 8 Bottom, 9, 10 & 11	Grid 12	
Cardiocondyla shuckardi	0.625	3.708	0.417	0.009	0.212		
Anoplolepis custodiens	0.250	2.167	3.389	186.019	64.576	35.667	45.194
Lepisiota laevis	0.042	0.208	9.028	4.407	29.811	3.694	0.292
Monomorium albopilosum	0.917	11.500	54.000	20.111	21.477	24.778	16.514
Monomorium sp.2	0.042	8.750	21.583	21.380	19.621	3.722	4.569
Pheidole sp.1	0.125	4.542	9.167	10.917	9.985	15.417	3.681
Solenopsis punctaticeps	0.792	0.250	2.889	41.861	63.076	23.833	5.653
Technomyrmex albipes	0.042	0.375	0.167	3.731	1.917	2.806	0.181
Tetramorium sericeiventre	0.083	1.625	1.861	2.019	1.606	0.167	0.319
Crematogaster sp.1	0.083	0.042		0.019	0.091	0.028	5.375
Lepisiota capensis		5.083	2.889	22.148	7.356	15.667	0.639
Tetramorium frigidum		1.000	0.361	2.028	1.348	6.167	0.375
Tetramorium sp.1		0.375	0.472	0.148	0.667	4.111	0.903
Camponotus vestitus		0.083		0.500	0.121	0.083	0.639
Pheidole sp.4		0.292	22.583	1.509	2.106		0.014
Hypoponera sp.1		0.125			0.008		0.014
Dorylus helvolus		0.042					0.278
Tetramorium sp.A01		0.042			0.136		
Hypoponera sp.2		0.125				0.083	
Tetramorium sp.A04			0.083			0.111	
Monomorium sp.1			0.028	0.009	0.136	0.028	1.764
Tetramorium setuliferum			0.194	0.509	13.667	0.750	4.764
Tetramorium vexator			0.778	1.435	1.871	1.889	0.292
Lepisiota longinoda			0.111			0.056	0.153
Tetramorium setigerum				0.148	0.561	0.972	0.819
Camponotus sp.1				0.157	0.068		0.014
Camponotus irredux				0.074	0.030	0.222	
Hypoponera sp.3				0.009	0.008		
Tetramorium sp.2				0.009			
Pheidole sp.2					0.008		4.528
Camponotus sp.8						0.083	
Lepisiota sp.3						0.028	
Tetramorium parasiticum						0.028	
Tetramorium sp.A05						0.944	
Camponotus transvaalensis							0.028
Camponotus sp.2							0.056
Camponotus sp.4							0.028
Cerapachys sp.1							0.653
Crematogaster sp.2							0.806
Lepisiota sp.2							0.278
Leptogenys intermedia							0.250
Meranoplus peringueyi							0.014
Oligomyrmex sp.1							0.014
Plagiolepis sp.1							0.014
Plectroctena mandibularis							0.014
Prionopelta sp.1							0.014
Technomyrmex sp.1							0.028
Tetramorium sp.A02							0.014
Tetramorium sp.A06							0.014
Total ants caught	72	968	4680	34469	31741	5088	7142
Number of species	10	19	18	23	25	25	38
Total pitfall samples	10	10	15	45	55	15	30

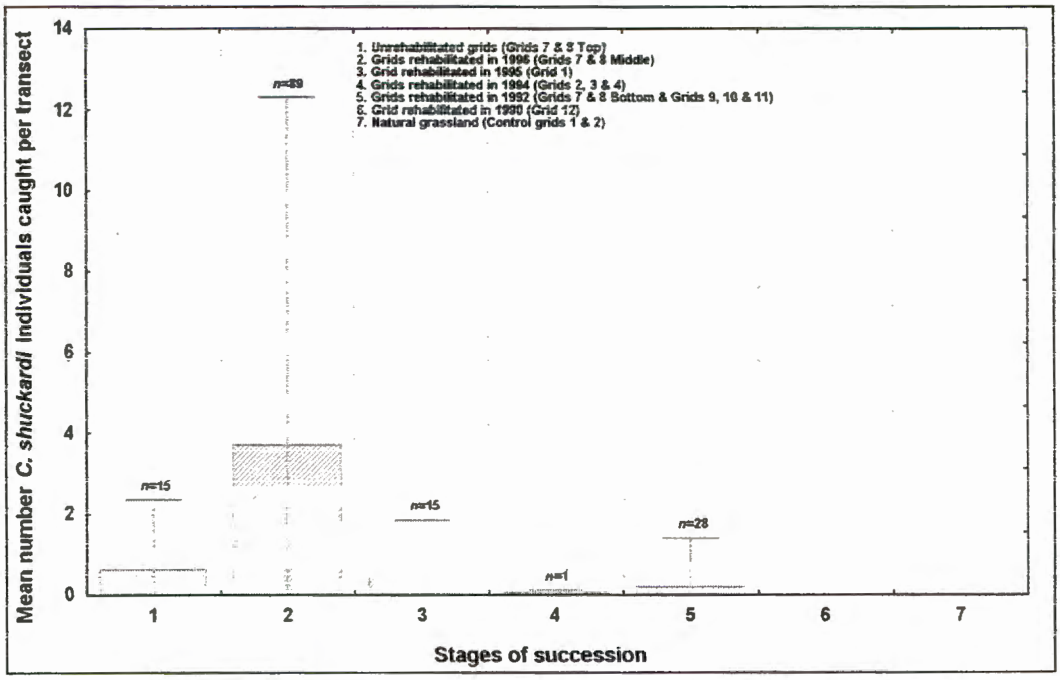

Figure 3.3: Mean number *Cardiocondyla shuckardi* individuals caught per transect, during different stages of succession (Bars indicate ±1sd).

3.1.2.2 Intermediate to late successional ant species.

Intermediate to late successional ant species are those that were more abundant on the ash dam grids at later stages of succession, although they were present on the unrehabilitated grids and grids rehabilitated in 1996. The best example of an intermediate to late successional ant species is *Anoplolepis custodiens*, which was caught in higher numbers during later stages of succession, although it was present on the unrehabilitated grids and grids rehabilitated in 1996 (Table 3.2; Figure 3.4).

Except for *C. shuckardi*, all the other nine ant species present on the unrehabilitated grids, became more abundant at later stages of succession (Table 3.2). These ant species could therefore, all be considered as intermediate to late successional species. Although *Crematogaster* sp.1 was present on all the ash dam grids, it was more abundant in the natural grassland (Table 3.2) and could therefore rather be considered as a grassland species which will be discussed in section 3.1.2.4.

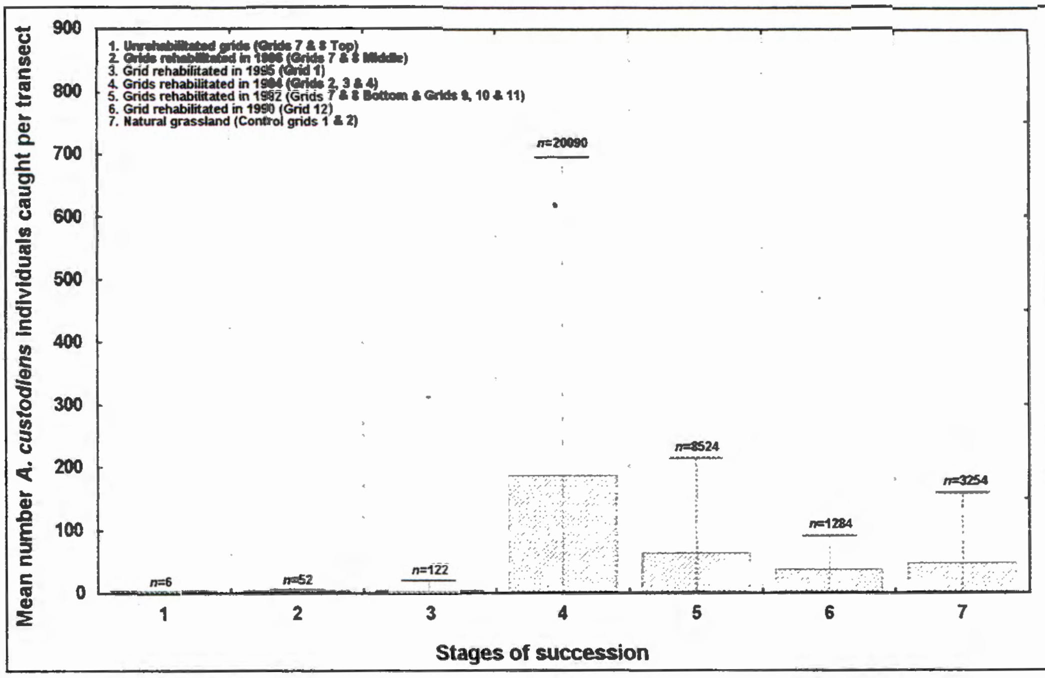

Figure 3.4: Mean number *Anoplolepis custodiens* individuals caught per transect, during different stages of succession (Bars indicate ±1sd).

Lepisiota capensis, *Tetramorium frigidum*, *Tetramorium* sp.1, *Camponotus vestitus*, *Pheidole* sp.4, *Hypoponera* sp.1, *Dorylus helvolus*, *Tetramorium* sp.A01 and *Hypoponera* sp.2 were caught at relatively early stages of succession (grids rehabilitated in 1996) and also during various older stages of succession (Table 3.2). Some of these ant species, such as, *Tetramorium* sp.A01 and *Hypoponera* sp.2 were not found in the adjoining natural grassland. These species are rare (Table 3.2) and there could just be a chance that they were not recorded, due to sampling inefficiency or their aversion for pitfall traps, hence making it difficult to catch these ant species. Table 3.2 shows that *Tetramorium frigidum* and *Tetramorium* sp.1 were caught in higher numbers, within the pitfall traps, on the oldest rehabilitated ash dam grid (Grid 12).

3.1.2.3 Late successional ant species.

Late successional ant species are those species that were not caught on the unrehabilitated and late rehabilitated ash dam grids (grids rehabilitated in 1996), and colonized at much later stages of succession. *Tetramorium* sp.A04, *Monomorium* sp.1, *Tetramorium setuliferum*, *Tetramorium vexator* and *Lepisiota longinoda* were absent from the unrehabilitated and 1996-rehabilitated areas (middle transects of grids 7 & 8), and first appeared in the catches from the 1995-rehabilitated ash dam grid (Grid 1; Table 3.2). *Tetramorium* sp.A04 was rare on the ash dam grids.

As in the case of *A. custodiens*, both *T. setuliferum* and *T. vexator* were also caught in relatively high numbers on all the older rehabilitated ash dam grids, therefore in later stages of succession (Figure 3.5 & Figure 3.6, respectively), making them good examples of late successional ant species. *T. setuliferum* showed exceptionally high numbers in the 1992-rehabilitated ash dam grids (Table 3.2 & Figure 3.5). Although *Monomorium* sp.1 and *Lepisiota longinoda* were caught on various rehabilitated ash dam grids they were more abundant in the natural grassland (Table 3.2).

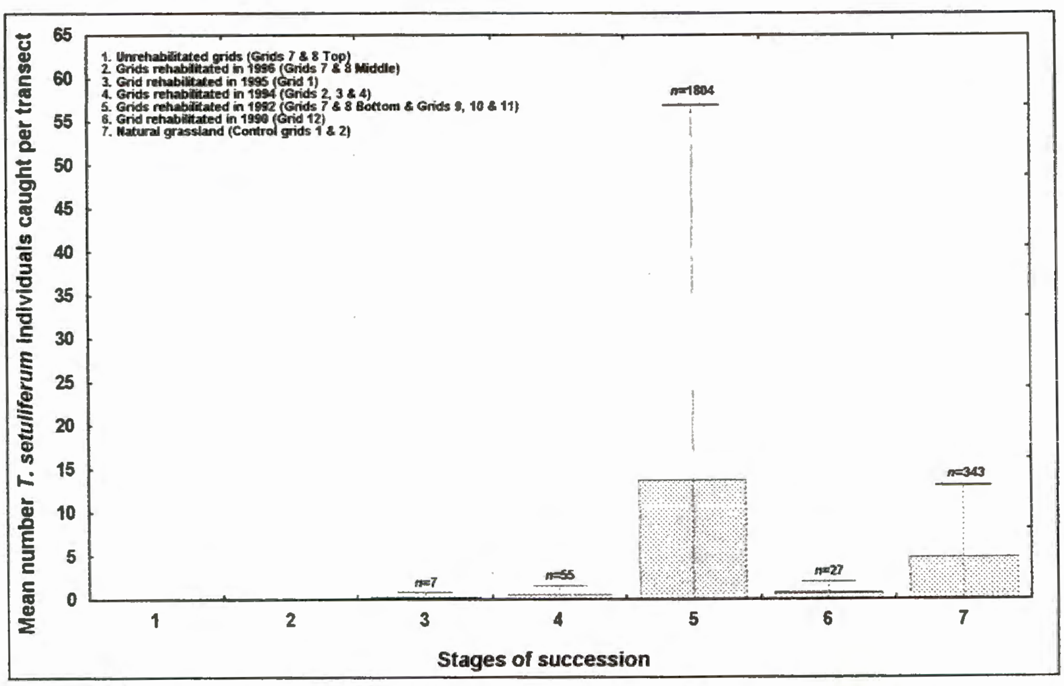

Figure 3.5: Mean number *Tetramorium setuliferum* individuals caught per transect, during different stages of succession (Bars indicate ±1sd).

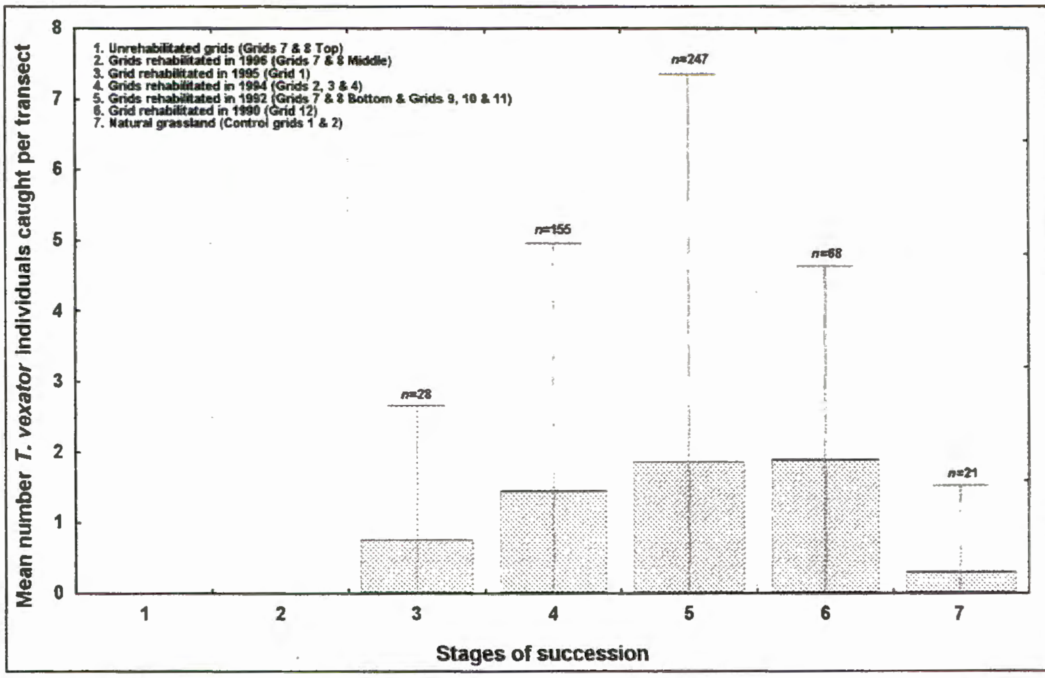

Figure 3.6: Mean number *Tetramorium vexator* individuals caught per transect, during different stages of succession (Bars indicate ±1sd).

Table 3.2 shows that *Tetramorium setigerum*, *Camponotus* sp.1, *Camponotus irredux*, *Hypoponera* sp.3 and *Tetramorium* sp.2 were not found on the unrehabilitated, 1996-rehabilitated and 1995-rehabilitated grids, and found only on much older rehabilitated ash dam grids. The last three of the above mentioned ant species were not found in the natural grassland grids either. Although *Camponotus* sp.1 was caught in low numbers in pitfall traps in the natural grassland, it was present within this area. Both *Hypoponera* sp.3 and *Tetramorium* sp.2 were rare in the pitfall traps (Table 3.2) and there could just be a chance that they were not recorded, due to sampling inefficiency or their aversion for pitfall traps, hence making it difficult to catch these ant species.

Of the above mentioned ant species, *T. setigerum* was the only abundant ant species, that was limited to late successional grids (Figure 3.7). As in the case of *T. setuliferum* and *T. vexator*, *T. setigerum* is also a good example of a late successional ant species, abundant within late successional grids.

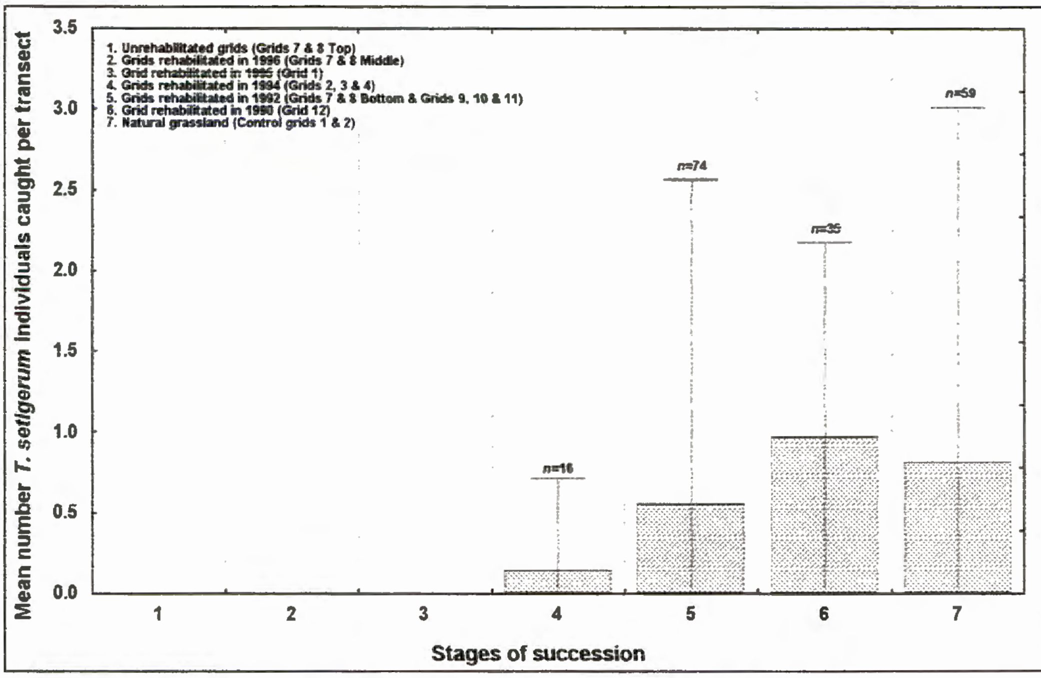

Figure 3.7: Mean number *Tetramorium setigerum* individuals caught per transect, during different stages of succession (Bars indicate ±1sd).

Although *Pheidole* sp.2 was caught on the ash dams, it was caught in low numbers, and was much more abundant in the natural grassland (Table 3.2). Table 3.2 illustrates that four ant species were sampled only on the oldest rehabilitated ash dam grid (Grid 12). These ant species were *Camponotus* sp.8, *Lepisiota* sp.3, *Tetramorium parasiticum* and *Tetramorium* sp.A05. However, only *Tetramorium* sp.A05 (alate ant species) was caught in sufficient numbers to make proper deductions regarding its presence in different stages of succession.

3.1.2.4 Grassland ant species.

Grassland ant species are those species that were only caught in pitfall traps within the natural grassland. These ant species were, *Camponotus transvaalensis*, *Camponotus* sp.2, *Camponotus* sp.4, *Cerapachys* sp.1, *Crematogaster* sp.2, *Lepisiota* sp.2, *Leptogenys intermedia*, *Meranoplus peringueyi*, *Oligomyrmex* sp.1, *Plagiolepis* sp.1, *Plectroctena mandibularis*, *Prionopelta* sp.1, *Technomyrmex* sp.1, *Tetramorium* sp.A02 and *Tetramorium* sp.A06. None of these species were found on the ash dam grids (Table 3.2).

3.1.3 Ant species diversity as an indicator of ecological change, due to rehabilitation success (Quantitative analyses).

Equitability (distribution of individuals among species) and species richness (number of species) are both components of ant species diversity. The general term "diversity", as used in this section, includes equitability and species richness as quantified in the Shannon diversity index, but the latter terms are used *senso stricto*, where necessary.

This part of the study was conducted to determine variation in the mean ant species diversity (Shannon diversity index), mean equitability and mean number of ant species (species richness) on ash dams, in relation to time since the initiation of rehabilitation (Table 3.3 & Figure 3.8). Mean number of ant species, rather than a richness index, such as Margalef's richness index were used during the analysis, due to variation in sampling size. This variation in sample size tends to obscure trends in Margalef's richness index values. Mean Shannon diversity, mean species equitability and mean species richness in the adjoining natural grassland were used throughout the study as a benchmark to compare with the ash dams.

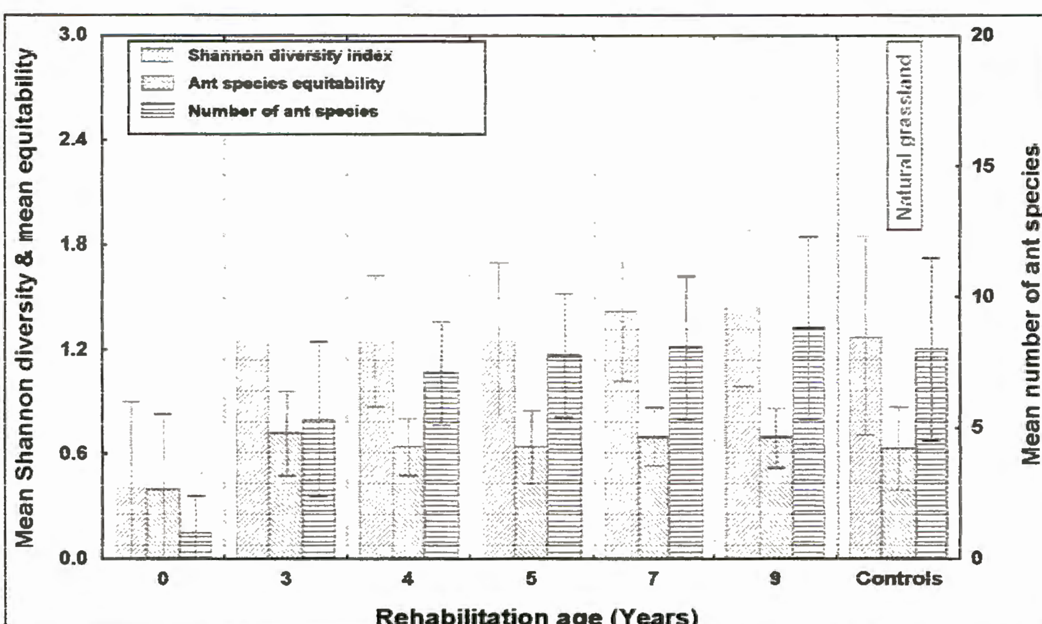

Figure 3.8: Mean Shannon diversity, mean species equitability and mean number of ant species, per transect, during different stages of succession, from the period 1997-1999 (Bars indicate ±1sd).

Table 3.3: Variation in the mean Shannon diversity index values, mean equitability values, mean species richness and standard deviations (sd) of the ant community, from 1997-1999 on the ash dam grids, in relation to the time, since these grids were rehabilitated. These values were also compared with that of the adjoining natural grassland. Diversity, equitability and richness values in each age class were treated as repeated measures, whereafter these repeated measures were then compared between grids. Significant differences indicated by a two-way ANOVA are given, together with a summary of Tukey's test for significance, where the line indicates no significant differences.

Rehabilitation age (Years)	Shannon diversity index (Mean ± sd)	Equitability (Mean ± sd)	Species richness (Mean ± sd)
0 (Unrehabilitated)	0.405 ± 0.495	0.390 ± 0.440	1.000 ± 1.383
3	1.247 ± 0.530	0.718 ± 0.241	5.333 ± 2.944
4	1.249 ± 0.374	0.640 ± 0.163	7.083 ± 1.977
5	1.250 ± 0.447	0.636 ± 0.213	7.787 ± 2.340
7	1.412 ± 0.396	0.700 ± 0.168	8.076 ± 2.734
9	1.434 ± 0.446	0.692 ± 0.172	8.806 ± 3.463
Natural grassland (Control grids)	1.273 ± 0.565	0.630 ± 0.239	8.000 ± 3.497
ANOVA	$F_{77.308}$=2.148, p<0.001	$F_{77.308}$=2.689, p<0.001	$F_{77.308}$=3.118, p<0.001
	0 3 4 5 Control 7 9	0 Control 5 4 9 7 3	0 3 4 5 Control 7 9

There was a steady increase in the mean ant species diversity up to the third year after rehabilitation (Table 3.3 & Figure 3.8). After the third year of rehabilitation, mean Shannon diversity index values, mean species equitability and mean ant species richness tended to increase up to the ninth year, since the initiation of rehabilitation (Table 3.3 & Figure 3.8). According to Tukey's test for significance (Table 3.3), the lowest significant mean Shannon diversity index values, mean equitability and mean number of ant species were found on the unrehabilitated transects of the ash dam grids. The mean Shannon diversity index values, mean species equitability and mean ant species richness in the unrehabilitated transects also differ significantly from that of the adjoining natural grassland (Table 3.3). Four up to nine year old rehabilitated ash dam grids had significantly more ant species, than the unrehabilitated and 3-year old rehabilitated ash dam grids. Three to four year old rehabilitated ash dam grids did not differ significantly, but had more ant species than the unrehabilitated ash dam grids (Table 3.3 & Figure 3.8).

An alternative approach that avoids the difficulties associated with indices of diversity is the use of graphical displays of both species richness and evenness (Curry 1994). This is, therefore, just another way to investigate successional changes in the diversity of the ant community, by looking at the slope and lengths of rank abundance curves, as illustrated in Figure 3.9. The curves are usually drawn as such that the ordinate represents the log of the percentage relative abundance (dominance), which is plotted against ranked species sequence, and the shape of these curves may be interpreted in terms of various species-abundance models. Data from 1997-1999 were used to rank ant species, according to their total relative abundances (log $n_i/N \times 100$) within various rehabilitated and unrehabilitated grids, as well as, in the adjoining natural grassland. Total relative abundance values of ant species in grids which were rehabilitated at the same time, were combined for the rank abundance curves (Figure 3.9). In Figure 3.9, ranked relative abundance of species from high values to low values is illustrated in log terms. Steep rank abundance curves indicate low equitability values (high dominance), which in turn indicate a low ant species diversity, whereas flatter rank abundance curves indicate high equitability values, indicating a high ant species diversity (Figure 3.9). Short rank abundance curves illustrate a low species richness, which also resulted in low diversity values, while longer rank abundance curves illustrates a higher ant species richness, which therefore also illustrates a high ant species diversity. From the rank abundance curves (Figure 3.9), one could also make some deductions, regarding the success of rehabilitation steps, in terms of the diversity in the ant community.

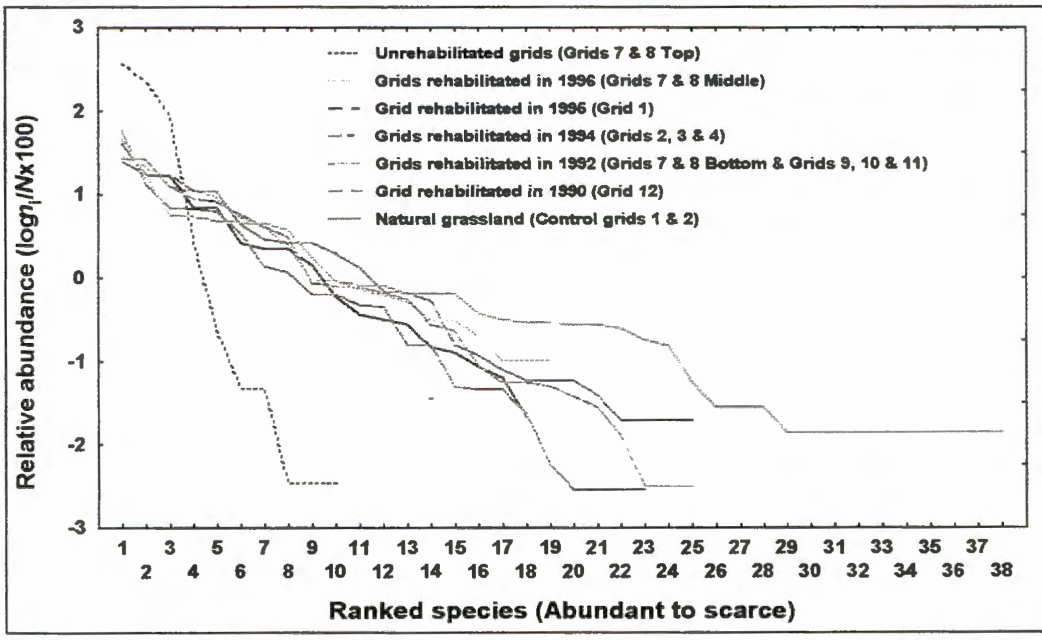

Figure 3.9: Rank abundance curves, illustrating the diversity in the ant community on ash dam grids, characterized by a specific stage of succession. A rank abundance curve for the natural grassland is also plotted.

As in the case of Figure 3.8, Figure 3.9 illustrates that both total ant species equitability and total richness values were low in unrehabilitated areas and higher on the rehabilitated ash dam grids, and in the natural grassland, leading to a gradient of increasing total ant species diversity from the unrehabilitated areas to older rehabilitated ash dam grids and in the natural grassland. There was a difference in sample size between the unrehabilitated survey and recently rehabilitated ash dam grids and the older rehabilitated ash dam grids. Only ten pitfall traps were recorded in one survey on the unrehabilitated survey areas, ten on the recently rehabilitated ash dam grids, while 15 pitfall traps or more were recorded on the rehabilitated ash dam grids, represented by older stages of succession. A higher total species richness was however found in grids rehabilitated in 1994 (Grids 2, 3 & 4), grids rehabilitated in 1992 (Bottom transects of grids 7 & 8, grid 9, 10 and grid 11) and in grid 12, which was rehabilitated in 1990, than in the unrehabilitated and late rehabilitated areas, illustrating a higher total ant species diversity on the older rehabilitated ash dam grids (5, 7 & 9-year old grids), which was also shown in Table 3.3. Figure 3.9 shows a longer and shallower rank abundance curve for the natural grassland, than for the rehabilitated areas, showing that more ant species were caught in total within the adjoining natural grassland, and that the number of individuals caught were more evenly distributed in the adjoining natural grassland, than on the ash dam grids. Although a total of 38 ant species were caught in the natural grassland, in comparison with the 25 ant species caught on the oldest rehabilitated ash dam grids (rehabilitated in 1990 and 1992; Figure 3.9), Figure 3.8 illustrates that a lower mean number of species per transect were caught in the natural grassland, than on these old rehabilitated ash dam grids. The reason why the mean number of species per transect was lower in the natural grassland, than in the nine-year old rehabilitated grid, in comparison with a higher total ant species caught in the natural grassland, than in the nine-year old grid will be discussed in detail in section 4.1.3.

3.2 The influence of edaphic variables on ant community structure on rehabilitated ash dam grids.

The objectives in this section are (1) to determine if there was any significant relationship between ant diversity and plant diversity, (2) to determine if there was any significant relationship between ant diversity and percentage vegetation cover, (3) to determine if there were any significant relationships between ant diversity and soil variables, such as percentage gravel, sand, silt and clay, pH, organic matter and conductivity, (4) to identify which plant or soil variables explain most of the variation in the diversity of the ant community, (5) to investigate if there were any associations between specific ant species and different plant communities, characteristic of different ash dam grids, and (6) to determine which soil variables were best correlated with specific ant species.

3.2.1 Patterns in the diversity of the ant community, in relation to plant species diversity and percentage vegetation cover on rehabilitated ash dams.

As was already discussed, equitability and species richness (number of species) are both components of species diversity. The general term, "diversity", as used in this section, has been described by equitability, species richness and Shannon diversity.

Plant communities remained relatively unchanged in the natural grassland and was therefore not used in this section. Furthermore the winter surveys and unrehabilitated areas were also excluded from these analyses, due to the huge bias in the dataset when these winter surveys and unrehabilitated areas were included.

The relationships between the different components of ant diversity, percentage vegetation cover and the different components of plant diversity, as well as, the percentage variance in each component of ant species diversity, accounted for by percentage vegetation cover and the different components of plant species diversity on rehabilitated ash dam grids, is summarized in Table 3.4.

Table 3.4: Results of a linear regression analysis, showing the relationships between ant Shannon diversity, ant species equitability and ant species richness, and four plant variables, plant Shannon diversity, plant species equitability, plant species richness and percentage vegetation cover on rehabilitated ash dam grids. The degree to which two of these variables are related is given by the correlation coefficient (*r*). Relationships are significant at *p*<0.05. The measure (fraction) of the proportion of the variability in each component of ant species diversity that is accounted for by variability in each component of plant species diversity and percentage vegetation cover is given by the coefficient of determination (r^2), (r^2x100 is the percentage variation explained).

Source of variance	Ant Shannon diversity				Ant species equitability				Ant species richness			
	F	p	r	r^2	F	p	r	r^2	F	p	r	r^2
Plant Shannon diversity	0.636	0.428	0.091	0.008	0.001	0.940	-0.004	0.000	5.140	0.026	0.250	0.063
Plant species equitability	0.002	0.961	0.006	0.000	0.000	0.998	0.000	0.000	0.013	0.910	-0.013	0.000
Plant species richness	1.038	0.312	0.115	0.013	0.001	0.978	-0.003	0.000	10.16	0.002	0.342	0.117
Vegetation cover (%)	0.028	0.869	-0.019	0.000	2.623	0.109	-0.182	0.033	14.26	0.000	0.395	0.156

Neither ant Shannon diversity, nor ant species equitability on the rehabilitated ash dam grids were significantly correlated with the three components of plant species diversity during the autumn, spring and summer months, and only an insignificant amount of variation in ant Shannon diversity and ant species equitability were explained by plant Shannon diversity, plant species equitability, plant species richness and percentage vegetation cover (Table 3.4).

On the other hand there were significant relationships between ant species richness and plant Shannon diversity, plant species richness and percentage vegetation cover on rehabilitated ash dam grids, with percentage vegetation cover explaining most of the variation in the richness of the ant community on rehabilitated ash dam grids (Table 3.4).

Table 3.4 illustrates that $0.395^2=0.156$ or 15.6% of the variation in the richness of the ant community is accounted for by percentage vegetation cover. The two components of plant diversity, plant Shannon diversity and plant species richness, explained 6.3% and 11.7% of the variation in the richness of the ant community on rehabilitated ash dam grids, respectively (Table 3.4). There was a weak relationship between the other component of plant species diversity, plant species equitability and ant species richness, and only a very small amount of variation in the richness of the ant community was explained by this plant variable.

The regression between ant species richness and percentage vegetation cover, is illustrated in Figure 3.10.

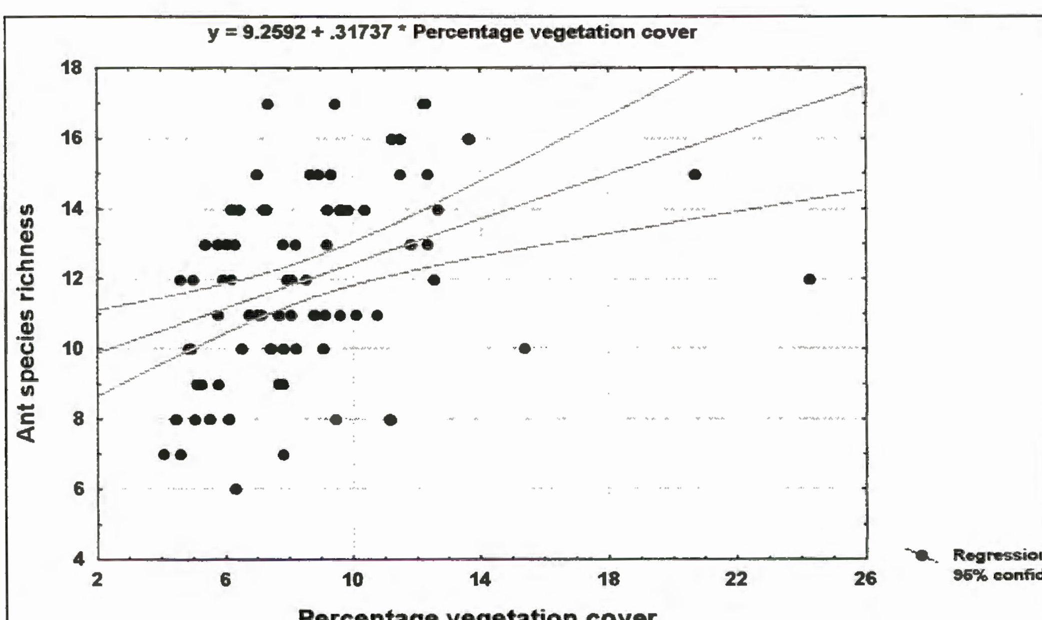

Figure 3.10: Linear relationship between total ant species richness and total percentage vegetation cover on rehabilitated ash dams at Hendrina Power Station, excluding the winter surveys.

Figure 3.11 illustrates that, of all the plant variables found to be significantly correlated with ant species richness (Table 3.4), only percentage vegetation cover tends to increase with age of rehabilitation.

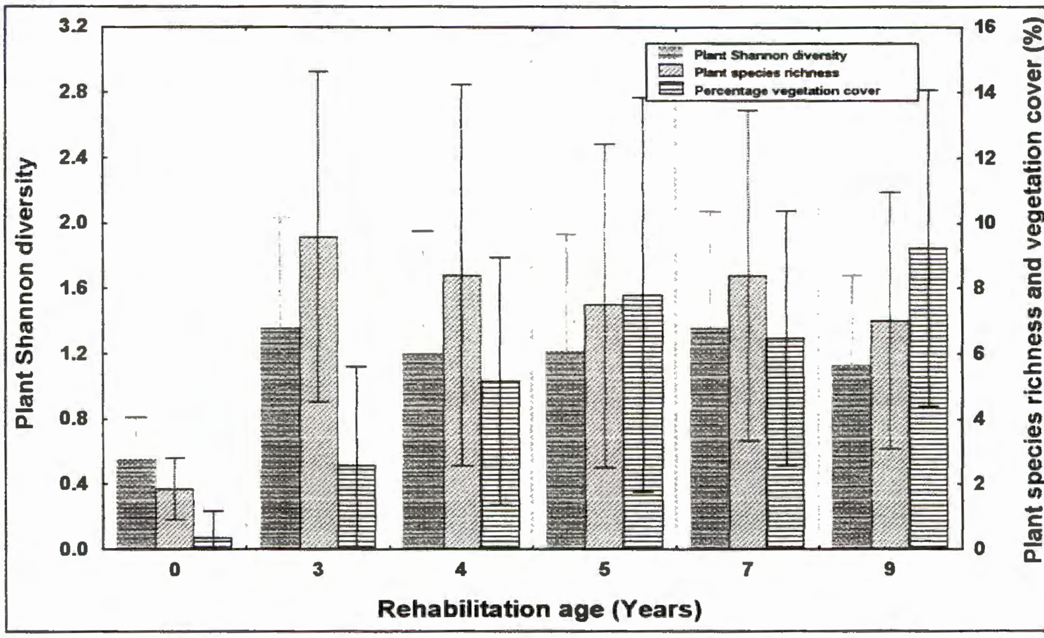

Figure 3.11: Mean plant Shannon diversity, mean plant species richness and mean percentage vegetation cover, per transect, during different stages of succession, from the period 1997- 1999 (Bars indicate ±1sd).

3.2.2 Patterns in the diversity of the ant community, in relation to soil characteristics on rehabilitated ash dams.

The relationships between the different components of ant species diversity on rehabilitated ash dams and the soil parameters listed below are going to be investigated in this section.

- particle size distribution of the soil (% gravel, % sand, % silt & % clay)
- pH of the soil
- electrical conductivity (EC) of the soil
- organic matter content within the soil, as determined by percentage carbon

Electrical conductivity of the substrate is a measure of the water soluble salt content or salinity of the soil (Grunwald, Iverson & Szafoni 1995). pH of the soil plays a major role in determining the availability of nutrients (Grunwald *et al.* 1995). The pH and salinity of the soil increase with fly ash utilization (Adriano *et al.* 1980), whereas Scougall *et al.* (1993), on the other hand, found that soil structure affects the micro-climate of the soil and, in return may affects soil decomposition and mineralization processes. In the top 10cm, soil usually contains about 1-3% carbon in organic compounds (Wild 1993). Soil analyses were only conducted during the winter survey of 1997. However, these soil characteristics were unlikely to change over a year and the soil variables were therefore applied for the data during 1997. In this analysis the natural grassland and unrehabilitated areas were also excluded. The relationships between the different components of ant diversity and different soil characteristics is illustrated in Table 3.5. To see whether the components of ant species diversity were good predictors or indicators of soil characteristics, simple linear regressions were used (Table 3.5).

Table 3.5: Results of a linear regression analysis, during 1997, showing the relationships between ant Shannon diversity, ant species equitability and ant species richness, and soil characteristics on rehabilitated ash dam grids. The degree to which two of these variables are related is given by the correlation coefficient (*r*). Relationships are significant at *p*<0.05. Significant contributions of each of the soil variables to the different components of ant species diversity on rehabilitated ash dam grids is given by the coefficient of determination (r^2), (r^2x100, is the percentage variation explained).

Source of variance		Ant Shannon diversity				Ant species equitability				Ant species richness			
		F	*p*	*r*	r^2	F	*p*	*r*	r^2	F	*p*	*r*	r^2
Percentage gravel	Fraction of particle size	3.069	0.086	-0.248	0.061	3.390	0.072	-0.259	0.067	0.544	0.465	-0.107	0.011
Percentage sand		0.340	0.562	0.085	0.007	0.232	0.632	-0.070	0.005	7.531	0.009	0.372	0.138
Percentage silt		0.702	0.406	-0.121	0.015	0.413	0.523	0.093	0.009	12.474	0.001	-0.458	0.210
Percentage clay		1.008	0.321	0.145	0.021	2.032	0.161	0.204	0.041	0.466	0.498	-0.099	0.010
pH		0.293	0.591	-0.079	0.006	0.000	0.991	0.002	0.000	1.225	0.274	-0.159	0.025
Electrical conductivity		0.006	0.942	0.011	0.000	0.712	0.403	0.122	0.015	2.060	0.158	-0.205	0.042
Organic matter (%C)		0.722	0.400	-0.123	0.015	1.145	0.290	-0.154	0.024	0.968	0.330	0.142	0.020

Neither ant Shannon diversity, nor ant species equitability on the rehabilitated ash dam grids were significantly correlated with the soil characteristics during 1997, and only an insignificant amount of variation in ant Shannon diversity and ant species equitability was explained by percentage gravel, percentage sand, percentage silt, percentage clay, pH, electrical conductivity and organic matter (Table 3.5).

Ant species richness on the rehabilitated ash dam grids, during 1997, was significantly correlated with only percentage sand and silt (Table 3.5). Ant species richness was positively correlated with percentage sand and negatively with percentage silt, with percentage silt explaining most of the variation in the richness of the ant community on rehabilitated ash dam grids (Table 3.5). Table 3.5 illustrates that $-0.458^2=0.210$ or 21% of the variation in the richness of the ant community is accounted for by percentage silt. Percentage sand explained 13.8% of the variation in the richness of the ant community on rehabilitated ash dam grids (Table 3.5). The regression between ant species richness and the soil variable which explained most of the variation in the richness of the ant community on rehabilitated ash dams, percentage silt, is illustrated in Figure 3.12.

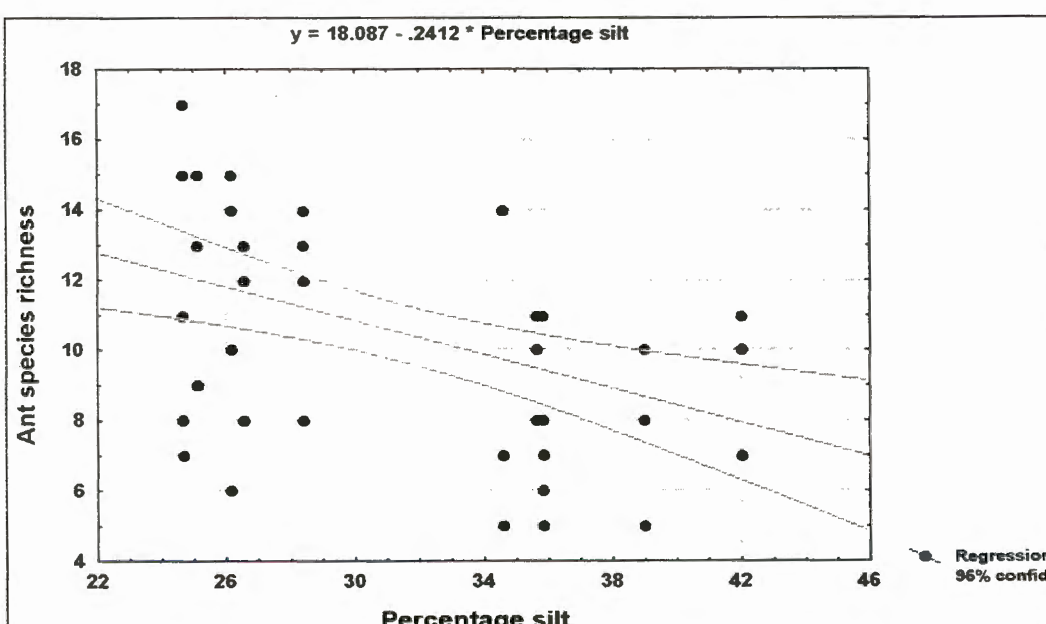

Figure 3.12: Linear regression between total ant species richness and percentage silt on rehabilitated ash dams at Hendrina Power Station, during 1997.

Figure 3.13 illustrates that the percentage silt on rehabilitated ash dam grids in 1997, tends to decrease as these ash dam grids became older.

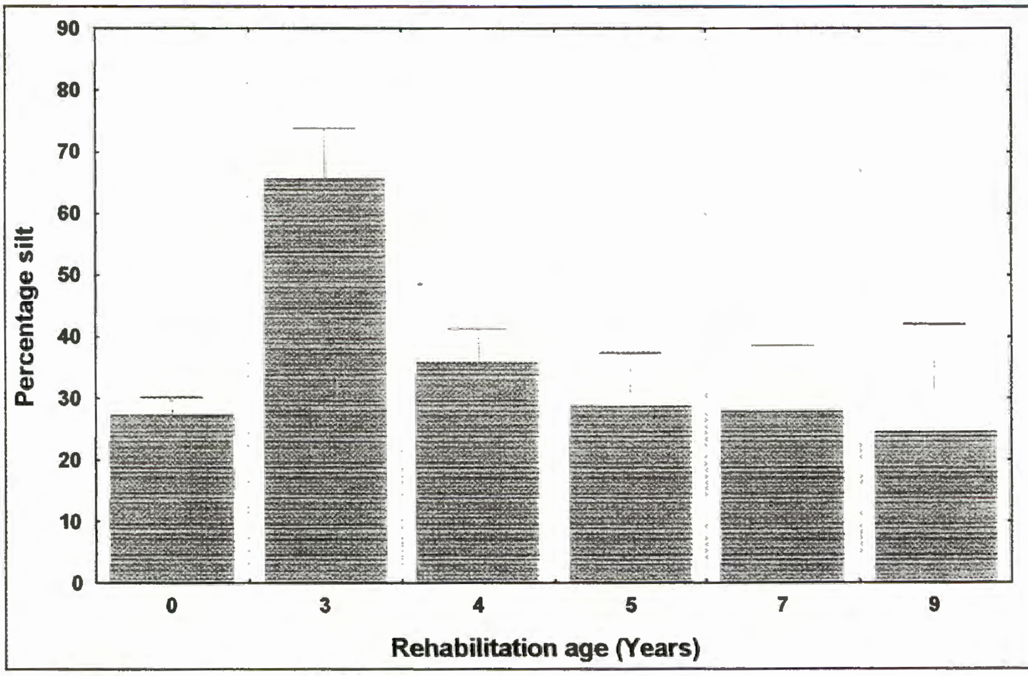

Figure 3.13: Mean percentage silt, per transect, during different stages of succession in 1997 (Bars indicate ±1sd).

Ant species richness was poorly correlated with the other soil variables, percentage gravel, percentage clay, pH, electrical conductivity and organic matter, and only a very small amount of variation in the richness of the ant community was explained by each of these soil variables.

3.2.3 Ordination of ant and plant species on unrehabilitated and rehabilitated ash dam grids, as well as in the natural grassland, along a gradient of successional stages.

The ordination of different ant species and various plant species on unrehabilitated and rehabilitated ash dam grids, as well as on natural grasslands were investigated by using indirect gradient analyses such as a Detrended Correspondence Analysis (DCA). For this section only data for summer and autumn were used, as this was the time when both ant and plant species were abundant.

The first ordination step (Figure 3.14) ordinates the unrehabilitated ash dam grids, rehabilitated ash dam grids and the natural grassland along two principal ordination axes, according to the plant species, present in these different areas. Plant species were used in this first ordination step to identify gradients according to vegetation. Three groups, along the first ordination axis were evident and represented the unrehabilitated ash dam grids, rehabilitated ash dam grids and the natural grassland (Figure 3.14).

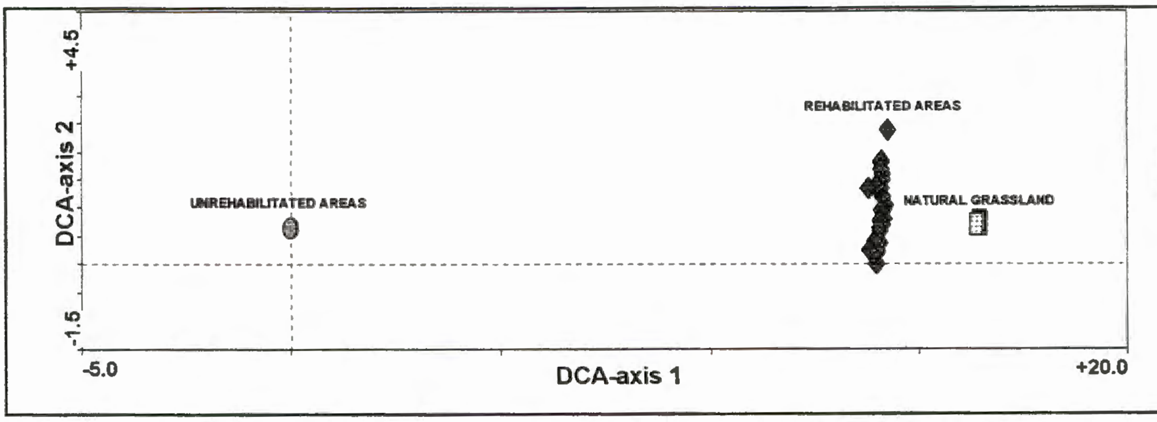

Figure 3.14: First ordination step of vegetation, showing the ordination of unrehabilitated ash dam grids, rehabilitated ash dam grids and grids in the adjoining natural grassland, along two principal ordination axes.

Unrehabilitated ash dam grids are compressed on the left side of the first ordination axis, rehabilitated ash dam grids are situated in the middle of the first ordination axis and grids in the natural grassland, are situated to the right of the first ordination axis. The only plant species which had established on the unrehabilitated areas, were the forbs, *Spergularia media* and *Chenopodium album*, leaving the area with plenty of bare ground. The ant species found to be associated with these disturbed conditions were *Monomorium albopilosum*, *Solenopsis punctaticeps* and *Cardiocondyla shuckardi* (Table 3.2).

The natural grassland, situated on the right side of the first ordination axis represents a *Brachiaria serrata-Setaria sphacelata* plant community (Table 2.2). Ant species which were associated with conditions in the natural grassland were mainly specialized ant species (Table 3.2). Ash dam grids, situated in the middle of the first ordination axis were rehabilitated at different stages. All the rehabilitated ash dam grids belong to the

Eragrostis curvula-Cynodon dactylon plant community (Table 2.2). These grids do however, represent different plant sub-communities and plant variants.

The objectives in the following sections were among other, to investigate possible associations between different ant and plant species, on rehabilitated ash dam grids, represented by slopes and plateaux areas. The associations between ant and plant species on ash dam grids which differ in aspect, adjoining area and rehabilitation age were also investigated.

3.2.3.1 Ordination of ant species and various plant species on the slopes of ash dams, in relation to various macro-environmental factors.

In the second ordination step (Figure 3.15), a Detrended Correspondence Analysis (DCA) was applied to the plant species data on different slopes of ash dam A & C (Grids 2, 3, 4 & 9). Ant species were chosen as supplementary data and were added afterwards, so that their relation to the plant species could be judged from the ordination diagram. Supplementary species differ from active species (plant species) in that they do not influence the definition of the ordination axes (Ter Braak & Šmilauer 1998). Grids 2, 3 & 4 represent slopes of ash dam A, while grid 9 represents a slope on ash dam C. The vegetation on all the slopes of ash dam A & C belong to the *Lespedeza cuneata-Hyparrhenia hirta* plant variant.

The Eigenvalues were 0.159 and 0.105 for the first two ordination axes, respectively, indicating, that there were no significant gradients along the first and second ordination axes, implying that the slopes of ash dam A & C were relatively homogenous, in terms of the plant assemblages within these grids. Although there were no significant gradients along the first and second ordination axes, the grids on the slopes of ash dam A & C, grouped separately along the first and second ordination axes. The three grids (2, 3 & 4) on the slopes of ash dam A grouped separately along the first ordination axis, while grid 9 grouped separately from the grids on the slopes of ash dam A, along the second ordination axis. From Figure 3.15 it is apparent that the three transects of grid 2 grouped on the left side of the first ordination axis, the three transects of grid 4 on the right side of the first ordination axis and the three transects of grid 3 somewhere in the middle.

Grid 2 is associated with perennial grasses such as *Pennisetum clandestinum* and *Hyparrhenia hirta* and it seems as if *Tetramorium vexator* was associated with these two perennials (Figure 3.15). Two perennial forb species, *Cyperus esculentus* and *Lespedeza cuneata*, characterized grid 3, where *Technomyrmex albipes*, ordinated with these two plant species. From Figure 3.15, it is apparent that *Anoplolepis custodiens* was caught in higher numbers on both grid 2 & 3, than on the other slopes of ash dam A & C (Grid 4 & 9). According to the above results it seems, as if, *A. custodiens* was associated with both perennial grass species, such as *H. hirta* and *P. clandestinum* and perennial forb species, such as *C. esculentus* and *L. cuneata.*

Grid 4 was characterized by plant species, such as *Eragrostis curvula*, *Digitaria eriantha*, *Conyza bonariensis* and *Cynodon dactylon*. It seems as if, ant species, such as *Solenopsis puntaticeps*, *Tetramorium frigidum* and *Monomorium* sp.2 were associated with the above mentioned plant species (Figure 3.15).

From Figure 3.15, it is evident that *Chamaecrista biensis*, *Eragrostis trichophora*, *Tagetes minuta*, *Bidens bipinata*, *Bidens formosa*, *Aristida congesta* and *Heteropogon contortus*, characterized the older, unburnt slopes of ash dam C (Grid 9). Ant species which seemed to be associated with the above mentioned plant species on grid 9, were *Monomorium albopilosum*, *Monomorium* sp.1, *Lepisiota capensis*, *Lepisiota laevis*, *Camponotus vestitus*, *Pheidole* sp.1, *Pheidole* sp.4, *Tetramorium setuliferum*, *Tetramorium sericeiventre*, *Tetramorium setigerum* and *Tetramorium sp.1*. Two of the *Tetramorium* species, *T. setuliferum* and *T. setigerum*, were closely ordinated with *B. bipinata*, *E. trichophora* and *C. biensis*, because they were all found mainly on the older rehabilitated ash dams.

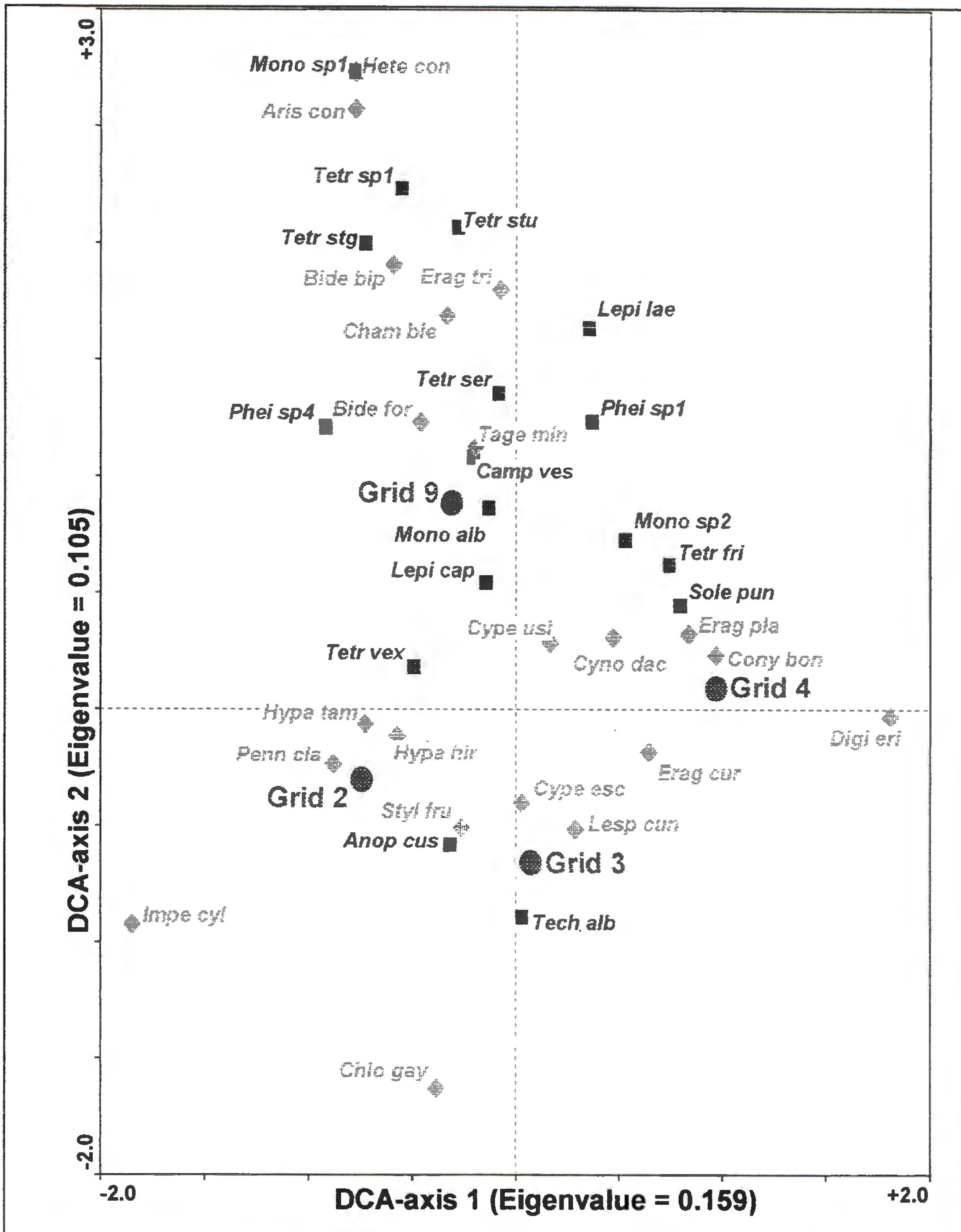

Figure 3.15: Detrended Correspondence Analysis (DCA) showing the ordination of ant species and various plant species on different slopes of ash dam A & C (Grids 2, 3, 4 & 9), characterized by different aspects, adjoining areas and stage of rehabilitation. A key for the abbreviations used in this ordination diagram is given in Appendix 1.

3.2.3.2 Ordination of ant species and various plant species on two slopes of grids 7 & 8, where each transect was rehabilitated at different stages.

In the previous ordination step all the transects of a specific grid were rehabilitated at the same time. In this ordination step the middle and bottom transects of grids 7 & 8 were rehabilitated at different stages. This analysis was done separately from the previous ordination step in order to investigate if there were differences in the plant and ant composition on transects, in the same grid, which were rehabilitated at different stages. For this analysis two middle transects of grids 7 & 8, rehabilitated in 1996, and two bottom transects on grids 7 & 8, rehabilitated in 1992 were used (Figure 3.16).

Both the middle and bottom transects of grids 7 & 8 are characterized by an *Eragrostis curvula-Cynodon dactylon* plant community. The middle transects of grids 7 & 8, do however differ from the bottom transects of these grids, due to different plant sub-communities and plant variants. The vegetation of the middle transects of grids 7 & 8 belonged to the *Amaranthus hybridus-Cyperus esculentus* plant sub-community and *Eragrostis teff-Enneapogon cenchroides* plant variant, while the vegetation of the bottom transects of grids 7 & 8, belonged to the *Hyparrhenia hirta-Eragrostis curvula* plant sub-community and *Lespedeza cuneata-Hyparrhenia hirta* plant variant.

A DCA was applied to the plant species data, whereas ant species were chosen as supplementary data. The ordination of ant species and different plant species is illustrated in Figure 3.16. Ordination of the plant species data, resulted in strong clustering of the transects of grids 7 & 8, along the first axis into two clusters at either ends of the axis, representing the middle transects of grids 7 & 8, which were rehabilitated in 1996 and the bottom transects of grids 7 & 8, which were rehabilitated in 1992. The middle transects of grids 7 & 8 cluster to the left of the first ordination axis, while the bottom transects of grid 7 & 8 cluster to the right of the first ordination axis. The Eigenvalue for the first ordination axis was relatively high (0.649), suggesting that the plant species composition on the middle transects and bottom transects of grids 7 & 8 were relatively dissimilar, therefore resulting in the clustering of these areas along the first ordination axis. The variation in the plant species composition in these two areas were best explained by the first ordination axis.

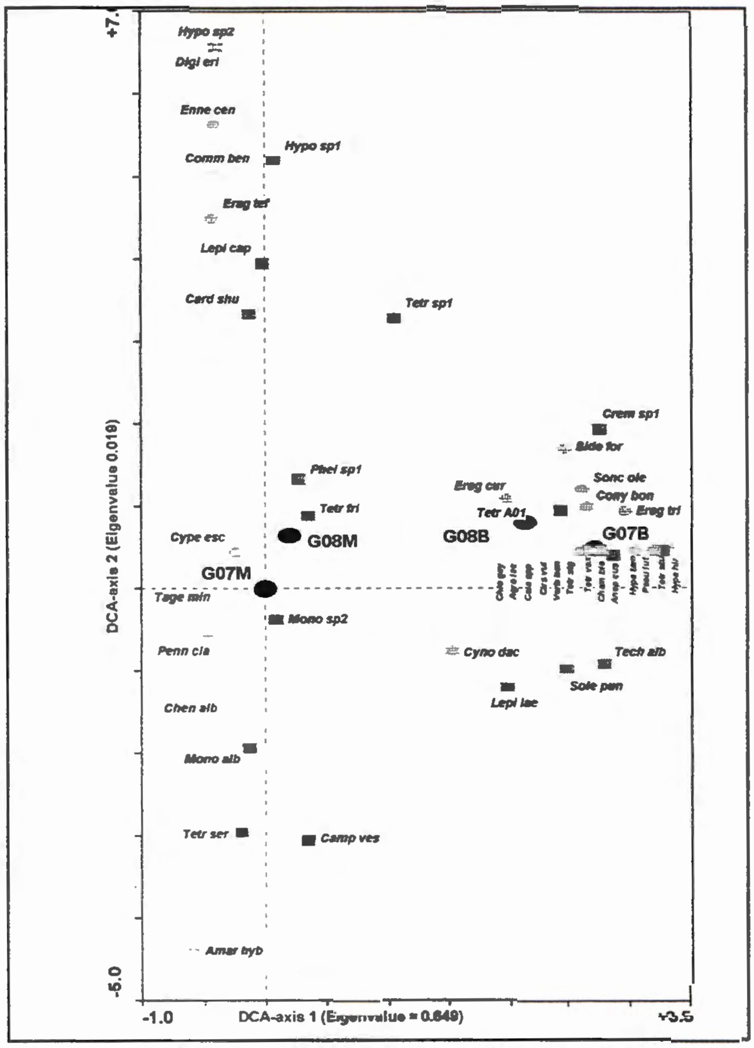

Figure 3.16: DCA-ordination diagram showing the ordination of ant species and various plant species on the middle and bottom transects of grids 7 & 8, each rehabilitated at different stages. A key for the abbreviations used in this ordination is given in Appendix 1

The middle transects of grids 7 & 8, situated to the left of the first ordination axis, are characterized by pioneer plant species such as *Cyperus esculentus*, *Tagetes minuta* and *Eragrostis teff*. Ant species, which seemed to be associated with these pioneer plant species on the middle transects of grids 7 & 8, were *Tetramorium sericeiventre*, *Monomorium albopilosum*, *Cardiocondyla shuckardi*, *Lepisiota capensis*, *Pheidole* sp.1, *Tetramorium frigidum* and *Monomorium* sp.2 (Figure 3.16).

The bottom transect of grid 7 and the bottom transect of grid 8, further grouped separately, along the first ordination axis in the ordination diagram (Figure 3.16). The bottom transect of grid 7 is characterized by plant species such as *Eragrostis curvula* and *Cynodon dactylon*. Ant species, such as, *Tetramorium* sp.A01 and *Lepisiota laevis* seemed to be associated with the above plant species. On the other hand plant species, such as, *Hyparrhenia hirta*, *Hyparrhenia tamba*, *Chamaecrista biensis*, *Eragrostis trichophora*, *Conyza bonariensis*, *Cirsium vulgare* and *Chloris gayana* are characteristic of the bottom transects of grid 8. Ant species, which seemed to be associated with the above mentioned plant species on the bottom transect of grid 8, were *Tetramorium setuliferum*, *Anoplolepis custodiens*, *Tetramorium vexator* and *Tetramorium setigerum*.

3.2.3.3 Ordination of ant species and various plant species on the plateaux of ash dams, in relation to various macro-environmental factors.

In the third ordination step (Figure 3.17) a Detrended Correspondence Analysis (DCA) was applied to investigate patterns in the ordination of ant species and various plant species on Grid 1 (plateaux of ash dam A), with vegetation of the *Lepidium bonariense-Eragrostis trichphora* plant variant, and Grids 10, 11 & 12 (plateaux of ash dam C), with vegetation of the *Chamaecrista biensis* plant variant. A DCA was applied to the plant species data, and ant species were selected as supplementary data.

The Eigenvalues for the first and second ordination axis were 0.454 and 0.064, while the length of the gradients were 1.577 and 0.812 for the first two ordination axes, respectively, illustrating that there was little variation in the composition of the plant community along the first two, principal ordination axes. Grid 1 grouped separately from grids 10, 11 & 12 (Figure 3.17) along the first ordination axis.

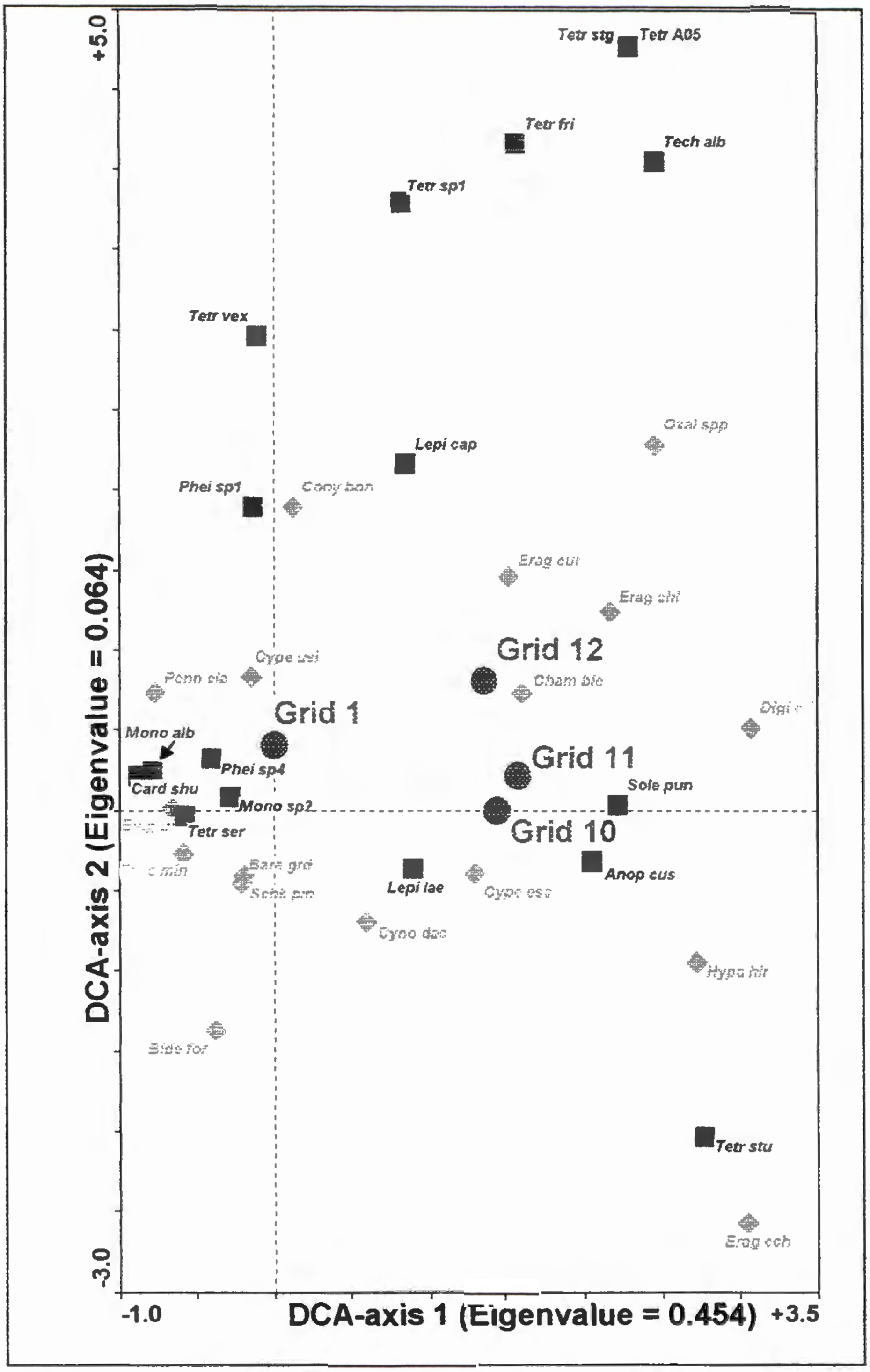

Figure 3.17: Detrended Correspondence Analysis (DCA) showing the ordination of ant species ■ and various plant species ♦ on plateaux areas of different ash dams (Grids 1, 10, 11 & 12). A key for the abbreviations used in this ordination diagram is given in Appendix 1.

By looking at the ordination diagram (Figure 3.17) it is evident that more open spaces were associated with grid 1, than in the case of grids 10, 11 & 12. Grid 1 was also characterized by early colonizing pioneer plant species, such as the annual forbs, *Bidens formosa* and *Tagetes minuta*. Ant species which seemed to be associated with these early colonizing plant species on the plateaux areas of ash dam A were *Cardiocondyla shuckardi*, *Monomorium albopilosum*, *Monomorium* sp.2, *Pheidole* sp.1 and *Tetramorium sericeiventre*.

By looking at the ordination diagram one can see that grids 10 & 11 and grid 12 grouped separately along the second ordination axes. The grids on the one side of the second ordination axis (Grids 10 & 11), were characterized by plant species, such as *Hyparrhenia hirta*, *Cyperus esculentus* and *Eragrostis echinocloidea* and less bare ground. Ant species which seemed to be associated with more bare ground and particular plant species on grids 10 & 11 were *Anoplolepis custodiens* and *Tetramorium setuliferum*.

Plant species which seemed to characterize Grid 12 were *Eragrostis curvula*, *Eragrostis chloromelas*, *Chamaecrista biensis* and *Oxalis* spp., with *E. curvula* being the most abundant (Morgenthal 1999; Figure 3.17). Grid 12 was also characterized by less bare ground (Figure 3.17). Ant species which seemed to be associated with the high vegetation cover and plant species on grid 12 were *Tetramorium frigidum*, *Tetramorium setigerum*, *Tetramorium* sp.1, *Tetramorium* sp.A05 and *Technomyrmex albipes*.

3.2.4 Correlations between ant species, various abundant plant species and percentage vegetation cover on rehabilitated ash dam grids.

A simple regression analysis was used to investigate possible relationships between ant species, various plant species and percentage vegetation cover on rehabilitated ash dam grids at Hendrina Power Station (Table 3.6). This part of the study was conducted to investigate if particular ant species were associated with various plant species and percentage vegetation cover, which characterized different stages of succession. Only plant species, with relative abundance values, greater than 5% were included and only rehabilitated ash dam grids were assessed (the top unrehabilitated transects of grids 7 & 8 were therefore excluded). A simple regression analysis was also used to determine which of the plant species or vegetation cover explained the highest amount of variation in the abundance of various ant species, in other words, which of the dominant plant species or vegetation cover had the greatest influence on the abundance of ant species on rehabilitated ash dam grids.

Another way to investigate the associations between ant and plant species is by means of a Canonical Correspondence Analysis (CCA; Figure 3.18). A Canonical Correspondence Analysis (CCA) was first applied to the relative abundance data of ant species on rehabilitated ash dam grids, after which the various abundant plant species and percentage vegetation cover on the rehabilitated ash dam grids were selected as environmental variables. Due to the presence of zero values in the dataset, ant and plant data were log transformed.

In the CCA ordination diagram (Figure 3.18) arrows indicate the strength and direction of various dominant plant species and percentage vegetation cover on the distribution of ant species along different ordination axes. Those plant species that have long arrows are more closely correlated in the ordination, than those with short arrows and are much more important in influencing ant community variation. Individual ant species, represented by points in the ordination diagram can be related to the various dominant plant species and percentage vegetation cover, represented by arrows, by drawing a perpendicular line from the arrow to the point representing the particular ant species. The order in which the points projects on to the arrow, from the tip of the arrow downwards, through the origin, is an indication of the position of individual ant species, in relation to the various dominant plant species and percentage vegetation cover.

Table 3.6: Results of a linear regression analysis, showing the relationships between ant species, various plant species and vegetation cover on rehabilitated ash dams. Ants and plant species are arranged into categories, according to where they occur in the rehabilitation succession. The degree to which ant species are related to the plant species and vegetation cover is given by the correlation coefficient (r), where * = $p<0.05$, ** = $p<0.01$ and *** = $p<0.001$. The proportion of variance in the relative abundances of ant species, as explained by the relative abundance of plant species and percentage vegetation cover is given by the coefficient of determination (r^2), (r^2 x 100, is the percentage variance explained).

	PIONEER PLANT SPECIES								LATE SUCCESSIONAL PLANT SPECIES											
	Tagetes minuta		*Cyperus esculentus*		*Eragrostis trichophora*		*Pennisetum clandestinum*		*Conyza bonariensis*		*Chamaecrista biensis*		*Cynodon dactylon*		*Eragrostis curvula*		*Hyparrhenia hirta*		Vegetation cover (%)	
	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2
Cardiocondyla shuckardi	0.715***	0.510	0.749***	0.562	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	-0.655***	0.430
Monomorium albopilosum	0.691***	0.477	nsc	nsc	0.437*	0.191	0.454*	0.207	nsc	nsc	nsc	nsc	nsc	nsc	-0.485**	0.236	-0.423*	0.179	-0.675***	0.456
Tetramorium sericeiventre	0.620***	0.385	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	-0.450*	0.203	nsc	nsc	-0.407*	0.166
Monomorium sp.2	0.485**	0.235	nsc	nsc	0.460*	0.212	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	-0.408*	0.166	nsc	nsc	-0.619***	0.383
Pheidole sp.4	nsc	nsc	nsc	nsc	0.658***	0.434	0.641***	0.410	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Tetramorium sp.A01	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	0.870***	0.757	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Tetramorium vexator	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	0.858***	0.737	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Tetramorium setigerum	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	0.857***	0.736	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Tetramorium setuliferum	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	0.449*	0.201	0.393*	0.155	nsc	nsc	nsc	nsc	nsc	nsc
Solenopsis punctaticeps	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	0.396*	0.156	nsc	nsc	nsc	nsc
Anoplolepis custodiens	-0.399*	0.159	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	0.528**	0.279	0.641***	0.410
Lepisiota capensis	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Lepisiota laevis	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Pheidole sp.1	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Technomyrmex albipes	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Tetramorium frigidum	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Tetramorium sp.1	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc

nsc - no significant correlation

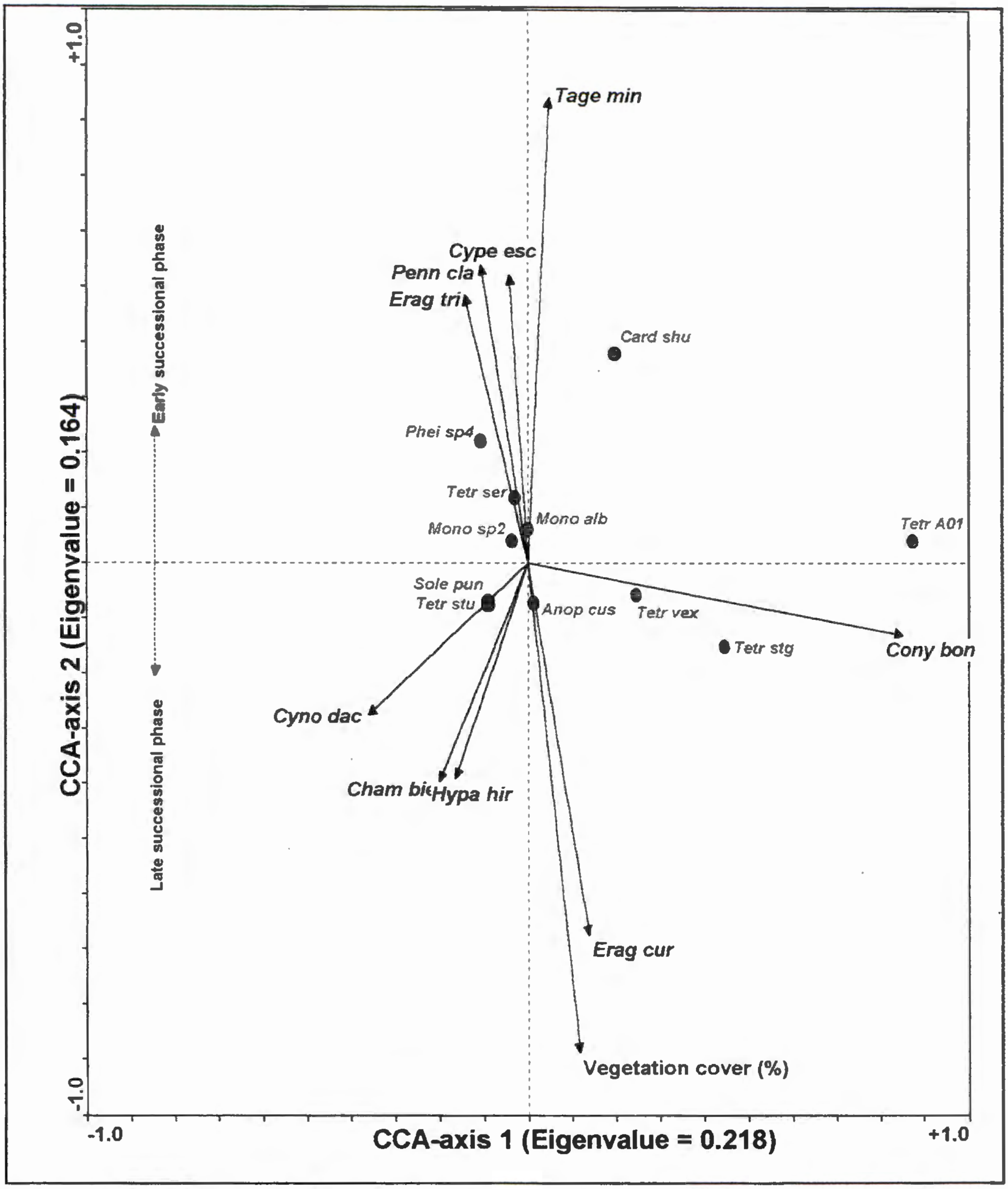

Figure 3.18: CCA ordination diagram showing the relationships between ant species, plant species and percentage vegetation cover on rehabilitated ash dam grids. A key for the abbreviations used in the ordination diagram is given in appendix 1.

Ant species with their perpendicular projections near to, or beyond the tip of the arrow will significantly be correlated with and influenced by the arrow. Those at the opposite end will be less strongly affected (Ter Braak 1987). *Cardiocondyla shuckardi*, *Monomorium albopilosum*, *Tetramorium sericeiventre*, *Monomorium* sp.2 and *Pheidole* sp.4 are associated with the pioneer plant species, *Tagetes minuta*, *Cyperus esculentus*, *Eragrostis trichophora* and *Pennisetum clandestinum* (Figure 3.18). Although *P. clandestinum* cannot be classified as a pioneer plant species, this perennial grass species was planted at the beginning of the rehabilitation attempt, to reduce erosion on the grids. This plant species is therefore treated as a pioneer plant species, in this regard, due to its presence early in the succession. Only *M. albopilosum* and *Pheidole* sp.4 were significantly correlated with *P. clandestinum*, where 20.7% and 41% of the variance in the abundance of these two ant species were respectively predicted by *P. clandestinum*. *C. shuckardi* is closely associated with *C. esculentus* and *T. minuta* on rehabilitated ash dams (Table 3.6), with *C. esculentus* explaining most of the variation (56.2%) in the abundance of *C. shuckardi*. In this present analysis, *C. shuckardi*, was the only ant species which was significantly correlated with *C. esculentus*. *M. albopilosum*, *T. sericeiventre* and *Monomorium* sp.2 were not only significantly correlated with *T. minuta*, but also with other pioneer plant species. *M. albopilosum* was, together with *T. minuta* and *P. clandestinum*, positively correlated with *E. trichophora* and negatively with *E. curvula* and *H. hirta*. *Monomorium* sp.2 was also positively correlated with *E. trichophora* and negatively with *E. curvula*, while *T. sericeiventre* was amongst *T. minuta* also negatively correlated with *E. curvula*.

Although the last three mentioned ant species were significantly correlated with various pioneer ant species, *T. minuta* explained most of the variation in the relative abundance of these ant species. The high significant percentage explanation of *T. minuta* to the variance in the relative abundance of the above mentioned ant species is also supported by the ordination diagram (Figure 3.18), in which the vector (arrow), representing *T. minuta* was relatively long and therefore had the biggest influence on the ordination of these ant species.

As found earlier, *Pheidole* sp.4 was positively correlated with *P. clandestinum*. There was also a positive association between this ant species and *E. trichophora*, and it seemed, that of all the plant species presented in Table 3.6, *E. trichophora* was the strongest associated with the abundance of *Pheidole* sp.4. Of all the ant species discussed so far only *Pheidole* sp.4 was not significantly correlated with percentage vegetation cover. The abundance of *C. shuckardi*, *M. albopilosum*, *T. sericeiventre* and *Monomorium* sp.2 caught within the pitfall traps on rehabilitated ash dams grids seemed to decrease with an increase in vegetation cover. Percentage vegetation cover explained 43%, 45.6%, 38.3% and 16.6% of the variance in the abundance of *C. shuckardi*, *M. albopilosum*, *T. sericeiventre* and *Monomorium* sp.2, respectively.

So far, only significant associations between ant species, pioneer plant species and percentage vegetation cover were addressed. Table 3.6 and Figure 3.18 do however illustrate that particular ant species were positively correlated with older successional plant species and/or a high vegetation cover. These ant species were *Tetramorium* sp.A01, *Tetramorium vexator*, *Tetramorium setigerum*, *Tetramorium setuliferum*, *Solenopsis punctaticeps* and *Anoplolepis custodiens*. Table 3.6 and Figure 3.18 illustrate that *Tetramorium* sp.A01, *T. vexator* and *T. setigerum* were only positively correlated with *Conyza bonariensis*. In all these correlations more than 70% of the variance in the relative abundance of these ant species was explained by *C. bonariensis*. *T. setuliferum* was positively correlated with *Chamaecrista biensis* and *Cynodon dactylon*, where *C. biensis* was the strongest associated with the relative abundance of *T. setuliferum*. Neither of the other ant species caught in the pitfall traps on rehabilitated ash dam grids were significantly correlated with the last two mentioned plant species.

The subterranean, *S. punctaticeps*, was positively correlated only with *Eragrostis curvula*, where more than 15% of the variance in the relative abundance of *S. punctaticeps* was explained by *E. curvula*. Lastly the pugnacious, *A. custodiens*, was significantly correlated with the pioneer plant species, *T. minuta*, and *H. hirta*. Table 3.6 and Figure 3.18 do however illustrate that *A. custodiens* decreased in abundance within areas dominated by *T. minuta*, while this ant species was positively correlated with *H. hirta*. Table 3.6 illustrates that of both the above correlations, *A. custodiens* was the strongest associated with *H. hirta* on rehabilitated ash dam grids. *A. custodiens* was also the only ant species, caught within the pitfall traps, found to be more abundant on rehabilitated ash dam grids with a high vegetation cover (Table 3.6 & Figure 3.18).

Although some ant species were associated with pioneer plant species, while others were associated with plant species and a relatively high vegetation cover characteristic of older rehabilitation, some ant species were not significantly correlated with any plant species, nor vegetation cover on the rehabilitated ash dam grids. These ant species were *Lepisiota capensis*, *Lepisiota laevis*, *Pheidole* sp.1, *Technomyrmex albipes*, *Tetramorium frigidum* and *Tetramorium* sp.1 (Table 3.6). These ant species were not presented in the ordination diagram.

3.2.5 Correlations between ant species and various soil characteristics on rehabilitated ash dam grids.

Possible associations between various ant species and edaphic variables, such as, substrate structure (particle size distribution), pH of the substrate, electrical conductivity (EC) and percentage organic matter in the substrate on rehabilitated ash dam grids were investigated, by using a Canonical Correspondence Analysis and simple regression analyses. As mentioned before in section 3.2.2, soil analyses were only conducted during the winter survey of 1997. However these soil characteristics were unlikely to change over a year and the soil variables were therefore applied for the data during of 1997. In this analysis the natural grassland and unrehabilitated areas were also excluded.

A forward selection of the edaphic variables, which had the greatest influence on the ordination of ant species on rehabilitated ash dam grids during 1997, are summarized in Table 3.7. The significance of a particular edaphic variable can be assessed through Monte Carlo testing of the axis associated with that variable, using the axis eigenvalue as the test statistic (Ter Braak & Prentice 1988). Thus in a CCA, one can test the significance of an edaphic variable in establishing the ordination pattern. The edaphic variables with the highest Eigenvalues were those variables which had the greatest influence on the relative abundances of various ant species.

Percentage sand made the largest significant contribution to the observed abundance of ant species on the rehabilitated ash dam grids during 1997 (Table 3.7). This is confirmed also in Figure 3.19 as indicated by the long arrow for this soil variable. Other soil variables represented by long arrows are percentage clay and percentage gravel in the substrate. These two soil variables also had a significant influence on the abundance of ant species on rehabilitated ash dam grids during 1997. The remaining soil variables, percentage carbon, percentage silt, pH and electrical conductivity seemed to have a minimal influence on the ordination of ant species on rehabilitated ash dam grids during 1997, with pH and electrical conductivity having the least influence.

Table 3.7: A forward selection of various soil characteristics, showing the influence of these soil variables on different ant species in general on rehabilitated ash dam grids during 1997.

Soil variables	Eigenvalue (λ)	ANOVA (F)	*p*-value
% Sand	0.326	4.776	0.010
% Clay	0.310	4.421	0.005
% Gravel	0.280	3.800	0.050
% Carbon	0.229	2.860	0.065
% Silt	0.205	2.468	0.060
pH	0.157	1.759	0.185
Conductivity (EC)	0.019	0.178	0.935

The associations between ant species and various soil characteristics on rehabilitated ash dam grids during 1997 are summarized in Table 3.8 and Figure 3.19. For this analysis only abundant ant species, which showed significant associations with various soil variables on rehabilitated ash dam grids were used. A simple regression analysis was also used to assess the most important soil variables which explained the highest amount of variation in the abundance of each ant species.

Table 3.8: Results of a simple linear regression analysis, showing the relationships between ant species and various soil characteristics on rehabilitated ash dam grids during 1997. The degree to which ant species are related to the different soil variables is given by the correlation coefficient (*r*), where * = *p*<0.05, ** = *p*<0.01, * = *p*<0.001. The proportion of variance in the abundance of ant species as explained by each soil variable is given by r^2, (r^2x100, is the percentage variance explained).**

	Percentage gravel		Percentage sand		Percentage silt		Percentage clay		pH		Electrical conductivity (EC)		Organic matter (% Carbon)	
	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2
Anoplolepis custodiens	nsc	nsc	0.728*	0.530	-0.740*	0.548	nsc	nsc	nsc	nsc	nsc	nsc	0.673*	0.453
Lepisiota capensis	nsc	nsc	0.765**	0.586	-0.764*	0.583	nsc	nsc	nsc	nsc	nsc	nsc	0.704*	0.496
Monomorium albopilosum	0.835**	0.698	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Pheidole sp.1	nsc	nsc	0.715*	0.515	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Pheidole sp.4	0.855*	0.731	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc	nsc
Solenopsis punctaticeps	nsc	nsc	nsc	nsc	nsc	nsc	0.766*	0.586	nsc	nsc	nsc	nsc	nsc	nsc

nsc - no significant correlation

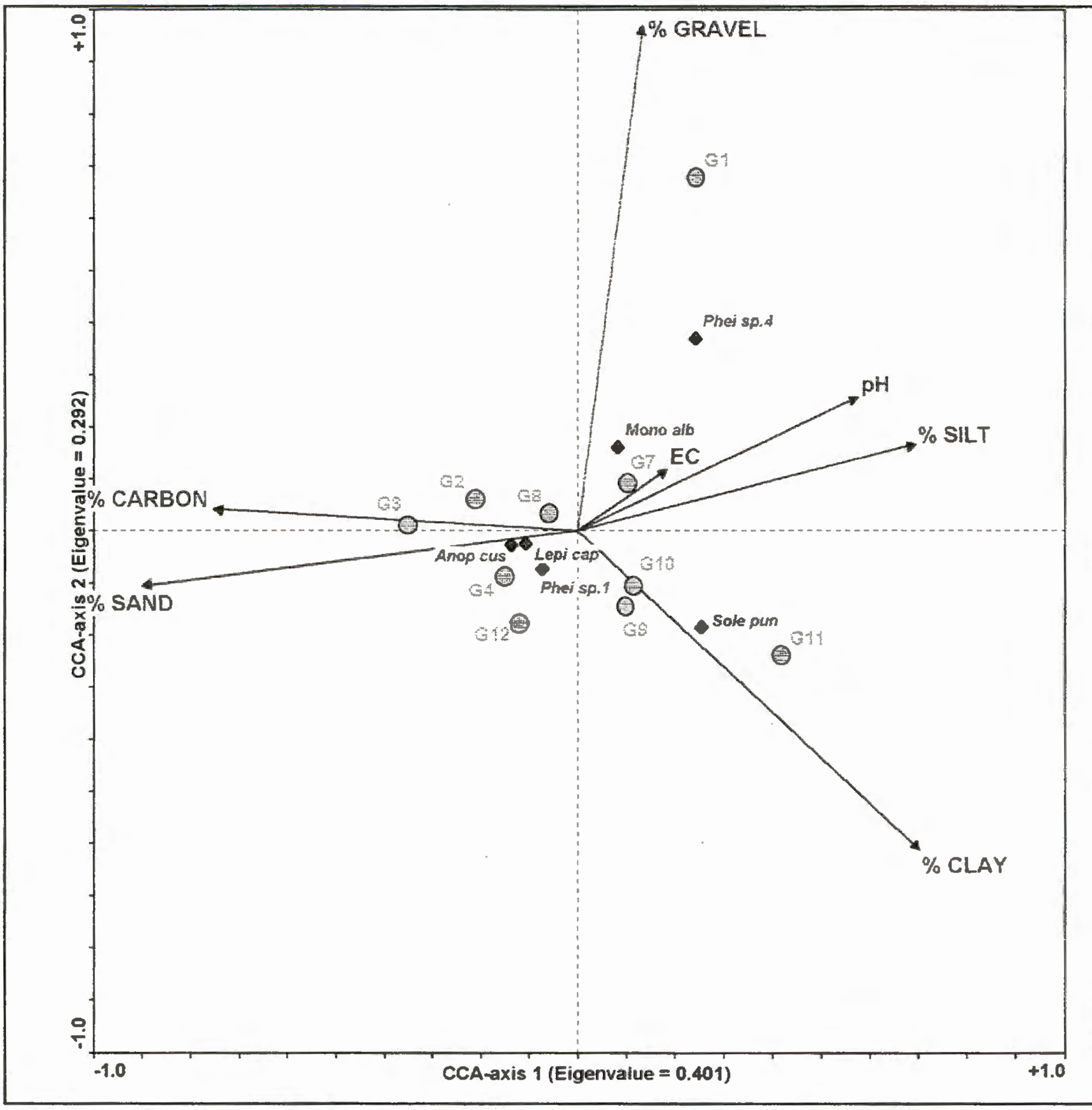

Figure 3.19: CCA ordination diagram showing the ordination of ant species in relation to various soil characteristics on rehabilitated ash dam grids during 1997. The abbreviations used in this ordination diagram is given in Appendix 1.

Only six of the abundant ant species caught within the pitfall traps on rehabilitated ash dam grids were significantly correlated with various soil characteristics during 1997. These species were *A. custodiens*, *L. capensis*, *M. albopilosum*, *Pheidole* sp.1, *Pheidole* sp.4 and *S. punctaticeps* (Table 3.8 & Figure 3.19). Both *A. custodiens* and *L. capensis* were positively correlated with sand content and organic matter and negatively with silt content (Table 3.8 & Figure 3.19). The coefficient of determination (r^2) showed that silt content was the best predictor of the abundance of *A. custodiens* on the rehabilitated ash dam grids during 1997, whereas most of the observed variation in the abundance of *L. capensis* was predicted by sand content, during this period. Silt content explained 54.8% of the observed variation in the abundance of *A. custodiens*, while 58.6% of the observed variation in the abundance of *L. capensis* was explained by sand content. Another abundant ant species, positively correlated with sand content was *Pheidole* sp.1 (Table 3.8 & Figure 3.19), where 51.5% of the observed variability in the abundance of this ant species was predicted by sand content (Table 3.8).

Figure 3.19 and Table 3.8 illustrate that *Monomorium albopilosum* and *Pheidole* sp.4 were directly related to gravel content on rehabilitated ash dam grids during 1997, where this soil variable describing 69.8% and 73.1% of the observed variance in the abundance of these two ant species, respectively. Lastly, the numbers of *S. punctaticeps* was positively correlated with clay content of the substrate and therefore tended to increase with an increase in clay content on rehabilitated ash dam grids (Table 3.8 & Figure 3.19). Clay content was found to be the most important predictor of *S. punctaticeps*, accounting for 58.6% of the observed variance (Table 3.8).

Variation in the mean gravel, sand, silt, clay and organic matter content of the substrate on rehabilitated ash dam grids during 1997 in relation to age of rehabilitation is illustrated in Figure 3.20. Gravel and silt content tend to decrease with rehabilitation age, while sand, clay and organic matter content tend to increase with rehabilitation age.

Neither abundant ant species on the rehabilitated ash dam grids were significantly correlated with pH and electrical conductivity during 1997 (Table 3.8). This is also reflected by the small eigenvalues and high *p*-values in Table 3.7 and the relatively short arrows, representing pH and electrical conductivity, in Figure 3.19. It therefore seemed as if pH and electrical conductivity had only a small, insignificant influence on the abundance of ant species on rehabilitated ash dam grids.

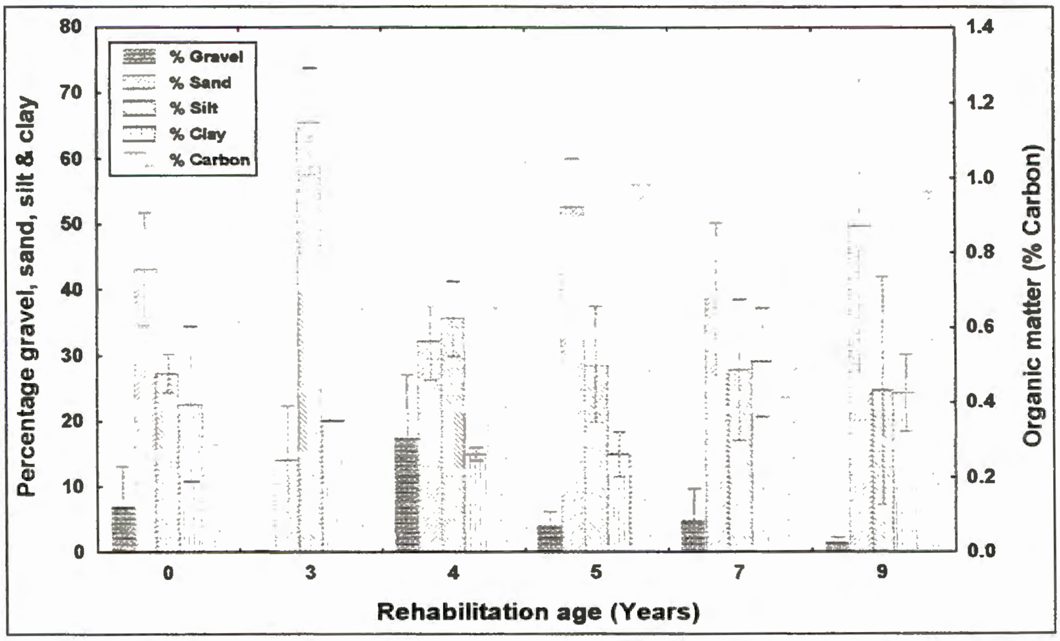

Figure 3.20: Mean gravel, sand, silt, clay and organic matter content of the substrate, per transect, during different stages of succession (Bars indicate ±1sd).

3.3 Seasonal changes in the abundance and diversity of ants on ash dams and in natural grasslands.

3.3.1 Seasonal activity of various ant species.

This section investigates the seasonal relative abundance of ant species on ash dams and in natural grasslands. In this part of the study, rainfall and temperature patterns are important for the interpretation of diversity and abundance patterns in the ant community. Total monthly rainfall at Hendrina Power Station, from March 1997-January 1999, is illustrated in Figure 3.21, whereas mean ambient minimum and maximum temperatures is illustrated in Figure 3.22. The highest rainfall occurred in summer. Mean minimum temperature for this area during the study period varies from 1 °C during the winter months to 13°C during the summer months. The mean maximum temperature for this area during the study period varies from 18°C in the winter months to 30°C in the summer. The region is therefore characterized by cool, dry winters and warm, wet summers.

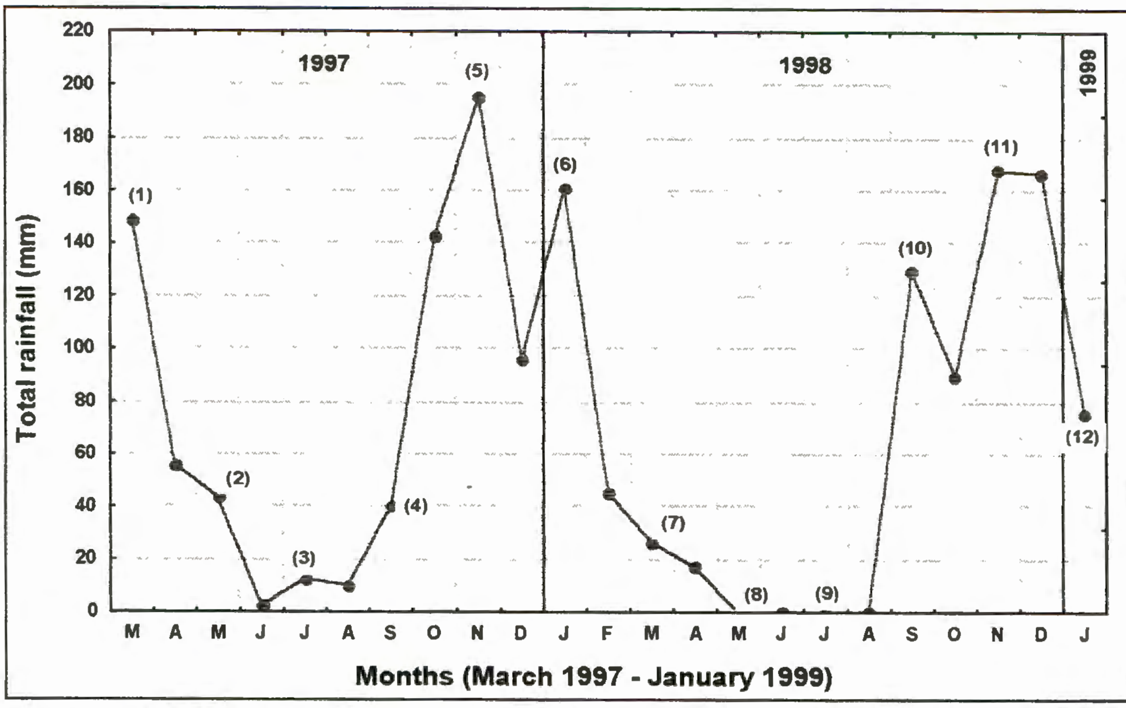

Figure 3.21: Total monthly rainfall at Hendrina Power Station from March 1997-January 1999. The numbers in brackets represent each bimonthly ant survey.

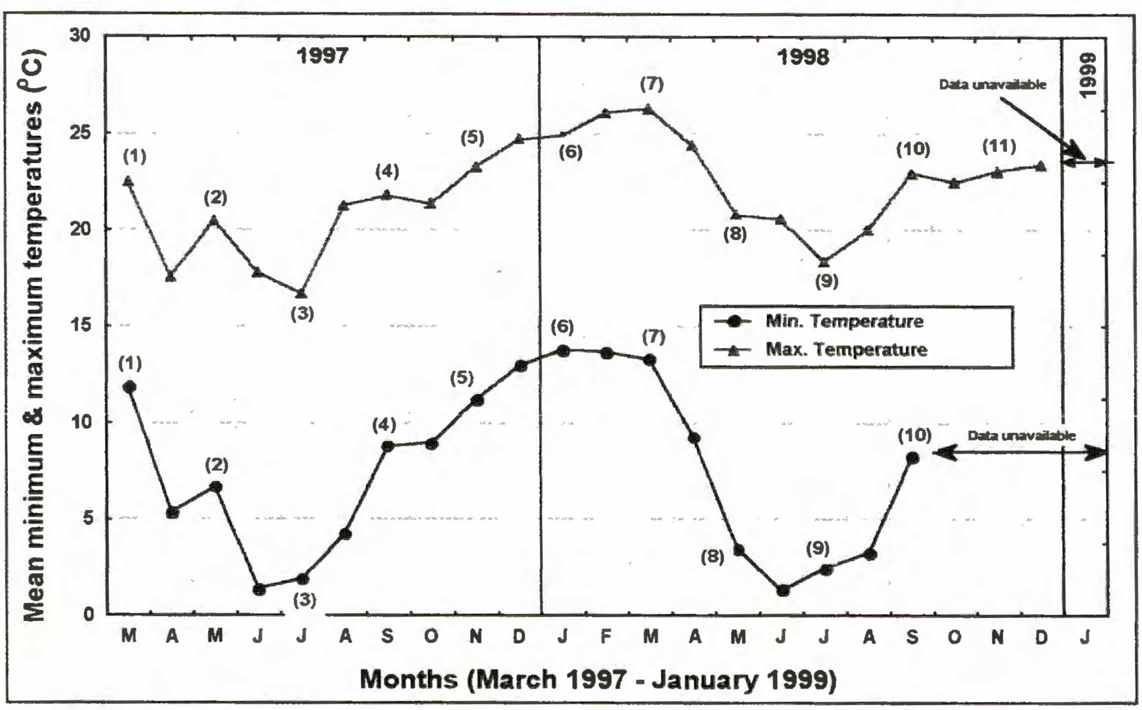

Figure 3.22: Mean monthly ambient minimum and maximum temperatures at Hendrina Power Station from March 1997-January 1999. The numbers in brackets represent each bimonthly ant survey.

Total seasonal abundances of different ant species caught on the ash dams and in the natural grassland during the study period are illustrated in Figure 3.23-Figure 3.37.

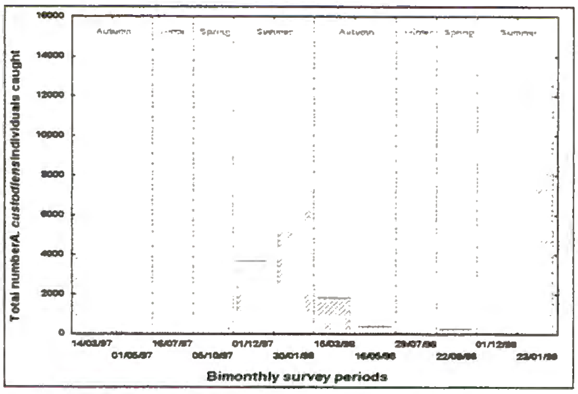

Figure 3.23: Total abundance of *Anoplolepis custodiens* during the different bimonthly surveys.

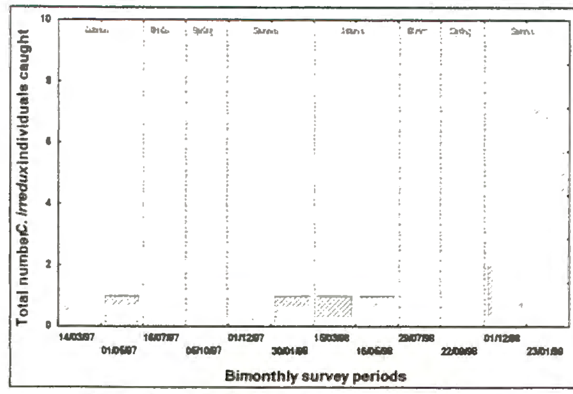

Figure 3.24: Total abundance of *Camponotus irredux* during the different bimonthly surveys.

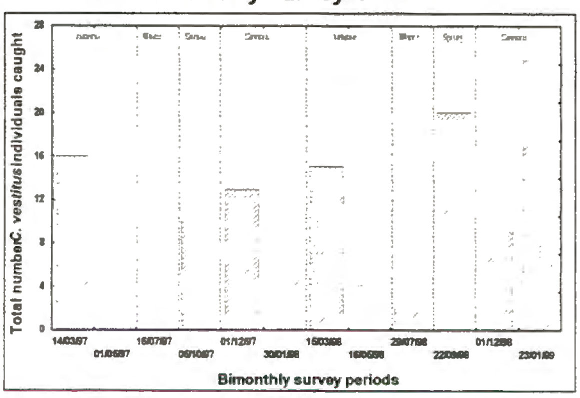

Figure 3.25: Total abundance of *Camponotus vestitus* during the different bimonthly surveys.

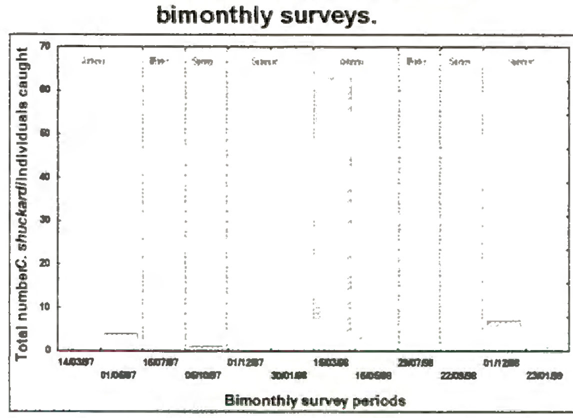

Figure 3.26: Total abundance of *Cardiocondyla shuckardi* during the different bimonthly surveys.

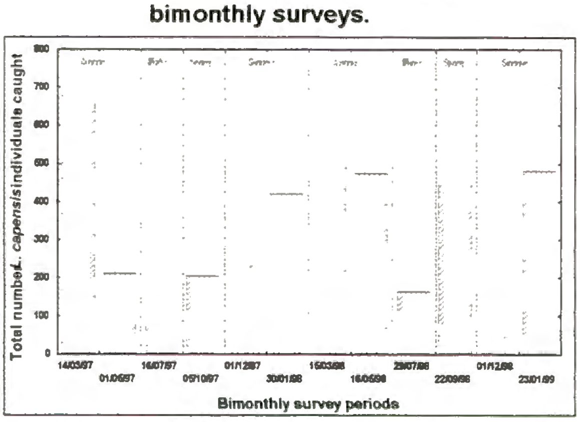

Figure 3.27: Total abundance of *Lepisiota capensis* during the different bimonthly surveys.

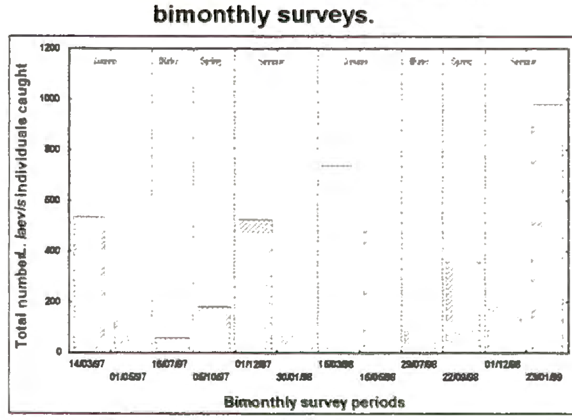

Figure 3.28: Total abundance of *Lepisiota laevis* during the different bimonthly surveys.

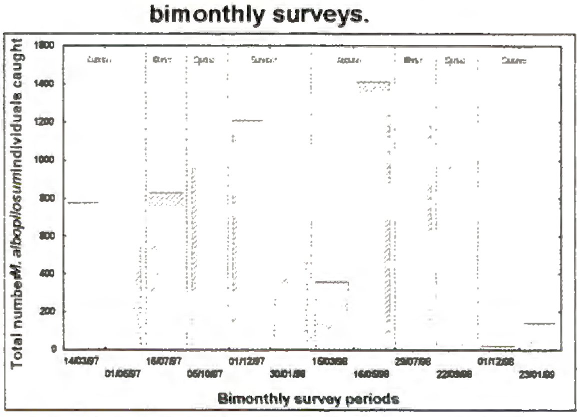

Figure 3.29: Total abundance of *Monomorium albopilosum* during the different bimonthly surveys.

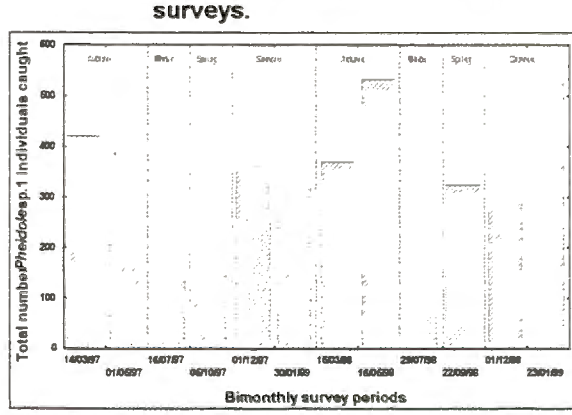

Figure 3.30: Total abundance of *Pheidole* sp.1 during the different bimonthly surveys.

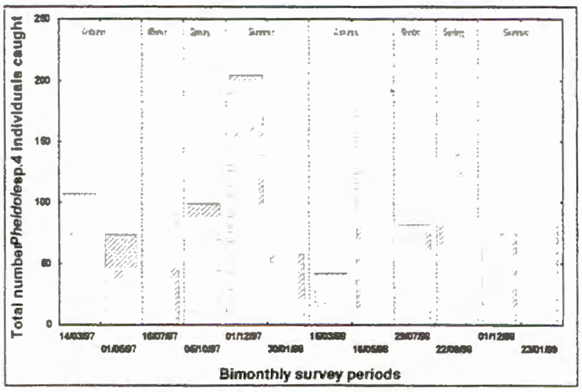

Figure 3.31: Total abundance of *Pheidole* sp.4 during the different bimonthly surveys.

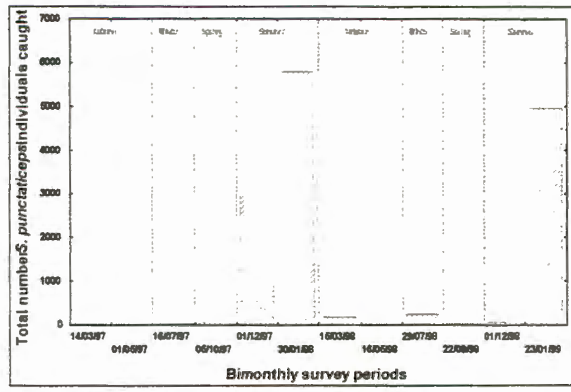

Figure 3.32: Total abundance of *Solenopsis punctaticeps* during the different bimonthly surveys.

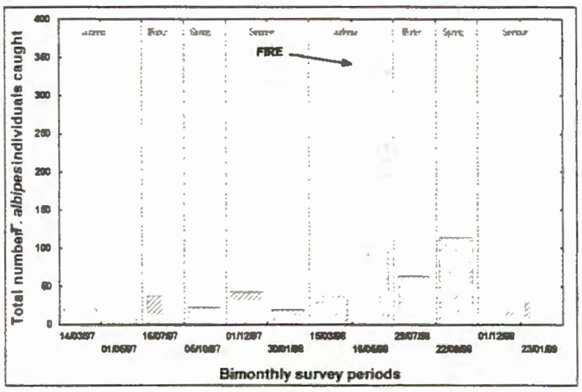

Figure 3.33: Total abundance of *Technomyrmex albipes* during the different bimonthly surveys.

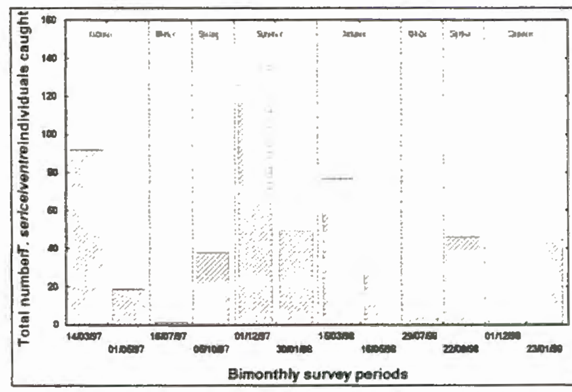

Figure 3.34: Total abundance of *Tetramorium sericeiventre* during the different bimonthly surveys.

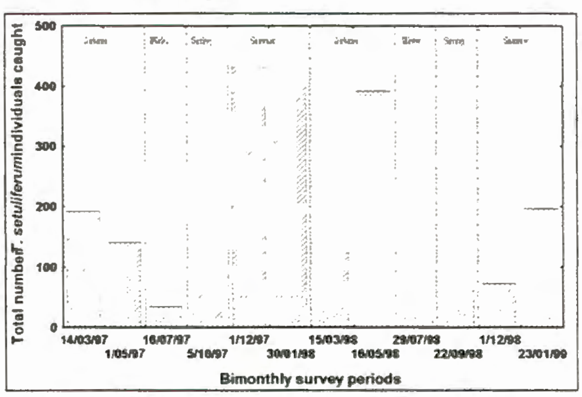

Figure 3.35: Total abundance of *Tetramorium setuliferum* during the different bimonthly survey.

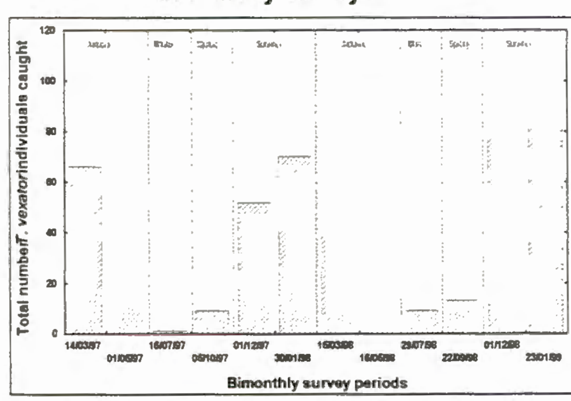

Figure 3.36: Total abundance of *Tetramorium vexator* during the different bimonthly surveys.

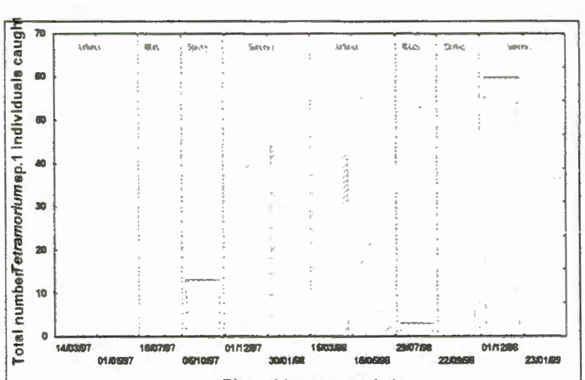

Figure 3.37: Total abundance of *Tetramorium* sp.1 during the different bimonthly surveys.

The relationships between ant activity, mean ambient temperature and total rainfall, as well as the percentage variation in the activity and abundance of various ant species, accounted for by mean temperature and total rainfall, is given in Table 3.9.

Table 3.9: Results of a linear regression analysis, showing the relationships between the activity (abundance) of various ant species, mean ambient temperature and total rainfall. The degree to which two of these variables are related is given by the correlation coefficient (*r*). Relationships are significant at $p<0.05$. The proportion of variation in the activity (abundance) of the various ant species, as explained by mean temperature and total rainfall is given by the coefficient of determination (r^2), (r^2x100 is the percentage variance explained.

	Mean temperature				Total rainfall			
	F	p	r	r^2	F	p	r	r^2
	Winter active ant species							
Monomorium albopilosum	3.307	0.099	-0.499	0.249	1.179	0.303	-0.325	0.106
Pheidole sp.1	4.316	0.065	0.549	0.232	0.049	0.830	0.070	0.005
Pheidole sp.4	0.151	0.706	-0.122	0.015	0.171	0.688	-0.130	0.017
Technomyrmex albipes	0.908	0.363	-0.289	0.083	2.362	0.155	-0.437	0.191
	Summer & Autumn active ant species							
Anoplolepis custodiens	5.420	0.042	0.593	0.352	0.681	0.429	0.252	0.064
Camponotus irredux	2.752	0.128	0.465	0.216	0.133	0.723	0.114	0.013
Cardiocondyla shuckardi	4.281	0.065	0.548	0.300	0.050	0.827	-0.071	0.005
Tetramorium setuliferum	2.202	0.169	0.425	0.181	0.136	0.721	0.116	0.013
Tetramorium vexator	14.186	0.004	0.766	0.587	3.004	0.114	0.481	0.231
Tetramorium sp.1	7.527	0.021	0.655	0.430	0.327	0.580	0.178	0.032
	Summer active ant species							
Solenopsis punctaticeps	4.153	0.069	0.542	0.293	0.765	0.402	0.267	0.071
	Spring, Summer & Autumn active ant species							
Camponotus vestitus	9.260	0.012	0.693	0.481	1.650	0.228	0.376	0.142
Lepisiota capensis	4.045	0.072	0.537	0.288	0.143	0.713	0.119	0.014
Lepisiota laevis	10.763	0.008	0.720	0.518	0.053	0.823	0.072	0.005
Tetramorium sericeiventre	6.274	0.031	0.621	0.386	0.546	0.477	0.228	0.052

Ant species were divided into different classes, according to their activity during different seasons. The activity (abundance) of some of the ant species in these classes were significantly correlated with mean temperature (mean of minimum & maximum temperatures), but not with rainfall (Table 3.9). Significant relationships between ant activity (abundance) in the different classes and mean temperature are illustrated in Figures 3.38-3.43. According to results obtained the classes were:

- **Winter active ant species** - *Monomorium albopilosum*, was the most winter active ant species (Figure 3.29), *Pheidole* sp.1 and *Pheidole* sp.4, were moderately active in winter (Figures 3.30 & 3.31, respectively) and *Technomyrmex albipes* was also active during the winter months (Figure 3.33). The activity of *M. albopilosum* drops noticeably in the warmer parts of the year. The four above mentioned ant species showed distinct activity during the winter months, but the abundances of these ant species were not significantly correlated with mean temperature and total rainfall (Table 3.9).

- **Summer and autumn active ant species** - These ant species showed high activity in summer and the warmer parts of autumn. These ant species were *Anoplolepis custodiens* (Figure 3.23), *Camponotus irredux* (Figure 3.24), *Cardiocondyla shuckardi* (Figure 3.26), *Tetramorium setuliferum* (Figure 3.35), *Tetramorium vexator* (Figure 3.36) and *Tetramorium* sp.1 (Figure 3.37). Of these ant species the abundance of only *A. custodiens*, *T. vexator* and *Tetramorium* sp.1 showed a significant positive correlation with mean temperature (Figure 3.38, Figure 3.42 and Figure 3.43, respectively). These positive correlations is also illustrated in Table 3.9. Mean temperature explains 35.2%, 58.7% and 43% of the observed variation in the abundance of *A. custodiens*, *T. vexator* and *Tetramorium* sp.1, respectively.

- **Summer active ant species** - Some ant species, such as, *Solenopsis punctaticeps* (Figure 3.32) were only active on ash dams and in natural grasslands during the summer months. There was no significant relationship between the numbers of *S. punctaticeps* and mean temperature (Table 3.9).

- **Spring, summer & autumn active ant species** - Particular ant species were active in the warm, spring, summer and autumn months. These ant species were *Camponotus vestitus* (Figure 3.25), *Lepisiota capensis* (Figure 3.27), *Lepisiota laevis* (Figure 3.28) and *Tetramorium sericeiventre* (Figure 3.34). The abundance of *C. vestitus*, *L. laevis* and *T. sericeiventre* showed significantly positive correlations with mean temperature (Figures 3.39, 3.40 & 3.41, respectively). Mean temperature explained 48.1%, 51.8% and 38.6% of the observed variation in the abundance of *C. vestitus*, *L. laevis* and *T. sericeiventre*, respectively (Table 3.9).

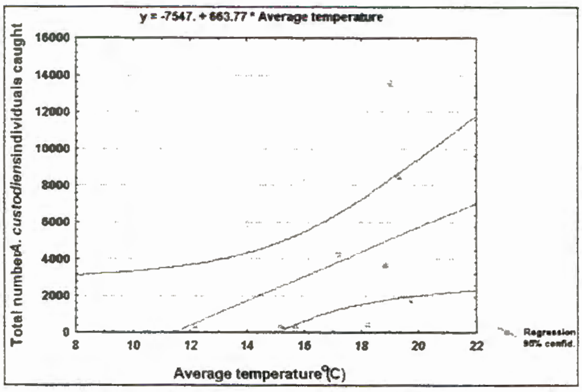

Figure 3.38: Positive relationship between total number of *Anoplolepis custodiens* caught and mean temperature.

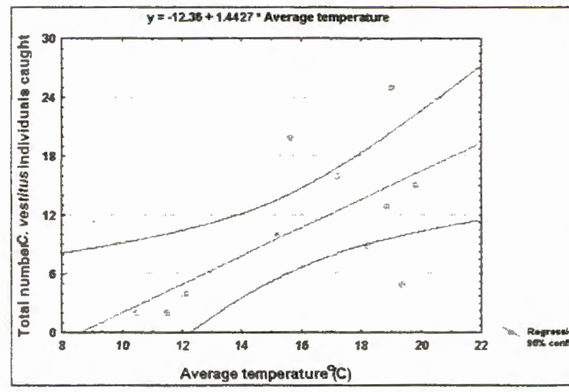

Figure 3.39: Positive relationship between total number of *Camponotus vestitus* caught and mean temperature.

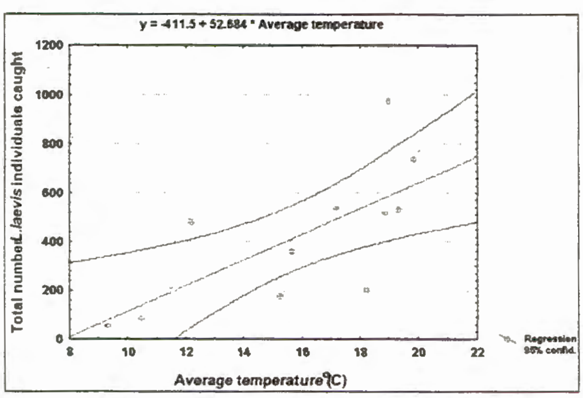

Figure 3.40: Positive relationship between total number of *Lepsiota laevis* caught and mean temperature.

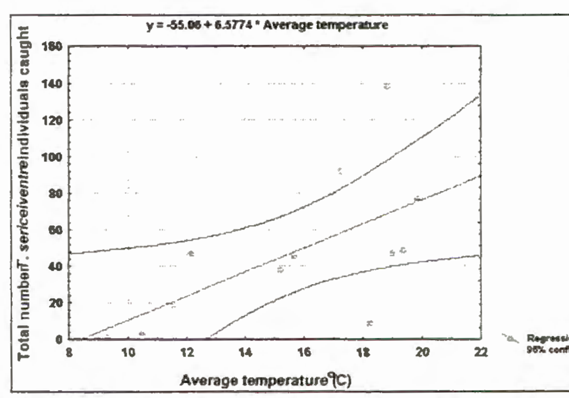

Figure 3.41: Positive relationship between total number of *Tetramorium sericeiventre* caught and mean temperature.

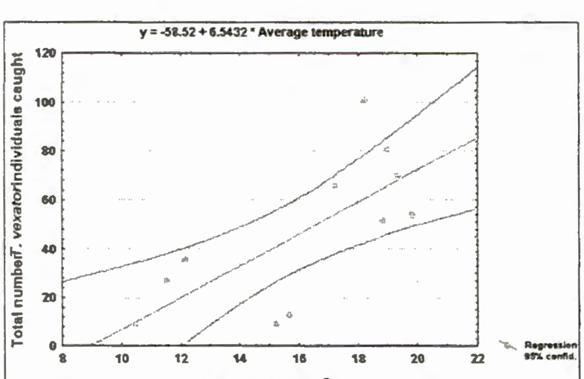

Figure 3.42: Positive relationship between total number of *Tetramorium vexator* caught and mean temperature.

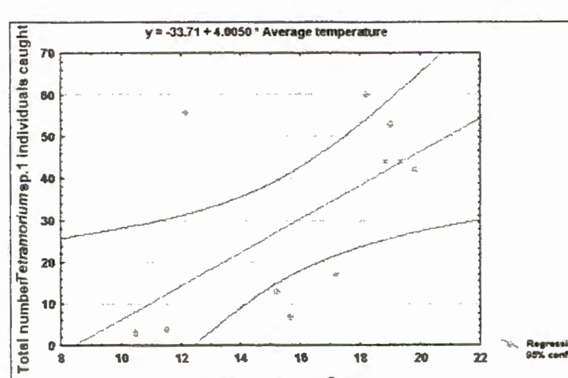

Figure 3.43: Positive relationship between total number of *Tetramorium* sp.1 caught and mean temperature.

Of all the ant species, discussed so far, it seems as if, mean temperature explained most of the variation in the abundance of *T. vexator* (58.7%), followed by *L. laevis* (51.8%). On the other hand, *Technomyrmex albipes* was active in all the seasons, but show exceptionally high numbers during the second autumn survey conducted in 1998 (Figure 3.33). The numbers of this tramp species was not significantly correlated with mean temperature (Table 3.9). The numbers caught of the remaining ant species were too low to show any seasonal patterns and were therefore ommited from further analyses.

3.3.2 Ant species diversity in different seasons.

In this section the seasonal variation in the diversity of the ant communities on ash dams and in natural grasslands will be investigated. Mean Shannon diversity index values, mean equitability values and mean number of species (species richness) of ants on ash dams and in natural grasslands, as determined for four seasons, over two years from 1997-1999 are presented in Table 3.10 and Figure 3.44. According to Miller's significance test, mean Shannon diversity was significantly lower in the winter and significantly higher in autumn (Table 3.10 & Figure 3.44). Mean equitability values were significantly higher in autumn and spring and lower in summer (Table 3.10 & Figure 3.44). Mean ant species richness was significantly lower in winter and spring, than in autumn and summer (Table 3.10 & Figure 3.44).

Table 3.10: Mean Shannon diversity index values, mean equitability values, mean number of ant species (species richness) and standard deviations of the ant community on ash dams and in natural grasslands during different seasons from 1997-1999. Significant differences indicated by ANOVA (F) and Kruskal-Wallis ANOVA (H) tests are given in red. A summary of Tukey's and Miller's significance test (1981) is given, where the line indicates no significant differences.

Seasons	Shannon diversity index (Mean ± sd)	Equitability (Mean ± sd)	Species richness (Mean ± sd)
Autumn	1.678 ± 0.316	0.678 ± 0.136	12.354 ± 2.419
Winter	1.295 ± 0.433	0.648 ± 0.201	7.333 ± 2.632
Spring	1.596 ± 0.320	0.700 ± 0.120	10.167 ± 3.017
Summer	1.512 ± 0.467	0.590 ± 0.184	13.396 ± 2.758
ANOVA	$H_{3,143}$=13.346, p<0.01	$H_{3,143}$=7.797, p<0.05	$F_{3,140}$=31.086, p<0.01
	Winter Summer Spring Autumn	Summer Winter Autumn Spring	Winter Spring Autumn Summer

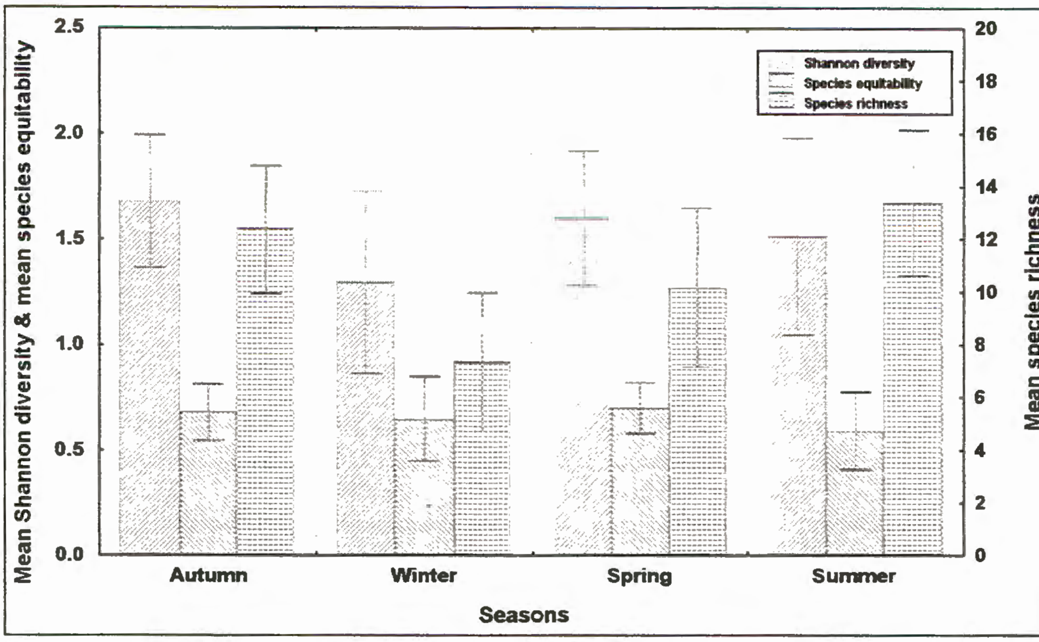

Figure 3.44: Seasonal changes in the mean Shannon diversity index values, mean ant species equitability and mean ant species richness on ash dams and in natural grasslands from 1997-1999 (Bars indicate ±1sd).

Neither of the mean Shannon diversity index values, mean equitability values, or mean number of ant species correlated significantly with mean rainfall. There was only a significant positive relationship between ant species richness on the ash dam grids and in natural grasslands and mean temperature (Figure 3.45), corresponding with higher numbers and species caught during summer months. Nearly 59% of the observed variation in the richness of the ant community is explained by mean temperature.

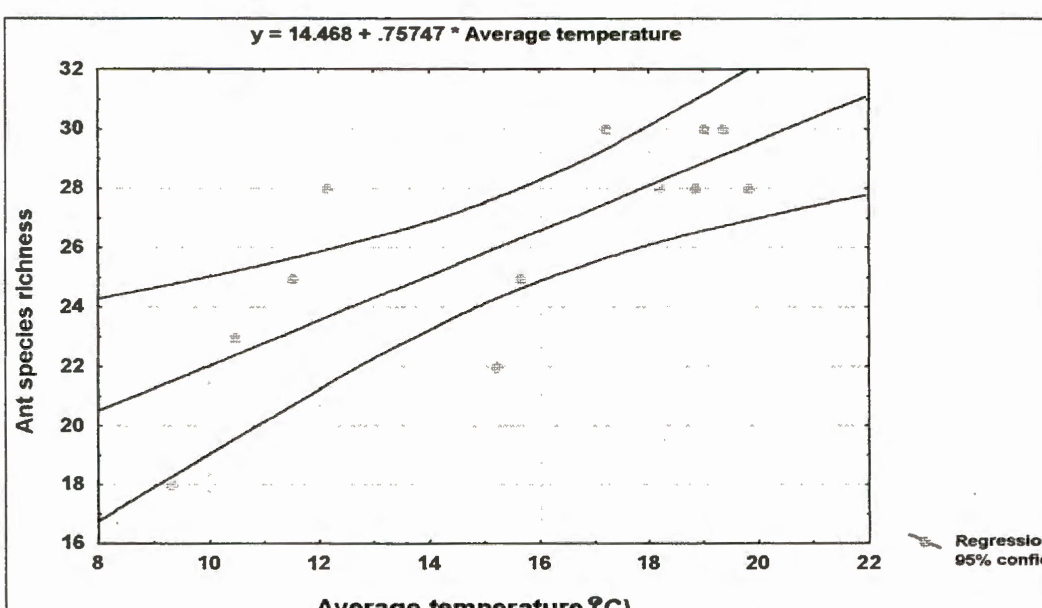

Figure 3.45: Positive relationship between the richness in the ant community and average temperature (r=0.767, r^2=0.589, p<0.01).

CHAPTER 4

DISCUSSION

4.1 Use of ants in determining the state of a habitat before and after rehabilitation.

4.1.1 Ant species composition on ash dams and in natural grasslands (Qualitative analyses).

Results obtained from the study at Hendrina Power Station showed that there were some distinct similarities between the ash dams and the natural grassland, but dissimilarities between these different habitats also exist. First of all more ant species (38) were collected in the natural grassland (Figure 3.2), compared to 34 species found on the ash dams (Figure 3.1). In another study on mineral sand mines near Richards Bay, South Africa, Majer & De Kock (1992) also collected more ant species in the forest control plot, than in the rehabilitated survey grids.

At Hendrina Power Station, however, these two habitats shared some ant species. The pugnacious ant, *Anoplolepis custodiens*, was the most abundant ant species in both the natural grassland and on the ash dams (Figure 3.1 & Figure 3.2). This ant species is therefore a good colonizer of both these habitats, as probably explained by its broad and generalized diet. *A. custodiens* is a very aggressive, abundant and active ant species, feeding on other ant species and insects (Steyn 1954) and could have had a competitive effect on other ant species in the natural grassland and on the ash dams. The high number of *A. custodiens* individuals, caught in the pitfall traps could probably be explained by the fact that workers release "danger" pheromones when potential food sources are discovered, which cause large number of individuals to exit the nest and to converge in the direction of the food source (Steyn 1954).

Further results (Table 3.2) indicated that *Lepisiota laevis, Monomorium albopilosum, Monomorium* sp.2, *Pheidole* sp.1, *Solenopsis punctaticeps*, *Technomyrmex albipes* and *Tetramorium sericeiventre* were also present on both the ash dams and in the adjoining natural grassland (Figure 3.1 & Figure 3.2), making them successful colonizers of disturbed and natural habitats. These ant species do not appear to have particular habitat and food preferences, and are able to colonize a wide range of habitats.

Of particular interest here, is *T. albipes* which has a widespread distribution throughout South Africa, where they cover a wide array of habitats, such as in houses and in the veld (Slingsby 1991). This is confirmed by our results, where this ant species was found in diverse habitats, ranging from the low habitat and structural diversity of the unrehabilitated ash dam grids to the more diverse habitat of the old rehabilitated grids and the natural grassland. Similar results were also obtained on rehabilitated open-cut mines in Northern Australia, where *T. albipes* was also present in both the mines and forest controls (Majer 1984a). The relatively low abundance of *T. albipes* on the ash dams and in the natural grassland is probably reflected by the small size of their colonies (Slingsby 1991). However, when food is freely available, huge colonies establish (Slingsby 1991). The low numbers of *T. albipes* could therefore suggest that little food is available on the ash dams for this ant species, and could therefore be used as a possible indicator of nutrient status of rehabilitated areas.

S. punctaticeps is mainly subterranean, and the workers having tiny eyes. Because of its subterranean habits its relative abundance could have been underestimated in the pitfall traps, yet despite this, it was the 2nd most dominant ant species on the ash dams and the 3rd most dominant species in the natural grassland (Figures 3.1 & 3.2). *S. punctaticeps* is important in the rehabilitation process, in which they fulfil a number of soil processes within the soil, such as soil mixing, aeration of the soil and the enhancement of water infiltration. *S. punctaticeps* probably feeds on both large and small arthropods.

To further explain why some ant species were present on both the ash dams, as well as in the natural grassland, one also need to consider the way in which these ant species disperse. Some of the ant species, such as *Monomorium* and *Pheidole* spp. spread by independent colony foundation, in which these ant species fly around in their search for available habitats. These ant species would colonize an area, when their needs are satisfied. Alate ant species, spreading by independent colony foundation could colonize a huge area relatively quickly, and could therefore probably explain the relatively high numbers of these ant species, on all the grids surveyed, even on the unrehabilitated survey areas and in the natural grassland.

Although the ash dams shared particular ant species with the natural grassland, some ant species were only found in the pitfall traps on the ash dams. These species were *Cardiocondyla shuckardi*, *Tetramorium parasiticum*, *Tetramorium* sp.2, *Tetramorium* sp.A01, *Tetramorium* sp.A04, *Tetramorium* sp.A05, *Camponotus irredux*, *Camponotus* sp.8, *Tetramorium* sp.A01, *Tetramorium* sp.A04, *Hypoponera* sp.2 & 3 and *Lepisiota* sp.3. Although these ant species were not caught in the natural grassland, this doesn't necessarily imply that they were absent from this area. There is a chance that they were present, but in low densities, making it difficult to catch these rare ant species. Andersen (1995) also found that *Camponotus* species have low relative abundances in any ant community throughout Australia. It is also possible that these ant species prefer the open conditions and more opportunities found on the ash dams, or that these ants species might also have been introduced to the area with the return of topsoil.

Tetramorium sp. A01 is a new species which had previously been collected from Golden Gate National Park. *Tetramorium parasiticum* has quite an unique behaviour in which this ant species parasitizes other *Tetramorium* species such as *Tetramorium sericeiventre*, where they invade the nests of these ants.

4.1.2 Progressive change in the composition of the ant community, due to succession (Qualitative analyses).

The previous section only discussed similarities and differences in the composition of the ant community on ash dams and in natural grasslands. However the ant communities in this study also showed marked habitat preferences and successional trends in their dispersal on the ash dams, especially in older rehabilitated ash dam grids, which are characterized by a higher habitat and structural diversity (Table 3.2). These ant species could therefore be regarded as indicators of rehabilitation success and on the overall state of a habitat at a given stage in the succession. Certain ant species could be indicators of disturbance, while others could be indicative of more successfully rehabilitated areas. Such indicator ant species could then be used in comparative studies when ecological disturbance is being investigated. A species has potential value as an indicator if its presence is indicative of certain environmental conditions, whereas its absence is indicative of the absence of those conditions (Keals & Majer 1991).

Ant species were divided into different classes, according to their presence, absence and abundance in the different stages of succession (See section 3.1.2).

- **Early successional species** (Section 3.1.2.1) - Pioneer ant species are the first ant species to colonize unrehabilitated and recently rehabilitated areas. These ant species are therefore indicative of an early successional phase (Lobry de Bruyn *et al.* 1997). From Table 3.2 and Figure 3.3, it seems as if *Cardiocondyla shuckardi* is characteristic of early successional conditions on ash dams and was one of the first colonizers of ash dams at Hendrina Power Station. Majer & De Kock (1992) found that *C. shuckardi* is an opportunistic ant species, indicative of recently rehabilitated sand mines in South Africa, where *C. shuckardi* was one of the first colonizers of these mines.

  Disturbed or highly stressed areas are characterized by a low behavioural dominance of ant species, with opportunistic ant species dominating these areas (Andersen 1997c). Opportunistic ant species are defined by their wide climatic and habitat tolerances, broad habitat distributions and poor competitive ability (Andersen 1997c), and are ideally suited for colonizing disturbed areas, by having unspecialized diets, flexible foraging times and being able to tolerate a wide variety of physical conditions (Andersen 1986a). Hölldobler & Wilson (1990) even found some species of *Cardiocondyla* in patches of soil in side walks and street gutters.

It seems therefore, that *C. shuckardi* has the characteristics of an opportunistic species. It colonized unrehabilitated and early successional areas, where other more specialized ant species were unable to do so. It disappeared from the older rehabilitated areas and natural grassland (Table 3.2; Figure 3.3), possibly as a result of the introduction and recolonization of more successful competitive ant species, better suited to the changes in habitat caused by vegetation succession (Jackson & Fox 1996). Majer & Nichols (1998) found that another species of *Cardiocondyla*, *C. nuda*, had also been regularly sampled in early years of rehabilitation, but was absent in the final year, indicating that it had disappeared from the succession. The presence of *C. shuckardi* in grids rehabilitated in 1992 and 1994 (Table 3.2; Figure 3.3), could indicate that rehabilitation in these relatively old grids was not yet optimal. The reason why some ant species were not caught in the pitfall traps on unrehabilitated and recently rehabilitated areas of the ash dams, could have been due to a lack of suitable niches and resources, unfavourable environmental conditions, such as a low organic matter content, unfavourable moisture conditions and excessive fluctuation in surface temperatures or soil structure.

- **Intermediate to late successional species** - From the results (Section 3.1.2.2) it seems as if opportunistic ant species, such as *C. shuckardi* are favoured by early stages of succession, while at later stages of succession, other ant species became more dominant. Although *A. custodiens* was present on all the rehabilitated ash dam grids and in the natural grassland, it is evident that *Anoplolepis custodiens* was caught in higher numbers on older rehabilitated ash dam grids (Figure 3.4), and it therefore seems as if this ant species is favoured by conditions, present in older stages of succession. As rehabilitation matures, the habitat changes and diversifies. Plants begin to produce seeds, there are some changes in the soil and more insect species are attracted to the area, which serve as prey for specific ant species. These conditions are therefore ideal for species with generalized diets, such as *A. custodiens*, which are able to utilize the vast amount of seed and prey on the greater number of insects. *A. custodiens* attacks live or dead prey and they are particularly fond of termites and often live in old termite mounds (Steyn 1954). This ant species is also predaceous on insects such as crickets and grasshoppers. *A. custodiens* is also one of the ant species, showing myrmecochory, where the seed of different plant species are distributed by these ants (Steyn 1954). As seed and plants become more abundant as rehabilitation matures, more insect species are attracted to such an area, providing plenty of food for generalized ant species, such as *A. custodiens* and possibly explains the higher abundance of this ant species in older rehabilitated grids. Although *A. custodiens* is not an indicator species by definition of Keals & Majer (1991), its abundance is indicative of nutrient stadiums and therefore of rehabilitation success.

The low initial number of *A. custodiens*, caught on the ash dams (Figure 3.4 & Table 3.2), might be because of the slow colonization rate, since they spread by colony fission. After the mating of the queens in their nuptial flights, they join old and existing nests, instead of starting new ones, and from there they expand their colony. This process takes quite a long time to complete and could probably explain the slow initial colonization rate of *A. custodiens*.

After the early colonization of opportunistic ant species, generalized ant species were next to colonize rehabilitated open-cut mines in Northern Australia, which were able to utilise the vast amount of seed, produced by the rapidly growing grasses (Majer 1984a). This is supported by results in this study. These ant species started to colonize, once topsoil was returned to the area and plant communities established. The build-up of seed-eating ants, such as *Pheidole* spp. in recently rehabilitated areas occurs rapidly, which could be attributed to the high densities of seed bearing plant species within these areas (Majer 1984c).

- **Late successional species** (See section 3.1.2.3) - With the exception of *Camponotus vestitus*, all the *Camponotus* species seemed to be favoured by conditions characteristic of late successional ash dam grids (Table 3.2), such as a diverse plant community, high vegetation cover and a dense litter layer. Results showed that *Camponotus irredux* was caught only on the much older rehabilitated areas of the ash dams, but was not found in the pitfall traps in the natural grassland. It's presence on the ash dams may be due to the fact that this ant species could have been introduced to the ash dams with the return of topsoil to the area, or their abundance was so low in natural grassland, that they weren't caught.

Some other *Camponotus* species prefer nectar as food, and nest especially under large, flat stones (Slingsby 1991), in decaying wood, or in termite mounds (Prins 1985), conditions more likely to occur in older rehabilitated and well managed areas. *Camponotus* species are poor competitors and are eaten by more competitive ant species (Slingsby 1991). They are therefore unable to colonize disturbed habitats, such as ash dams efficiently, because of their poor competitiveness in obtaining the limited food sources, found on the ash dams.

From Table 3.2 it seems as if, *Tetramorium frigidum* and *Tetramorium* sp.1 were the first *Tetramorium* species to colonize the ash dams, after topsoil was returned to the area, whereas *Tetramorium setuliferum* (Figure 3.5) and *Tetramorium vexator* (Figure 3.6) became abundant at a much later stage of succession when more plant species established, producing a vast amount of seed. It seems as if, *Tetramorium setigerum* (Figure 3.7) was the last *Tetramorium* species in the succession of ant species to colonize the ash dams, and was caught in higher numbers on older rehabilitated ash dam grids, making this ant species a good indicator of an older, more mature stage of rehabilitation. The older rehabilitated ash dam grids are characterized by a higher plant species diversity, more litter, more seed, the presence of suitable niches and resources and other favourable environmental conditions, and possibly explain the higher number of *T. frigidum*, *Tetramorium* sp.1, *T. setigerum*, *T. setuliferum* and *T. vexator*, caught on these older rehabilitated grids and in the natural grassland. The high numbers of the above mentioned *Tetramorium* species on older rehabilitated ash dam grids could also be related to the abundance of seed. Ant species which are dependent on seed for food did not establish colonies, until the third year after rehabilitation of bauxite mines in Western Australia, which corresponds with the fact that plants did not set seed for at least 2 years following their establishment (Majer *et al.* 1984). Although the majority of *Tetramorium* species, found in the pitfall traps at Hendrina were indicative of late succession, Burbidge *et al.* (1992) found that some *Tetramorium* species were indicative of highly disturbed environments in Western Australia.

Although *Camponotus* sp.8, *Lepisiota* sp.3, *Tetramorium parasiticum* and *Tetramorium* sp.A05 were only caught on the oldest rehabilitated grid (Grid 12; Table 3.2), their abundance within this grid was too low to make proper deductions, regarding their use as indicators of rehabilitation success. It is possible that these ant species were from incipient colonies and were only accidentally caught in the pitfall traps. On the other hand the colonies might be small, hence making it difficult to catch these ants. *Tetramorium* sp.A05 is an alate species, which spread by independent colony foundation. This ant species can fly and disperse in search for possible nesting sites and food and will eventually colonize, once a suitable habitat is found. It is possible that this ant species was caught in the pitfall traps while searching for possible nesting sites or food. The ant species mentioned in the beginning of this paragraph, might also show an aversion for pitfall traps, making this sampling technique inefficient for catching these ant species, and stressing the importance of using additional sampling techniques. Lastly the presence of these ant species on the oldest rehabilitated grid indicated advanced rehabilitation conditions, not found on early successional ash dam grids. Ant species, such as, *Dorylus helvolus*, *Plectroctena conjugata*, *Crematogaster* spp. and *Pheidole megacephala* were found by Majer & De Kock (1992) to be indicative of older, more successful rehabilitated areas.

- **Grassland species** (See section 3.1.2.4) - The natural grassland probably represents the climax stage of succession and management strategies should aim towards this condition, if stability and sustainability of the ash dams is the objective. Although there were similarities in the composition of the ant community between the ash dams and the natural grassland, the ash dams were unable to meet the demands of particular ant species (Table 3.2), especially those with specialized diets, such as *Leptogenys intermedia*, *Cerapachys* sp.1 and *Plectroctena mandibularis*, ant species with particular habitat requirements, such as *Crematogaster* sp.2, *Camponotus transvaalensis* and *Camponotus* sp.2 & 4, as well as other species which benefit in some way from the high habitat and structural diversity of the natural grassland, such as *Lepisiota* sp.2, *Technomyrmex* sp.1, *Oligomyrmex* sp.1, *Plagiolepis* sp.1, *Prionopelta* sp.1, *Meranoplus peringueyi*, *Tetramorium* sp.A02 and *Tetramorium* sp.A06.

In a study conducted on rehabilitated bauxite mines, Majer *et al.* (1984) also found that specialized ant species, such as *Cerapachys* were absent from the rehabilitated areas, as well as litter dwelling ant species, while Majer & Nichols (1998) indicated that specialist predators were present in the forest control grids, but absent from the rehabilitated areas.

All the above mentioned ant species, found in the pitfall traps within the natural grassland at Hendrina Power Station were unable to colonize the ash dams, probably due to their specialized needs, not met on the ash dams, the lack of suitable niches, and unfavourable environmental conditions, such as a low plant diversity, more open spaces and the absence of particular insect species, which serve as prey for particular ant species. It could be assumed that specialized ant species were also less tolerant to the elevated temperatures on the ash dams, due to a lower vegetation cover (Talbot 1934, Pressick 1972, Levins *et al.* 1973; Tremper 1975). Changes in the vegetation structure, changes in the micro-climate and loss of food resources all had a negative impact on specialized ant species (Lobry de Bruyn 1993; Andersen 1997a). The large, solitary forager, *P. mandibularis* is a good example. *P. mandibularis*, mainly feeds on termites, but other studies have shown that this ant species may also feed on millipedes and beetles (Prins 1985). However, no termites, nor termite mounds were found on the ash dams, which could explain the absence of *P. mandibularis* on ash dams. The ground-dwelling, *Cerapachys* sp.1, is myrmecophagous (feeding on ants; Prins 1985), with a main diet consisting of *Pheidole* species (Brown 1975). *Pheidole* species were present, not only in the natural grassland, but also on the ash dams. However *Cerapachys* sp.1 could be more species specific, preferring *Pheidole* sp.2, which was abundant within the natural grassland. Another specialist predator is *L. intermedia*, with a main diet consisting of isopods (Bolton 1975), which could be assumed to be more abundant within the natural grassland.

Ponerine ant species, such as *Cerapachys* sp.1, *L. intermedia* and *P. mandibularis* have ergatoid (wingless) queens and are therefore constrained in their ability to disperse to the ash dams. It may however be possible that some of these specialized ant species were present on the ash dams, but due to low numbers and relative sampling inefficiency, these specialized ant species may not have been caught. It is also possible that it is difficult to catch these ant species due to their small colony size.

Camponotus transvaalensis and *Camponotus* sp.2 were found to be scarce in the pitfall traps within the adjoining natural grassland (Table 3.2), and more individuals were collected during nest excavations and hand collections, performed in the adjoining grassland. These two ant species are nocturnal in their behavior, and have distinctive chimney-like nest entrances. The function of these structures is not clearly known, but may play a role in the prevention of flooding of the nests during the wetter months of the year. These nests are abundant in the adjoining natural grassland, with an average of two nests per $1m^2$. No nests were, however, observed on the ash dams, probably due to the unsuitable substrate found on the ash dams, in which these ant species were unable to construct nests. *Camponotus* species were found to be effective for comparing various survey areas in Australia, but was ineffective in more natural survey areas (Andersen 1997b). Majer & De Kock (1992) found that some *Pheidole* and *Camponotus* species were present only in the forest control plot.

One species of the cocktail ants, *Crematogaster* sp.1, was caught in the pitfall traps on nearly all the ash dam grids, but was most abundant in the pitfall traps within the natural grassland (Table 3.2). The low numbers caught on the ash dam grids, suggest that this ant species was unable to colonize the ash dams successfully. This particular ant species was only caught as winged queens, searching for possible nesting sites on the ash dam grids. This species will not establish colonies, unless the particular area provide suitable nesting spaces, in terms of food resources and habitat diversity. The low abundance of *Crematogaster* sp.1 proved that their habitat requirements were not met on the ash dams. Burbidge *et al.* (1992) also showed that some species of *Crematogaster* were indicative of relatively undisturbed environments. The other cocktail ant, *Crematogaster* sp.2 was only caught in the pitfall traps within the natural grassland (Table 3.2), where the workers were observed near rocks. Due to the absence of rocks on the ash dams, it is probable that this ant species was unable to colonize the ash dams, simply because their habitat requirements were not met on the ash dams. One management strategy which would enhance habitat diversity and the colonization of *Crematogaster* sp.2 of the ash dams, would be the introduction of rocks to the ash dams. Increasing the habitat structure of the ash dams would not only lead to the colonization of particular ant species, but would also increase the aesthetic value of the ash dams. The presence of *Crematogaster* sp.2 in the natural grassland is not only linked with presence of rocks. There's also a possible association between this ant species and lycaenid butterflies, where these butterflies were only found in the natural grassland, due to the presence of their specific food plant only in this area. The dispersal of *Crematogaster* sp.2 may be linked, with the distribution of these lycaenid butterflies. This is still a hypotheses which needs to be tested in further studies.

Some ant species which were caught in the pitfall traps, only within the adjoining natural grassland were encountered only once, during all the surveys. These species were *Technomyrmex* sp.1, *Oligomyrmex* sp.1, *Plagiolepis* sp.1, *Prionopelta* sp.1, *Meranoplus peringueyi*, *Tetramorium* sp.A02 and *Tetramorium* sp.A06. There are a few possible reasons to explain the low abundance, not only of the above mentioned ant species within the natural grassland, but also other specialized ant species, not encountered in the pitfall traps during the study. These reasons are: (1) their aversion for pitfall traps, (2) the fact that not all niches were monitored and (3) their poor competitiveness within the natural grassland. The fact that not all niches in the natural grassland were monitored increased the chance that some ant species could have been missed by the sampling programme. The lower number of individuals caught in the natural grassland, is characteristic of the natural grassland, where there was more competition between specialized ant species present within this area. The latter is especially true for *M. peringueyi*, as this ant species spend much of their energy in avoiding interference with other ants (Andersen 1995). When these ant species are disturbed they retract their antennae into antennal grooves, tuck their legs under a dorsal shield, and lie in a motionless, pupal position (Hölldobler 1988). Some of these ant species have specialized habitat and feeding requirements, and were unable to colonize the ash dams as a result of a low habitat and structural diversity, or simply because their specialized requirements were not met on the ash dams. It is however possible that these ant species could have been present on the ash dams in low densities, but due to possible sampling inefficiency these ant species could have been missed by the sampling programme. *Prionopelta* sp.1 has previously only been collected from grasslands in Kwa-Zulu Natal (H. Robertson, pers. comm).

Table 3.2 showed that, although *Dorylus helvolus* and *Pheidole* sp.2 were caught in the pitfall traps on the ash dams these two ant species were favoured by the high habitat and structural diversity of the natural grassland and were therefore more abundant in this area. The prey of *D. helvolus* consists of various types of small animals (Prins 1985), which are probably more abundant within the natural grassland, possibly also explaining the higher abundance of

D. helvolus in the pitfall traps within the natural grassland, than in the pitfall traps on the ash dams.

Pitfall trapping does not sample cryptic ant species, such as, *Hypoponera* spp. very efficiently, or these ant species were only encountered sporadically, excluding them as ideal indicators of rehabilitation success. Majer & Nichols (1998) also found that some ant species such as *Hypoponera congrua* and *Meranoplus* spp. were cryptic species or have small colony sizes, and could therefore easily have been missed by a sampling programme. Although *Hypoponera* species were not found to be successful indicators of particular habitat conditions during different stages of succession at Hendrina Power Station, Majer (1984a) indicated that litter-foraging ant species such as *Hypoponera* spp. appear to colonize an area, once a dense and decomposing litter layer has formed. It seemed therefore as if these ant species will colonize older rehabilitated areas. Other ant species which were only caught sporadically on the ash dam grids, were *Tetramorium* sp.A01 and *Tetramorium* sp.A04.

The above results showed that there was a progressive change in the structure of the ant community, from the unrehabilitated survey, representing the pioneer stage of succession, up to the oldest rehabilitated survey area and natural grassland, in which some ant species indicated particular habitat conditions in the different stages of succession. The rate and extent of faunal establishment will depend on factors such as the extent of site rehabilitation, the size and shape of the reclaimed area and the proximity of suitable colonizers (Majer 1989; Curry 1994). Majer (1990) states that potential colonizing ant species must come from the surrounding environment in which the disturbed area is located. However, results also confirm that there were no significant patterns in the dispersal and abundance of some ant species, caught in the pitfall traps on ash dams at Hendrina Power Station. Results showed that the climax stage (natural grassland), in terms of the composition of the ant community had not yet been reached on the ash dams, with specialized ant species still under-represented. Majer & Nichols (1998) found that climate specialists, cryptic species and specialist predators were the group of species, still under-represented in their study, on the rehabilitated areas in the 14^{th} year since the initiation of rehabilitation. The absence of specialized ant species from the ash dams, proved that rehabilitation is still incomplete and rehabilitated ash dams had failed to meet the demands of specialized ant species.

The factors which probably may enhance the return of ant species to a disturbed area is described by a number of workers. Majer *et al.* (1982) found that soil type, vegetation association, climate, rehabilitation method and rainfall might influence ant return, whereas Majer (1985) found that time since rehabilitation, percentage ground cover, foliage cover, plant cover density, plant species richness, diversity and evenness, the amount of litter, the disappearance of bare ground and the presence of logs contributed to the successful colonization of ants. Inadequate rehabilitation techniques will retard ant recolonization in an area and the time necessary for the rehabilitated areas to converge to undisturbed controls will increase correspondingly (Majer & Nichols 1998). Finally Majer & Nichols (1998) suggest that the rate of ant return to different types of rehabilitation applications may differ from that of other faunal groups, such as higher order predators including spiders, litter decomposers e.g Collembola and vertebrates. Other environmental factors which further enhance ant recolonization and ant return to rehabilitated ash dams will be dealt with in section 4.2.

4.1.3 Successional trends in the diversity of the ant community (Quantitative analyses).

This particular study has indicated that a diverse ant community occurred on both the older rehabilitated ash dam grids and in the natural grassland, despite the fact that the ash dams are disturbed habitats, characterized by an overall low habitat and structural diversity, as well as, a poor nutrient status.

From Figure 3.8 and Figure 3.9 it is clear that a diverse ant community had failed to establish on the unrehabilitated areas of the ash dams. However the diversity of the ant community increased when topsoil and a seed mixture were applied. Results showed that the steep rank abundance curve, as illustrated in Figure 3.9, was due to the dominance of only a few ant species, such as *Monomorium albopilosum*, *Solenopsis punctaticeps* and *Cardiocondyla shuckardi*, which were able to benefit in some way or the other from the conditions on the unrehabilitated areas.

Colonization is an asymptotic process, proceeding most rapidly initially (Strong, Lawton & Southwood 1984). On the ash dams at Hendrina Power Station, ant species diversity, which is an indication of ant return or resilience, also increased rapidly for the first three years after rehabilitation. Results showed that, although ant species diversity (ant return) on the ash dams did not stabilize, it leveled off after three years of rehabilitation, indicating that ant species still colonized the ash dams, but accumulated at a slower rate. In another study, Jackson & Fox (1996) found a different successional trend in diversity of the ant community on mineral sand mines in Australia, in which ant species diversity did not increase continually with time since rehabilitation, but reaches a maximum, from which it then stabilizes.

The steady increase in the diversity of the ant community on the ash dams up to the 3rd year after rehabilitation was initiated (Figure 3.8), indicated that pioneer ant species, such as *Cardiocondyla shuckardi*, immediately started to colonize the unrehabilitated grids, but declined in abundance after three years of rehabilitation. It is also evident that other ant species, especially those with opportunistic and generalized habits, immediately colonized the ash dams when topsoil was returned to the area and plants began to establish, providing a suitable habitat for these ant species. Andersen (1997c) showed that ant species with low behavioral dominance, such as poor competitive ant species, reached their peak abundance relatively quickly, but declined rapidly thereafter. The initial built-up of ants in the early stages of rehabilitation was probably associated with the rapid growth of grasses and forbs and may also be indirectly related to high primary productivity associated with the application of fertilizer (Majer 1985). At early stages of rehabilitation, soil processes, such as nutrient cycling, were enhanced by the initial input of fertilizer, which could lead to a concomitant increase in the diversity of the ant community, up to the third year after rehabilitation was commenced, due to the fact that the soil had stabilized, plant species established, a dense litter layer had formed and more food was available.

The slow rate of ant species accumulation on the older rehabilitated ash dam grids (grids older than 3 years), could be an indication of competition between the increasing number of ant species for the limited food and niches, and also that some ant species leave the succession, due to the lack of suitable niches and resources, unfavourable environmental conditions, as well as a low habitat and structural diversity. It could also reflect the low rate of plant growth and food source development (Majer 1981). Lastly it could also be an indication that these older rehabilitated ash dam grids slowly began to take on the characteristics of the natural grassland.

Although it seems as if the older rehabilitated ash dam grids began to take on the characteristics of the natural grassland, specialized ant species are still under-represented on the older rehabilitated ash dam grids. The fact that specialized ant species had not colonized the older rehabilitated ash dams successfully, indicates that restoration of the original ant community is not complete and stability on the older rehabilitated ash dams had not been achieved. However, there are ways to enhance the return of specialized ant species and stability on the ash dams. Strategies through human interference include: additional planting and seeding operations, more topsoil, annual burning, the application of fertilizers, and/or increasing the structural diversity of the habitat, such as introducing large rocks and logs to the area. These strategies would also benefit other faunal groups, and could therefore, increasing the aesthetical value of the ash dams. These strategies are probably the quickest and more expensive options, which first have to be tested on a small scale, before large expenditures could be recommended. Leaving the rehabilitated ash dams to let nature take its course, is the cheapest option but will take a very long time to achieve stability and sustainability.

By looking at the rank-abundance curves for the grids, represented by different stages of succession it is evident that the steepness of the unrehabilitated survey area curve (Figure 3.9) reflects a low species richness and a high dominance of a few ant species, illustrated in Figure 3.8. When ash dam grids became older, more plants established producing a vast amount of seed, more niches were created, more food became available and the habitat and structural diversity of the area increased. These conditions lead to the establishment of a rich and diverse ant community on these older rehabilitated ash dam grids, illustrated by shallow rank-abundance curves. The rank-abundance curve for the natural grassland highlights the high ant species diversity and species richness found in this area. A higher total ant species richness was found in the natural grassland, than on the rehabilitated ash dams (Figure 3.9), possibly due to the fact that control areas provide a greater number of potential nesting and foraging sites, than disturbed areas (Andersen 1986a). In similar studies, Majer (1992; 1996) also found that the number of ant species and genera within rehabilitated bauxite mines in Brazil were always less in the rehabilitated area, than in the control areas, but increased with rehabilitation age, while Majer *et al.* (1982) found that both ant species diversity and ant species richness were lower in the rehabilitated areas, than in the control plots. Dunlop & Majer (1985) illustrated that ant species richness was higher in the control areas and in 5-year old rehabilitated sites, than in other rehabilitated areas.

According to Table 3.2, a higher total number of ant species (38) were caught in the natural grassland, than in the 7 and 9-year old rehabilitated as dam grids, during all the sampling periods. More specialized ant species were present in the natural grassland, which had failed to colonized the ash dams, therefore explaining the higher total number of ant species caught in the natural grassland. Figure 3.8 does contradict this, but could be explained by the calculation as mean number of species per transect. The abundance of the scarce specialist species in the natural grassland was very low and although the total number of species caught was higher, few species were caught per transect, resulting in the non-reflection of higher diversity. The trend seemed to be that higher diversity coincided with lower abundance. This observation may also reflect the shortcomings of pitfall trapping and proved that sampling of the ant community in the natural grassland with pitfall traps were not precise and successful enough to sample particular ant species, such as specialized species.

The hypothesis was that rehabilitation would be optimal and successful when ant species diversity on the ash dams would tend to resemble the diversity of the natural grassland. Although the mean ant species diversity was slightly higher in the 7 and 9-year old rehabilitated ash dam grids, than in the natural grassland and Figure 3.9

shows a flatter and longer rank abundance curve for the natural grassland, than the rehabilitated ash dam grids, Table 3.3 illustrates that mean diversity in the 3-9 year old rehabilitated grids compared well with that of the adjoining natural grassland. Similar trends were observed on rehabilitated open-cut mines in Northern Australia (Majer 1984a), where it was found that ant species diversity and species evenness on rehabilitated areas were similar to that of the control plots. Keals & Majer (1991) found that evenness values in disturbed areas were similar to that of the undisturbed areas, although the richness values in the disturbed areas were lower. Equitability values on rehabilitated bauxite mines in Brazil, converged to that of the controls in the 5^{th}-11^{th} year, since rehabilitation (Majer 1996). On the other hand, Majer *et al.* (1982) showed that ant species equitability values in rehabilitated sand mines were higher than in the control plots, while Jackson & Fox (1996) found that ant species diversity on mineral sand mines in Australia exceeded control levels by the 6^{th} year after rehabilitation.

Although the composition and mean species diversity of the ant community on the ash dams resemble that of the natural grassland up to the 9^{th} year after rehabilitation, it is evident that the complete restoration of the natural grassland fauna as well as the high species richness and number of specialized ant species in the natural grassland had not yet been reached on the ash dams during the survey, and it is evident that these processes will take considerably longer than the 9 year study period.

Majer (1984a) postulated that complete restoration of the forest fauna in mined areas will take considerably longer than 7 years. Majer & De Kock (1992) found that the number of ant species in the rehabilitated sand mines at Richards Bay resemble that of the dune forest in the 13^{th} year since rehabilitation was initialized, while Greenslade & Majer (1993) found that the ant fauna start to resemble that of the forest control after 10-13 years of rehabilitation. Fox & Fox (1982) found that total faunal recovery might take 17 years. Jackson & Fox (1996) suggested that the composition of the ant community approached, but did not match the controls after 18 years. Majer (1996) illustrate that the habitat requirements of ant species on rehabilitated bauxite mines in Brazil, had not been restored by the eleventh year since the initiation of rehabilitation, and he suggested that additional managerial strategies are needed to enhance the colonization of ant species. According to Majer & Nichols (1998), the ant fauna of the rehabilitated survey areas had still not converged to that of the forest in the 14^{th} year since rehabilitation was initiated, where they found that species richness was generally lower than in the forest control. Majer & Nichols (1998) found that ant species richness in some of the rehabilitated areas are within the range of the forest control sites in the 5^{th} year after the start of rehabilitation.

Lastly it was proved that the trend of increasing species diversity, species richness and evenness on the rehabilitated and unrehabilitated ash dam grids were well illustrated by rank/relative abundance curves. Results also showed that rank abundance curves gave a true and confident reflection on the overall successional changes in the number of ant species, which colonized the ash dam grids and the natural grassland. The increasingly longer and flatter rank-abundance curves with increasing age of rehabilitation confirm the increasing role and presence of ant species in succession.

4.2 Influence of habitat characteristics on succession of ants.

4.2.1 Vegetation characteristics as components influencing the diversity of the ant community on rehabilitated ash dam grids.

Ant species diversity and particularly ant species richness, correlated possitively with plant Shannon diversity, plant species richness and percentage vegetation cover (Table 3.4). On rehabilitated ash dams ant diversity, plant diversity and percentage vegetation cover are correlated simply because they're all responding positively to age of rehabilitation (Figure 3.11). An increase in the diversity and richness of the plant community, lead to a higher habitat heterogeneity and resource availability (Abramsky & Rosenzweig 1984), which probably contributed to a higher ant species diversity. Some ant species are dependent on particular plant species for food and nesting purposes e.g seed-gathering ants require seed with elaiosomes, while others require plant excretions, which are only produced in quantity by a narrow range of plant species (Majer *et al.* 1984). In such cases ant diversity is enhanced by plant species diversity (Majer *et al.* 1984). Plant species richness or vegetation structural diversity also support a richer ant fauna, due to the provision of food, shelter and nesting sites (Abensperg-Traun *et al.* 1996). Abensperg-Traun *et al.* (1996) also states that both ant and plant species richness vary with different vegetation types, and needed to be examined for different environmental conditions. The existence of a greater plant species richness in rehabilitated areas is likely to satisfy the requirements of an increasing number of ant species, since the diversity of host specific prey and Homoptera, sap and seed sources would be increased (Majer *et al.* 1984). Dunlop & Majer (1985) also found a higher ant species richness in certain areas and postulated that these higher richness values might be attributed to a greater concentrations of shrubs in these areas, which supply a continuous amount of honeydew and leaf litter.

Open conditions in areas with low vegetation cover might limit certain ants by reducing the availability of micro-arthropods such as Collembola, upon which many ant species feed (Majer *et al.* 1984). Ward, Majer & O'Connell (1991) state that an increase in plant and litter cover should facilitate decomposition processes in disturbed areas.

Relationships between ant species diversity and different vegetation characteristics have been studied by several workers. Majer & De Kock (1992) found that ant species richness tracks that of the plants on mineral sand mines in South Africa. Multiple regression analyses conducted by Keals & Majer (1991) illustrates that ant species richness in Western Australia was positively correlated with plant species richness, time since rehabilitation, percentage plant and litter cover and the presence of large logs. In addition Majer (1985) showed that ant species richness was positively correlated with time since rehabilitation, litter cover, foliage cover, vegetation cover, plant cover density, plant species diversity, plant species richness and plant species evenness and was negatively correlated with percentage bare ground.

One aim of this study was to identify plant variables associated with the diversity of the ant community. From this study, percentage vegetation cover was the major vegetation characteristic correlating with ant species diversity on rehabilitated ash dam grids, with plant species richness of secondary importance (See section 3.2.1; Table 3.4 & Figure

3.10). Majer *et al.* (1984) & Majer (1992) found that ant species richness is best predicted by plant species richness, plant structural diversity, time since rehabilitation and percentage plant cover on rehabilitated bauxite mines in Western Australia. However, according to Abensperg-Traun *et al.* (1997) total faunal richness was poorly correlated with the structure and richness of the plant community in Western Australia. Ant species richness in an agricultural part of Western Australia was not significantly correlated with habitat structural variables and plant species richness and limited success was achieved in the use of plant species richness in predicting the richness of the ant community (Abensperg-Traun *et al.* 1996). Although there were positive correlations between ant species diversity and various plant variables, the real effect could be due to some other factors, influencing these plant variables, with a concomitant influence on the diversity of the ant community. These factors have to be investigated further.

4.2.2 Soil characteristics as additional components influencing the diversity of the ant community on rehabilitated ash dam grids.

The coefficient of determination (r^2), is not only a measure of the amount of variation in the diversity of the ant community (x) is accounted for by environmental factors (y), but also indicates to what extent other factors are influencing x and y. It follows that a high percentage of the variation in the diversity of the ant community on rehabilitated ash dam grids is not accounted for by plant species diversity and vegetation cover alone, and other habitat characteristics could also be involved. Characteristics such as soil structure and texture, soil pH, electrical conductivity and soil organic matter content would also influence ant species diversity. Relative proportions of clay, silt and sand in a sample of soil is referred to as soil texture (Wild 1993). Soil texture reflects the size distribution of particles or the mechanical composition, while soil structure is determined by the degree of aggregation of soil particles and by the nature and distribution of pores and pore space (Curry 1994).

It was found that soil texture and structure was significantly correlated with the diversity of the ant community, in particular on the richness component of ant species diversity on rehabilitated ash dam grids (See section 3.2.2; Table 3.5). Percentage silt content seems to have the biggest influence on the diversity (species richness) of the ant community, with percentage sand being of secondary importance (Table 3.5). On rehabilitated ash dam grids ant species diversity (species richness) tended to decrease significantly with an increase in the silt content of the substrate, but increases with an increase in the sand content of the substrate. On rehabilitated ash dams ant diversity and percentage silt content are negatively correlated, possibly only because ant species diversity increases with age of rehabilitation, while percentage silt content decreases with age of rehabilitation.

The physical properties of soil depend largely on the sizes of the soil particles (soil texture) and on their arrangement (soil structure). To a large extent texture and structure influences aeration, permeability, infiltration capacity and water movements in the soil (Curry 1994), and the availability of water to plants, which could influence growth of plant roots, where soils with a high silt content become waterlogged after rain (Wild 1993). In soil dominated by coarse sand, water retention is low and drainage is rapid. Soils with high contents of fine sand and silt have low infiltration rates (Wild 1993). Pore space is discrete in clay soils and continuous in well-aggregated medium-textured soils and sandy soils (Curry 1994).

The negative effect of silt content on the diversity of the ant community (Figure 3.12) is therefore probably mediated via the effect of this soil variable on vegetation characteristics and thereby on resource and niche availability for ant species. Silt content could have had a direct influence on the plant community and viability on the rehabilitated ash dams probably via its effect on substrate moisture content, influencing plant growth. A high silt content often coincides with a low availability of moisture within the soil. This could have curtailed plant growth on the rehabilitated ash dam grids with a detrimental influence on the ant community. This is also reflected by the positive correlation between ant species diversity and plant diversity and vegetation cover on rehabilitated ash dam grids (Table 3.4), where ant species is lower on rehabilitated ash dam grids, with low plant species diversity and vegetation cover. Ants are therefore indirectly associated with silt content, via its possible effect on plant growth, with a concomitant indirect influence on the availability of suitable niches and resources for ant species. The influence of silt content on the diversity of the ant community could also have been directly, due to the effect of silt content on the physical habitat of ants, where soils dominated by silt could possibly limit the burrowing activity of ants. A lower plant species diversity and plant species richness on rehabilitated ash dams grids, with a low moisture availability, as a result of a high silt content, could also have led to less seed and prey items for ant species, also explaining the negative correlation between ant species diversity and silt content (Figure 3.12). Curry (1994) found that invertebrates, particularly those that are sensitive to dessication, tend to be more abundant in heavy clay soils which are less subjected to dessication than light sandy and silt soils (Curry 1994).

By looking at the correlations between ant diversity and various habitat characteristics (Table 3.4 & Table 3.5), it seems that ash dams with a high plant species diversity, vegetation cover and suitable soil conditions would be likely to accommodate a diverse ant community. It could therefore be assumed that the recolonization rates of ant species on rehabilitated ash dams could probably be enhanced by not only increasing the diversity of the plant community and vegetation cover, but also by managing the soil characteristics added to the ash dams. The latter could possibly be reached by using soils with high water infiltration and water retention in rehabilitation programmes. Soils with a high silt content and compaction tendency of the soil must be avoided.

Overall, no factor could be identified as a key factor of overriding influence on the diversity of the ant community. Other factors could also be involved which need to be tested in further studies. Several factors which could also attribute to the change in the diversity of the ant community are summarized by various authors. In a study of 30 bauxite mines in Western Australia, ant species richness was positively correlated with total invertebrate species richness, as well as the abundances of a wide range of invertebrate groups (Majer 1983; Andersen 1997a). Andersen (1997a) showed that ant species richness was highly correlated with soil microbial biomass. On sand mines at Richards Bay, ant species richness increased and then declined for a period when *Pheidole megacephala* was abundant, after which species richness increased once again (Majer & De Kock 1992). In another study by Majer (1985) on mineral sand mines in Australia, a lower ant species richness was found in older plots, than in the young plots possibly due to interspecific competition with *Pheidole megacephala*. Majer (1984b) suggested that the return of ant species to an area is indirectly affected by climate and rainfall, which had a major influence on micro-climate as well as plant growth and plant species richness. Majer (1996) compared the accumulation of ant species in different regions with each other and found that the return of ant species to an area is more rapid in areas with a more favourable rainfall distribution.

In all the correlations between ant species diversity, plant and soil variables, the latter variables were significantly correlated only with ant species richness (Table 3.4 & Table 3.5). Ant species richness therefore proved to be a more reliable parameter of the diversity in the ant community when the influence of habitat characteristics on ant species diversity were investigated and gave a more representative reflection of the diversity in the ant community during succession. It is therefore recommended to use this parameter in rehabilitation studies. Majer *et al.* (1984) states that both ant diversity index values and ant species richness are representative parameters of the ant community in disturbed areas. Keals & Majer (1991) suggested that inspection of a combination of both species richness and evenness values provide more valuable information on the state of the environment, than Shannon's diversity index values. These aspects must be taken into account in diversity studies. However, ant species richness gives an underestimation of rehabilitation success, due to the fact that some ant species, such as those that are cryptic or specialized, are not commonly captured, or due to the fact that some ant species could be inactive at a particular sampling time (Majer 1992). Curry (1994) states that although species richness is the simplest measure of community diversity, its usefulness as an index for making comparisons between communities is limited because the number of species recorded depends on the size of the area sampled and because equal weight is given to scarce and abundant species. Shannon's diversity index is of limited value in describing the diversity of the ant community, but is useful for calculating the equitability index (Room 1975). The use of species equitability as an indication of rehabilitation success also has some limitations, due to the fact that equitability values would vary considerably when placing pitfall traps near ant nests or trails (Burbidge *et al.* 1992).

4.2.3 Macro-environmental factors determining the ordination of ant and plant species on rehabilitated ash dams and in the natural grassland.

The rehabilitated ash dams at Hendrina Power Station, represented in the middle of the first ordination axis of Figure 3.14, constitute artificial hills in an otherwise relatively flat grassland landscape. Differences in the physical characteristics, such as aspect, topography and ecological status of the adjoining areas and mediated via differences in micro-climates may influence the rate at which re-vegetated communities recover, with an indirect influence on colonizing ant communities.

The ordination of ant and plant species on ash dams, not only revealed the possible preference of ant species for slopes with different aspect, adjoining area and rehabilitation age (Section 3.2.3.1; Figure 3.15), but also their preference for plateaux areas, characterized by different ecological status and rehabilitation age (Section 3.2.3.3; Figure 3.17). The three grids on the slopes of ash dam A (Grids 2, 3 & 4) grouped separately along the first ordination axis, probably due to differences in aspect, mediated via microclimates (Figure 3.15). Spatial factors could also account for the ordination pattern observed, since grids 2 & 3 are adjoined by disturbed areas, whereas grid 4 is adjoined by the natural grassland. The separate ordination of ant and plant species on grids 2, 3 & 4 and grid 9 may reflect differences in the rehabilitation age of these grids. Grids 2, 3 & 4 were rehabilitated in 1994, whereas grid 9 was rehabilitated in 1992. Another possible explanation for the separate grouping of grid 9 and the grids on the slopes of ash dam A, is that grid 9 was never burnt, whereas grids 2, 3 & 4 were burnt in 1998.

The ordination divided the grids on the plateaux of different ash dams into two broad groups along the first ordination axis - grid 1 situated to the left of the first ordination axis and grids 10, 11 & 12 to the right (Section 3.2.3.3; Figure 3.17). The major features separating the two group of grids on plateaux areas were rehabilitation age and ecological status. Grid 1 was rehabilitated during 1995, grids 10 & 11 were rehabilitated during 1992, whereas grid 12 was rehabilitated during 1990 and therefore had a higher ecological status.

Although the gradient distance on the second ordination axis was small, grid 12 grouped separately from grids 10 & 11, (Figure 3.17) reflecting the influence of different rehabilitation age on the ordination of plant and ant communities in these areas. Survey areas on the left side of the first ordination axis (Grid 10 and 11) are two neighboring grids and were rehabilitated by using the same rehabilitation method. The separation of grids on the plateaux of ash dam C, along the second ordination axis (Figure 3.17) also reflects the dominance of the perennial grass species, *Hyparrhenia hirta* on grids 10 & 11 and the perennial grass species, *Eragrostis curvula* on grid 12. The analysis showed however that the variation on the second ordination axis is very small and only explained a slight amount of variance in the ordination (Eigenvalue = 0.036). It could therefore be assumed that rehabilitation age had no significant influence on the composition of ant and plant species on grids 10, 11 & 12.

Results (Section 3.2.3.2; Figure 3.16) further revealed the clear separation of ant and plant species along a gradient of rehabilitation stage. The ordination of the different transects of grids 7 & 8 with respect to axis 1 clearly reflects the influence of rehabilitation age and rehabilitation method as demonstrated in transects rehabilitated in 1996 (middle transects), and transects rehabilitated in 1992 (bottom transects) by means of a different rehabilitation method (Figure 3.16; See also section 2.1.2 and Table 2.1 for the rehabilitation methods used). The ordination based on plant and ant species data, therefore, effectively clustered the middle and bottom transects of grids 7 & 8, according to the patterns of known environmental heterogeneity due to the time since rehabilitation and rehabilitation methods.

The separate grouping in the ordination of the bottom transect of grid 7 and the bottom transect of grid 8 along the first ordination axis (Figure 3.16), regarding the composition of the plant and ant community could possibly be due to differences in aspect and moisture levels. The bottom transect of grid 7 had a western aspect and is drier, than the bottom transect of grid 8. The bottom transect of grid 8 had a southern aspect. It could therefore be assumed that the plant and ant species which were present on the bottom transect of grid 7 were associated with dry, west-facing slopes, while the plant and ant species which were present on the bottom transect of grid 8 were associated with wetter, south-facing slopes.

4.2.4 Indicative value of various ant species on ash dams and natural grassland, in relation to macro-environmental and other environmental factors, such as plant and soil factors.

When the indicative value of ant species on ash dams is investigated, one has to look not only at the associations between ant species and various macro-environmental factors, but also at correlations between these ant species and various other environmental factors, such as plant species composition, percentage vegetation cover, soil texture and structure, pH, organic matter and conductivity of the soil. These associations and correlations are important to identify certain parameters of rehabilitation success. Table 4.1 was composed to summarize a qualitative interpretation of quantitative multivariate analyses of the relationships between environmental factors and specific ant species.

The clear separation of the unrehabilitated ash dam grids, rehabilitated ash dam grids and natural grassland, along the first ordination axis (Section 3.2.3; Figure 3.14) suggests that the vegetation communities in these areas are markedly different, both in floristic composition and physiognomy. The maximum length of the gradient on the first ordination axis is 16.496 SD, therefore indicating a strong unimodal response on the first ordination axis, implying that the plant assemblages were markedly divergent on the unrehabilited ash dam grids, rehabilitated ash dam grids and in the adjoining natural grassland. When the maximum gradient length exceeds 4 SD, the data show a strong unimodal response (Ter Braak & Šmilauer 1998). The clear separation of the unrehabilitated, rehabilitated ash dams and the natural grassland along the first ordination axis also suggest that conditions on the ash dams were not as favourable in these areas, as in the natural grassland, therefore leading to the establishment of a less diverse plant community and the colonization of less specialized ant species.

During succession on rehabilitated ash dams, specific soil properties were found and soil conditions become favourable for plant communities to establish successfully on the ash dams, which could be correlated with the successful colonization of particular ant species. The close correspondence between ant and plant communities on rehabilitated ash dam grids at Hendrina Power station suggests related patterns of community development. The associations between ant and plant species and soil factors were also investigated by several authors. For example Andersen (1997a), found the composition of the ant community on rehabilitated Uranium mines in Australia to be strongly correlated with plant species composition. Rosbach & Majer (1983) demonstrated that ant species composition is associated with vegetation types and different soil types in Western Australia.

Greenslade & Thompson (1981) found that ant community structure and species composition are influenced by vegetation structure such as vegetation pattern, height, vegetation cover and associated micro-climate.

Figure 3.18 revealed two clearly separated plant successional groups on rehabilitated ash dams - an early successional group e.g grid 1 and the middle transects of grids 7 and 8, dominated by pioneer plant species with a low vegetation cover and particular soil conditions, which were dominated by opportunistic, pioneer ant species (See section 4.2.4.1) and a second late successional group e.g grid 2, 3, 4, 9, 10, 11, 12 and the bottom transects of grids 7 & 8, characterized by late successional environmental conditions, which were dominated by late successional ant species (See section 4.2.4.2). Plant species, represented by arrows in the ordination diagram, situated at the top of the first ordination axis are pioneer plant species (Figure 3.18), which are also represented in the green block of Table 3.6. On the other hand, plant species situated at the bottom of the first ordination axis are late successional species, which are represented in the purple block of Table 3.6. The arrow representing a high percentage vegetation cover also pointed downward. The upward direction of the

Table 4.1: Ant species, characteristic of macro-environmental and other environmental factors, such as plant and soil factors.

Characteristic ant species	Early successional grids	Pioneer plant community	Late successional grids	Late successional plant community	Aspect of the slopes				Soil factors						
					North	East	West	South	%Gravel	%Sand	%Silt	%Clay	pH	EC	%Carbon
Cardiocondyla shuckardi	+	+													
Monomorium albopilosum	+	+							+						
Monomorium sp.2	+	+													
Pheidole sp.4	+	+							+						
Tetramorium sericeiventre	+	+													
Anoplolepis custodiens			+	+	+		+			+	−				+
Lepisiota capensis										+	−				+
Pheidole sp.1										+					
Solenopsis punctaticeps			+	+								+			
Tetramorium setigerum			+	+											
Tetramorium setuliferum			+	+											
Tetramorium vexator			+	+											
Tetramorium sp.A01			+	+											

arrows in the ordination diagram could therefore indicate pioneer conditions on the ash dams, while the downward direction of the arrows, presenting different plant species and a high vegetation cover could indicate conditions, characteristic of older rehabilitation. Similarly, ant species, situated in the top part of the ordination diagram, represented in the green block of Table 3.6, are early colonizing ant species, where they were closely associated with pioneer plant species occurring in this top part of the ordination diagram, while ant species in the bottom part of the ordination diagram, represented in the purple block of Table 3.6 are probably late colonizing species, associated with late successional plant species and a high vegetation cover, which probably first start to colonize the ash dams once conditions became suitable for them. Early and late successional ant communities could therefore also be recognized. The late successional ant community had a higher species diversity than the early successional community.

4.2.4.1 Ant species indicative of early successional conditions on rehabilitated ash dam grids.

Table 3.6 and Figure 3.18 (Section 3.2.4) showed strong significant correlations between various ant species, pioneer plant species and a low vegetation cover. The significant relationships are summarized in Table 4.1 which indicated that ant species, such as *C. shuckardi*, *M. albopilosum*, *Monomorium* sp.2, *T. sericeiventre* and *Pheidole* sp.4 could be indicative of pioneer habitats on rehabilitated ash dam grids, such as grid 1 and the middle transects of grids 7 & 8, which are characterized by the presence of pioneer plant species (Table 4.1), such as *Cyperus esculentus*, *Tagetes minuta*, *Eragrostis trichophora* and a low habitat and structural diversity, such as a low vegetation cover (Table 3.6). These ant species showed an aversion for older rehabilitated ash dams (Table 3.6), characterized by the presence of *Eragrostis curvula* and *Hyparrhenia hirta* stable plant communities, possibly due to the presence of more successful competitive ant species. The above mentioned ant species were strongly correlated with pioneer plant species and vegetation cover, and responded negatively to age of rehabilitation.

The presence of *C. shuckardi* in grid 1 (Figure 3.17) and on the middle transects of grids 7 & 8 (Figure 3.16) could be indicative of disturbance, pioneer conditions and proved that these areas are in an earlier stage of succession, than older rehabilitated ash dam grids, such as grids 10, 11 & 12. By looking at the ordination diagram (Figure 3.16), it seemed as if the middle transects of grids 7 & 8, had not yet met the demands of ant species, such as *Anoplolepis custodiens*, *Tetramorium setigerum*, *Tetramorium setuliferum* and *Tetramorium vexator*, (which were found to be indicative of older rehabilitated areas on the ash dams - Table 3.2).

Pioneer ant species were also found to be associated with various soil factors, associated with early successional ash dam grids (Table 3.8; Table 4.1 & Figure 3.19). Most of these associations seemed to be associated with changes in the texture and structure of the soil (Table 3.8). As found in this section, pioneer ant species such as *M. albopilosum* and *Pheidole* sp.4 seemed to be indicative of a high gravel content within early successional grids (Table 3.8 & Table 4.1).

Gravel particles are relatively coarse with large pore spaces. Although soils with a high gravel content are well aerated, porous and permeable, soil particles are loosely aggregated and cannot hold water very efficiently and tend to have a low water content. From Figure 3.20 it seems as if these conditions are probably less suitable for plant species characteristic of older rehabilitation, but leaves a niche for pioneer plant species, with which pioneer ant species such as *M. albopilosum* and *Pheidole* sp.4 were found to be associated. The association of these pioneer ant species with soil structure and texture could also be via other physical unknown factors, such as the suitability of the soil for nest construction.

4.2.4.2 Ant species indicative of late successional conditions on rehabilitated ash dam grids.

There is clear evidence that some ant species were associated with plant species, associated with older rehabilitated ash dam grids and a high vegetation cover (Table 3.6 and Figure 3.18 in Section 3.2.4). As rehabilitated grids on the ash dams became older, stable plant communities, such as *H. hirta* (Grids 10 & 11; Figure 3.17) and *E. curvula* (Grid 12; Figure 3.17) established, as well as forbs and legumes, such as *Chamaecrista biensis* and *Conyza bonariensis*. Legumes play an important role in nutrient cycling (Ward *et al.* 1991). Legumes also increase nitrogen content within the soil, and the rapidly growing understorey should provide a favourable micro-climate for decomposer organisms. These older rehabilitated areas are also characterized by a high vegetation cover and a denser litter layer, than on early successional grids. The dominance of *H. hirta* in older rehabilitated areas such as in grids 10 & 11 (Figure 3.17), could possibly be a result of fire within these areas during 1998, since it is known that fire stimulates the growth of *H. hirta* (Morgenthal 1999). Based on field experiments these areas are also characterized by a high activity of the Highveld Gerbil, *Tatera brantsii*, which favours open areas, characteristic of these grids (Bronner, Wright, Van Hamburg, Morgenthal & Michael 1999). Due to the high burrowing activity of *T. brantsii*, these areas are modified and seemed to favour particular ant species. On the other hand, a possible explanation for the dominance of *E. curvula* on grid 12 (Figure 3.17) is that *T. brantsii* was absent from this area, and the area was not burnt during the study, which favour other ant species.

It seems as if ant species, such as *A. custodiens*, *S. punctaticeps*, *T. setuliferum*, *T. setigerum*, *T. vexator* and *Tetramorium* sp.A01 could be indicative of older successional, more stable rehabilitated ash dams, such as grids 2, 3, 4, 9, 10, 11, 12 and the bottom transects of grids 7 & 8, which are characterized by the presence of older successional plant species (Table 4.1), such as *Hyparrhenia hirta*, *Eragrostis curvula*, *Cynodon dactylon* and *Conyza bonariensis*, as well as a high vegetation cover (Table 3.6). Similarly, the negative correlation between *A. custodiens* and *T. minuta* (Table 3.6) also reflected the aversion of *A. custodiens* for early successional ash dam grids. The possible associations between the above mentioned ant species and plant species characteristic of older successional stages, suggest that these ant species were, after the early colonizing ant species, such as *C. shuckardi*, next to colonize the rehabilitated ash dam grids, when more perennial forb and grass species established on the ash dams. This also corresponds with section 3.1.2 and section 4.1.2.

Table 3.6 and Figure 3.18 showed that where rehabilitation strategies at Hendrina were aimed towards a *H. hirta* stable plant community and a high vegetation cover, *A. custodiens* (Figure 3.15 & Table 3.6) and *T. vexator* (Figure 3.15) seemed to be indicative of these areas. According to Figure 3.15, *A. custodiens* also seemed to be more associated with north (Grid 2) and west-facing slopes (Grid 3), which were probably characterized by warmer micro-climates, the continued establishment of plant species, such as *H. hirta*, and a higher vegetation cover, which favours *A. custodiens*. However, Figure 3.15 and Figure 3.17 showed that *A. custodiens* was associated with *H. hirta* on both plateaux areas and slopes of different ash dams. It seems therefore, as if *A. custodiens* was associated with *H. hirta* on rehabilitated ash dam grids, regardless the different ash dams, topography, aspect etc.

S. punctaticeps seemed to be indicative of areas where rehabilitation strategies were aimed towards an *E. curvula* stable plant community (Figure 3.15; Figure 3.16 and Table 3.6). Areas dominated by *E. curvula*, such as Grid 12 (Figure 3.17) were also characterized by the presence of a dense litter layer. Andersen (1986b) found that the distribution of *Solenopsis* species is probably related to litter content, and could therefore explain the positive correlation between *S. punctaticeps* and *E. curvula* on older rehabilitated ash dam grids, in which a dense litter layer was present.

A. custodiens, *S. punctaticeps*, *T. setuliferum*, *T. setigerum*, *T. vexator* and *Tetramorium* sp.A01 were positively correlated with pioneer plant species, possibly due to the fact that they responded positively to age of rehabilitation. However, other environmental conditions, not attended to in this study, such as a higher abundance of seed and other soil factors could also have had an influence on the relative abundance of these ant species in older successional grids. *T. setuliferum* was seen harvesting seeds of the grass species *H. hirta*, where this ant species benefits from the large amount of seed which is produced by this grass species and therefore possibly explains the association between this ant species and *H. hirta*, although no significant relationship between *H. hirta* and *T. setuliferum* was found (Table 3.6 & Figure 3.18). It could therefore be assumed that the association between *T. setuliferum* and older rehabilitated ash dam grids could be due to other factors.

CCA ordination (Figure 3.19 & Table 3.8) revealed that late successional ant species could also be indicative of various soil factors associated with older rehabilitated ash dams. As in the case of pioneer ant species (Section 4.2.4.1), most of these associations seemed to be associated with changes in the texture and structure of the soil, although Table 3.8 shows some correlations between late successional ant species and organic matter content of the soil. Although ant species such as *Lepisiota capensis* and *Pheidole* sp.1 were not significantly correlated with older successional plant species on rehabilitated ash dam grids, they appeared to be indicative of various soil factors, associated with older rehabilitated ash dam grids. Together with the late successional ant species, *A. custodiens*, other species, such as *L. capensis* and *Pheidole* sp.1 seemed to be associated with sand content of the soil, whereas only *A. custodiens* and *L. capensis* seemed to be associated with organic matter content of the soil (Table 3.8 and Figure 3.19). The two last mentioned ant species were also negatively correlated with silt content. Sand and organic matter content of the substrate seemed both to be higher in older rehabilitated ash dam grids, whereas silt content tended to be lower (Figure 3.20). The abundance of *A. custodiens* and *L. capensis* tended to increase with rehabilitation age and may explain the significant positive correlations between these two ant species, sand and organic matter content of the substrate. The negative correlation between *A. custodiens* and *L. capensis* and silt content on the other hand suggest that both these ant species and silt content responded negatively to age of rehabilitation. The high sand and organic matter content within the soil in older rehabilitated areas could therefore, apart from the presence of suitable plant species, be one of the reasons for the high abundance of *A. custodiens*. However, the high abundance of *A. custodiens* in older rehabilitated ash dam grids cannot be explained only by one or a few soil characteristics, since many other factors could also be involved, which will be discussed in the next few paragraphs.

The additional effect of soil structure and texture, as well as organic matter content, on the abundance of *A. custodiens* is probably an indirect effect of these soil factors on the plants with which this ant species is associated, with a concomitant influence on the availability of food, niches and resources. This is confirmed by Curry (1994) where he found that the physical and chemical characteristics of soil indirectly affect invertebrates above ground through their influence on vegetation and plant growth. Curry (1994) found soil attributes, such as temperature and moisture content, soil organic matter, texture, structure and porosity, soil pH and base status to be of great significance in this regard.

Soil texture and structure determine to a large extent the distribution and movement of water in the soil and the availability of water to plants. It also affects the growth of plant roots (Wild 1993). In soils dominated by silt, pore space are small, so water transmission is slow, root growth may be restricted and the soil may become waterlogged after rain (Wild 1993). Soils with a high silt content could therefore have had a negative effect on plant growth, such as *H. hirta* and could therefore also affect *A. custodiens* negatively, explaining the negative correlation found between the abundance of *A. custodiens* and silt content (See also section 4.2.2). The direct effect of silt content on plant growth also seemed to influence *L. capensis* indirectly. In contrast with soils dominated by silt, soils with a high sand content have bigger pore spaces, so that water transmission is faster and root growth may be enhanced. Soils with a high sand content are also well aerated, have a high permeability, infiltration capacity and water can move freely and with ease through the soil - conditions suitable for plant growth. Sand content could therefore affect ant species, such as *A. custodiens*, *L. capensis* and *Pheidole* sp.1, positively, via its positive contribution to plant growth.

On the other hand, organic matter increases the ability of soil to retain water available to plants (Wild 1993). Plant growth is also enhanced by a high organic matter within the soil. Organic matter is added from above-ground plant parts, trees, roots and to a lesser extent from microbial and animal tissues (Curry 1994). The content of organic carbon in soil is therefore set by the quantity of organic matter that enters the soil each year and the rate of decomposition of the soil organic matter (Wild 1993). The distribution of organic matter in the soil profile is related to local site characteristics and decomposition rates (Curry 1994). Organic matter helps to stabilize aggregates and keep open the macropores needed for infiltration, which will reduce run-off and erosion

(Wild 1993). Soil organic matter also influences many soil properties, including increased water-holding capacity and enhanced cation exchange capacity, which influence the nature of the soil habitat and also the type and abundance of plant species, which established on the ash dam grids at various stages of succession. It also provides the energy and nutrient base for the community of soil decomposers (Curry 1994).

A high organic matter content within the soil of rehabilitated ash dams could attract various insects on which *A. custodiens* are dependent for food, therefore possibly explaining the positive association between the abundance of *A. custodiens* and organic content within the soil (See section 4.1.2, for the food preferences of *A. custodiens*). Ant species are probably to a lesser extent directly influenced by organic matter content, through the metabolism of the organic compounds which provides ants with energy for growth, locomotion and reproduction, and also the carbon required for the synthesis of cell components (Wild 1993).

The minerals in the clay fraction impart chemical and physical properties to soil which strongly influence its behaviour, for example in adsorbing cations, anions and pesticides and acting as a source of plant nutrients (Wild 1993). The above characteristics therefore could have a positive effect on plant communities, especially plant species characteristic of older rehabilitated areas, such as *Eragrostis curvula*, with which *S. punctaticeps* was found to be associated (Table 3.6 & Figure 3.18), therefore explaining the positive correlation between *S. punctaticeps* and clay content within the substrate of older rehabilitated ash dam grids. *S. punctaticeps* is in this regard, indirectly influenced by clay content within the substrate, due to its effect on vegetation.

All the above correlations between ant species and various soil factors on rehabilitated ash dam grids are therefore via the direct effect of soil conditions on vegetation characteristics, plant species composition, food availability and viability. However in some cases soil structure and texture had a direct effect on ant species probably via their influence on the physical habitat of ant species.

The significant correlations between ant species and various plant and soil factors showed that ant species composition is, together with ant species richness, an efficient and reliable parameter when changes in the habitat, due to succession is being investigated. However, vegetation and soil factors cannot be regarded as sole agents influencing the structure of the ant community - other factors are also involved. Therefore, the applicability of successional trends and indicative value of ants at Hendrina to other areas, has to be investigated in further studies.

4.3 Seasonal changes in the structure of the ant community on ash dams and in natural grasslands.

Globally, temperature is an important factor controlling the occurrence of ants and high population abundances are characteristic of drier, warmer climates (Curry 1994). Weather, notably temperature and moisture, is undoubtedly of major importance in determining population density (1) by its direct effect on the biology, metabolic processes and growth rates of individuals and populations and (2) by its indirect effect on the food supply and the general conditions of the habitat (Curry 1994). Seasonal changes in resources, such as food and shelter, therefore, determine the abundance and diversity of the ant community on ash dams. Seasonal changes also determine the abundance and occurrence of other organisms, on which ant species feed, influencing the abundance, activity and diversity of ants. This kind of study not only gives valuable insight into the seasonal changes occurring in the abundance and diversity of the ant community, but also determines the best time of the year for ant sampling. It is therefore valuable to know the temporal abundance of different ant species.

4.3.1 Differences between ant species in seasonal activity.

Surface-dwelling invertebrates, such as ants are often faced with marked variations in diurnal and seasonal temperature (Curry 1994). The habitat on the ash dams was continually changing, particularly on a seasonal basis, different resources may become available during different seasons and the resources utilized by different ant species were separated spatially (Begon, Harper & Townsend 1990) leading to different seasonal activities. It is clear from the results, that there are differences in the seasonal activity of ant species, in which some ant species are winter active, some are more active in summer and autumn, others are only active in summer, while some ant species are active in spring, summer and autumn (See section 3.3.1; Figure 3.23-3.37). Andersen (1992) also found that daily and seasonal foraging activity may differ between ant species. Ants are basically omnivorous but there is considerable variation between species and within species at different times of the year, depending on food availability and the requirements of the colony (Curry 1994).

4.3.1.1 Summer and autumn active ant species.

From the results it is clear that *Anoplolepis custodiens* (Figure 3.23), *Camponotus irredux* (Figure 3.24), *Cardiocondyla shuckardi* (Figure 3.26), *Tetramorium setuliferum* (Figure 3.35), *Tetramorium vexator* (Figure 3.36) and *Tetramorium* sp.1 (Figure 3.37) are more regularly caught in autumn and summer. In another study De Bie & Hewitt (1990) illustrate that *A. custodiens* is more abundant during autumn and spring, with a sharp decline during mid-summer and winter. During the present study at Hendrina Power Station, *A. custodiens* was observed as one of the most active ant species in warm summer months, excavating soil material from their nests and was seen carrying dead insects to their nests. Food is more abundant during summer and autumn, which probably lead to an increase in the activity of this ant species. The above trend is also explained by Majer & Abbott (1989) where they found that prey items such as soil and litter invertebrates were most abundant between late December and March. This was also the time of the year when *A. custodiens* was active on ash dams at Hendrina Power Station (Figure 3.23). The high activity of the seed harvesting, *T. setuliferum*, during autumn and summer could probably be related to the abundance of seed (Figure 3.35). This was also illustrated in a study by Twigg, Majer & Stynes (1982), where the foraging activity of some ant species were related to seed drop. Majer (1985) found that seasonal changes, especially temperature, affect seed removal rates by ants.

The high activity of *A. custodiens* and other ant species on ash dams and in the natural grassland, during summer and autumn, could therefore probably be attributed to a combination of high temperatures and rainfall, which stimulate activity and productivity, both of the ants themselves and their potential prey species. This is illustrated by Dean (1992) where he found that the time and temperature at which ants forage are influenced by the time at which food items are available. The high activity in the summer months is typical for ants of temperate climates (Vanderwoude *et al.* 1997).

4.3.1.2 Summer active ant species.

In contrast with the previously mentioned ant species, which were active both in autumn and summer, other ant species, such as *Solenopsis punctaticeps* (Figure 3.32) were only active during summer, when the soil is wetter and therefore more penetrable. Majer *et al.* (1982) found that high summer moisture levels and penetrability would facilitate the burrowing activity of soil organisms. Together with rain water, more food particles entered the soil, during the rainy seasons, creating a more suitable niche for this subterranean ant species.

4.3.1.3 Winter active ant species.

As expected, nearly all ant species caught in the pitfall traps on the ash dams at Hendrina Power Station have lower activity in winter, than in the warmer months, but some are more winter active than others, showing that when temperature declines, these species become active. The response of *M. albopilosum* (Figure 3.29), *Pheidole sp.4* (Figure 3.31) and *Technomyrmex albipes* (Figure 3.33) to temperature is entirely different to that of the other ant species, where these ant species were relatively active throughout the year, even in the winter months, a period during which other ant species were inactive or less active. On ash dams different ant species can co-exist and avoid competition by means of differential resource utilization (Begon, Harper & Townsend 1990) and temporal partitioning (Schoener 1974). Alternatively, Begon, Harper &

Townsend (1990) stated that two species can utilize the same resources and co-exist, if their ability to do so influenced by environmental conditions, such as seasonal abundance of resources and if they respond differently to these conditions. This could be achieved by different seasonal activity of ant species, where they foraged during different seasons on different resources. Although resources were scarce during the winter months, it is possible that *M. albopilosum*, *Pheidole* sp.4 and *T. albipes* adopted to utilize the limited resources, when other ant species were inactive and competition for resources was low, explaining the high numbers of these species. The high abundance of *M. albopilosum*, *Pheidole* sp.4 and *T. albipes* during the winter months also suggest that food sources were abundant and diverse, even in the winter months, illustrating the importance of functional diversity in ecosystems, especially in resource availability and diversity. The above mentioned ant species had therefore a competitive advantage over other autumn, summer and spring active ant species for limited food supplies, by foraging at much lower temperatures, creating functional and temporal diversity. Lynch, Balinsky & Vail (1980) also found that particular ant species avoid competition with other ant species, by foraging at much lower temperatures and by ceasing surface activity during the warm, mid-summer periods, when other more successful competitive ant species were active. The higher activity of *M. albopilosum*, *T. albipes* and *Pheidole* sp.4 in winter, than other ant species could also be due to physiological differentiation between species (Tremper 1975; Lynch *et al.* 1980). *M. albopilosum*, *T. albipes* and *Pheidole* sp.4 could therefore have had lower Critical Thermal Maximum (CTM), than ant species active at higher temperatures.

Some winter active ant species use different strategies to tolerate the cold temperatures during winter. Ant species, such as *M. albopilosum* is black in colour and could therefore absorb sunlight more effectively, than other non-black ant species. *T. albipes* survives the cold winter months by establishing nests in warm places. This species is well known for its ability to build nests in warm environments, even in man-made structures, such as homes, burglar alarms etc. The exceptional high number of *T. albipes* individuals caught on ash dams and in the natural grassland, during the third survey conducted in 1998 (Figure 3.33) could be due to an effect of an intense veld fire, which had destroyed all the vegetation in nearly all the grids on the ash dams and in the natural grassland and caused a temporary modification to the habitat. *T. albipes* may be able to benefit from the open conditions, caused by the fire and increased foraging activity, as a result of severe food shortage, might have led to increased numbers caught. Burning could also have led to greater pitfall trapping effectiveness, due to removal of litter and ground cover, which could have lead to the increase in the number of *T. albipes* caught (Andersen & Yen 1985).

4.3.1.4 Spring, summer & autumn active ant species.

Results indicated that *Camponotus vestitus* (Figure 3.25), *Lepisiota capensis* (Figure 3.27), *Lepisiota laevis* (Figure 3.28) and *Tetramorium sericeiventre* (Figure 3.34) prefer conditions present during the warm spring, summer and autumn months. The relatively high activity of these ant species during all these seasons, reflect their ability to benefit from a wide range of food and nesting sites, also illustrating the high functional and resource diversity on ash dams and in natural grasslands.

The lower activity and abundance of *Camponotus vestitus*, *Lepisiota capensis*, *Lepisiota laevis*, *Pheidole* sp.1, *Tetramorium sericeiventre* and *Tetramorium setuliferum* caught on the ash dams and in the natural grassland, during winter, possibly reflect that prey items, seeds and other food items were less abundant during these winter months. The low numbers of *A. custodiens*, *L. capensis*, *L. laevis*, *M. albopilosum*, *S. punctaticeps*, *T. sericeiventre* and *T. setuliferum* caught on the ash dam grids and in the natural grassland, during the last survey conducted in 1998, could possibly be due to heavy rain during this survey. Although the activity and therefore the number of individuals caught were higher in warmer seasons, it seemed as if other prevailing weather conditions, such as heavy rain and/or cloud cover could have negative influenced on the activity of particular ant species on the ash dams and in the natural grassland (Andersen 1986a).

4.3.2 Seasonal and other factors leading to the seasonal activity of specific ant species on ash dams and in the natural grassland.

Results indicated that the activity of some ant species, caught in pitfall traps on the ash dams and in the natural grassland is controlled by average temperature, in which some ant species were positively correlated with average temperature (Figure 3.38-3.43). All these ant species tended to increase with an elevation in temperature. None of these ant species were however significantly correlated with rainfall, showing that temperature patterns had a greater influence on the seasonal activity of ant species on the ash dams and in the natural grassland at Hendrina Power Station, than rainfall patterns. Temperature is determined by the amount of radiation reaching the earth, which in turn depends on many factors , such as time of the day, season, latitude, aspect, altitude, cloud cover, vegetation cover, soil colour etc. (Curry 1994). Dean (1992) states that ant activity and behaviour of above-ground ant species are controlled by ambient and soil-surface temperatures, as well as competitive interactions between ant species, whereas Vanderwoude *et al.* (1997) found a positive relationship between ant species abundance and temperature in Australia. In studies by Andersen (1992; 1995), temperature and humidity were regarded as key factors controlling ant activity and distribution and low temperatures was found to be the principal abiotic stress which influenced ant community structure. Dean (1992) also found that ant activity was limited by low temperatures. Extremely high temperatures is also an important stress on ants, but ants avoid it, by inactivity during the hot parts of the day (Andersen 1995).

The only ant species that appeared to correlate significantly with mean temperature on the ash dams and in the natural grassland, were *A. custodiens* (Figure 3.38), *C. vestitus* (Figure 3.39), *L. laevis* (Figure 3.40), *T. sericeiventre* (Figure 3.41), *T. vexator* (Figure 3.42) and *Tetramorium* sp.1 (Figure 3.43), therefore explaining the relatively high activity of these ant species during the warmer parts of the year, illustrated in section 4.4.1. In another study, Dean (1992) also found *A. custodiens* to be less active in the southern Karoo, South Africa, during cold periods, where he did not record any *A. custodiens* individuals when the ambient temperature was between -1°C and 7°C, but found that this ant species became active in the winter months when the soil-surface and ambient temperatures reached 10°C. In summer he found that this ant species became active when the surface-soil and ambient temperatures were slightly higher than 11°C and 15°C respectively (Dean 1992). Other authors demonstrated that *A. custodiens* is active from dawn till dusk, and shows a decline in activity when the ground temperature was higher than 40°C and becomes active when the soil temperature was between 13°C and 16°C (De Bie & Hewitt 1990).

A. custodiens travels long distances to visit sap-feeding insects, and are therefore more exposed to unfavourable climatic conditions (De Bie & Hewitt 1990), than many other ant species. This ant species copes with overexposure by means of a behavioral process known as thermal respiting, where this ant species "rests" in small bushes or shrubs (De Bie & Hewitt 1990). They scavenge during the day and hide underground under extreme environmental conditions (Steyn 1954).

It is important to note that temperature is not the sole agent responsible for the seasonal activity of ants on the ash dams and in the natural grassland, but other factors could also be involved, which have to be tested in further studies. Lobry de Bruyn (1993) found that ant foraging activity is not only dependent on prevailing weather conditions such as temperature, rainfall, humidity and cloudiness, but also food supply. Andersen (1986a) states that ant activity is regulated by prevailing weather conditions, such as heavy cloud cover, rain or extremely high temperatures, which in return may also affect the availability of food supplies. Different seasonal ant activity reflects changes in the availability of food, or may be related to physiological differences and interspecific competition between species (Lynch 1981). According to Andersen (1986a), patterns of ant community organization is controlled by climate and vegetation structure, while interspecific competition is a less important factor.

4.3.3 Seasonal variation in the diversity of the ant community.

Results (Table 3.10 & Figure 3.44) illustrate significant seasonal changes in the mean Shannon diversity index values, mean species equitability and mean number of ant species (species richness) on ash dams and in the natural grassland. Dunlop & Majer (1985) also found that ant species equitability varies with season. From the results it is evident that the mean equitability of the ant community was significantly lower in summer, than in the other seasons, possibly as a result of the high abundance of

Anoplolepis custodiens during this period. Fox & Fox (1982), found that dominant ant species influence ant species diversity, in particular ant equitability. Lobry De Bruyn (1993) found that less abundant ant species increased in numbers during March and November, where dominance of several ant species lead to a lower ant species equitability during these periods. In another study, Andersen (1992) also found that the abundance and diversity of other ant species under favourable conditions are suppressed by dominant ant species.

Further results showed that mean Shannon diversity and mean ant species richness were significantly lower in winter, than in the other seasons. Vanderwoude *et al.* (1997) found that ant species richness was higher in the Australian summer months, Lobry de Bruyn (1993) found a higher ant species richness and activity in the spring and summer months in Western Australia, Andersen (1986a) showed that ant species richness reached peak values during summer, while Hinkley & New (1997) showed that ant species richness in the Mount Piper Grassland, Australia, declined significantly from June to September. On the other hand, Keals & Majer (1991) illustrated that both ant species richness and equitability values remain relatively constant from late spring to early autumn. The lower diversity in the ant community during the winter months (Table 3.10 & Figure 3.44) probably reflect the scarcity of food and nesting sites.

4.3.4 Seasonal factors leading to the seasonal variation in the diversity of the community on ash dams and in the natural grassland.

Ant species richness on the ash dams and in the natural grassland was the only component of ant species diversity, which significantly correlated positively with mean temperature, again showing the importance of the richness component of ant species diversity in rehabilitation studies. As temperature increases food became more abundant to ant species, leading to a higher activity of different ant species, therefore explaining the increase in species richness with an increase in temperature. The elevation in the richness of the ant community also explains the higher ant species richness during autumn, spring and summer, than in winter. Neither Shannon diversity, species equitability, nor ant species richness were significantly correlated with rainfall, and it therefore seems, as if rainfall had no significant influence on the diversity of the ant community, in the short term. Van Schagen (1986) showed that ant species richness was positively correlated with temperature and negatively with rainfall.

From the results it is clear that one should sample throughout the year to investigate seasonal changes in the diversity of the ant community, but the peak time for doing ant surveys, is in late summer and early autumn, for this is the time when ant species were most active and abundant. It is also the time of the year when prey items, food, nectar and seed are readily available for particular ant species. Read (1996) and Keals & Majer (1991) stated that monitoring in the hot, summer months is the best time for doing ant surveys, when both the range of species and the number of ants are maximized. Winter surveys should however be performed to obtain winter-active species (Keals & Majer 1991).

CHAPTER 5

CONCLUSION

5.1 Indicative value of ants at Hendrina Power Station.

The study at Hendrina Power Station showed that, not only are plants important when rehabilitation success is being investigated, but that ants are also an integral part of the ecosystem on the ash dams, which describe the state and condition of a habitat during succession and therefore have to be considered as parameters of rehabilitation success. Not only are these type of studies important for biologists, but could also provide strategies for industries like Eskom to improve their rehabilitation. The ant community concept at Hendrina Power Station has proved useful in considering the ways in which ant communities interact with one another and with their environment. Not only do the components of ant community structure, such as species diversity and species composition, react considerably to disturbance and were indicative of different successional stages, but ants also fulfilled a number of essential processes on the ash dams and were indicative of various macro-environmental, vegetation and soil factors.

Ants can be used as indicators of rehabilitation success on ash dams at Hendrina Power Station for the following reasons:

- **They were abundant.**

  Ants were abundant in the pitfall traps on both the ash dams and in the natural grassland, making them a sufficient group of animals to work with, when the rehabilitation of disturbed industrialized sites are being investigated. Some ant species such as *Anoplolepis custodiens*, *Monomorium albopilosum*, *Lepisiota capensis* and *Lepisiota laevis* were highly abundant in the pitfall traps on the ash dams and in the natural grassland.

- **They were easily sampled and sorted.**

  Ants are practical to use and were sampled, sorted and identified with relative ease, without using expensive and specialized techniques or equipment. Pitfall trapping was a cheap and efficient method of sampling surface-active ant species at Hendrina Power Station, due to the open conditions found on the ash dams. However, with additional sampling methods and little more expenditures a more complete census of the ant community at Hendrina Power Station was obtained.

- **They reacted differently and quickly to disturbance.**

  Ant communities on ash dams and in the natural grassland were sensitive to ecological change. Ecological succession on the ash dams was characterized mainly by a progressive increase in the diversity of the ant community, accompanied by a sustained increase in the abundance of ant species, reflecting a high abundance first by pioneer ant species, such as *Cardiocondyla shuckardi* and then later on by generalized ant species, such as *Anoplolepis custodiens* and more specialized ant species, such as *Camponotus* spp. etc.

- **They are indicative of different successional stages.**

  Three stages of succession were discernible on the ash dams and in the natural grassland. Differences in the rehabilitation history and age of various ash dam grids were primarily responsible for the variation in plant species present and therefore resources available to ants. Ant recolonization was rapid up to the third year since the initiation of rehabilitation was reached, due to the immediate colonization of pioneer ant species. Ant recolonization (ant species diversity) increased up to the ninth year since the initiation of rehabilitation, but at lower rates than in the pioneer stage of succession. This study at Hendrina Power Station therefore demonstrated that the return of ant species to an area is rapid during the early stages of succession, but declined thereafter.

  In the early stages of succession ant species, such as *C. shuckardi*, *M.*

albopilosum, *Pheidole* sp.4 etc. seemed to be indicative of pioneer and harsh conditions on the ash dams, such as a low plant diversity, the presence of pioneer plant species, such as *Tagetes minuta* and *Cyperus esculentus*, a low vegetation cover and a loose substrate with a high gravel content and less organic matter. These ant species could therefore be regarded as indicators of recently and poor managed areas. The unrehabilitated and recently rehabilitated ash dam grids is therefore simpler in its architecture and supports a correspondingly less varied ant fauna, than the older rehabilitated ash dam grids and the natural grassland. In the second stage of succession, pioneer ant species were soon replaced by generalized and specialized ant species better adapted for conditions in older rehabilitation. This stage of succession reflected habitat development from pioneer conditions to older and favourable conditions for ants, such as the presence of stable plant communities (*Hyparrhenia hirta* and *Eragrostis curvula*), a well-developed litter layer, higher vegetation cover, diverse plant community and soils with a high sand and organic matter content. Ant species, such as *A. custodiens*, *S. punctaticeps* and various *Tetramorium* species seemed to be indicative of these conditions. These ant species can therefore be regarded as indicators of stable and well managed areas. Conditions present in older rehabilitated ash dam grids also seemed to promote ant species diversity and similarly the return (resilience) of ant species to the ash dams. The natural grassland which represented the last and most advanced stage of succession is characterized by a high floristic diversity, high crown cover, high vegetation cover, dense litter layer and the soil was heavy and rocky, therefore more suitable for specialized ant species such as *Leptogenys intermedia*, *Cerapachys* sp.1, *Plectroctena mandibularis*, *Crematogaster* sp.2, *Camponotus transvaalensis* and *Camponotus* sp.2 & 4.

It is evident that the presence or absence of an ant species during different stages of succession resulted from the degree of pre-adaption of these species to prevailing conditions. The above mentioned ant species will not necessarily be dominant in the different areas. The correlation between ants and various environmental variables at Hendrina Power Station also gave valuable insight into the factors influencing the ability of various ant species to colonize rehabilitated areas. On rehabilitated ash dams at Hendrina Power Station only ant species richness was significantly correlated with various habitat characteristics, suggesting that ant species richness is the most important parameter of the diversity of the ant community when rehabilitation success is being investigated. Ant recolonization, measured by ant species richness seemed to be enhanced by plant species diversity, percentage vegetation cover and sand content of the substrate, whereas silt content seemed to have a negative influence on the species richness and recolonization rates of ants.

The dissimilarities in the composition and diversity in the ant community on the ash dam grids and in the natural grassland suggest that ant communities are influenced negatively by local industrial activities. For the rehabilitation process to be successful, the resulting ecosystem must strongly resemble the structure and composition of the so-called natural ecosystem, and must be sustainable and resilient enough to survive short-term unfavourable environmental conditions, such as droughts and fire. Results showed that although the ash dams had met the demands of diverse ant community and that there were some similarities between the ash dams and the natural grassland regarding the structure of the ant community, the ash dams failed to meet the demands of specialized ant species, even in the oldest rehabilitated ash dam grids, where these ant species were still under-represented, showing that complete restoration of the original natural grassland and the stability in the ant community on the ash dams had not yet been reached, although ant species diversity levelled off, when the ash dams became older. This study has demonstrated that full ecosystem recovery will take a considerable amount of time, if attainable at all.

Therefore, additional management strategies, such as the introduction of large logs and rocks need to be implemented on the ash dams, not only to enhance ecosystem resilience and minimize the impact of disturbance on the structure of the ant community, but also to regulate the micro-climate of ant species and to increase the aesthetic value of the ash dams. The aim of Eskom's rehabilitation programme should therefore be to increase the habitat and structural diversity on the ash dams. A resurvey of older rehabilitated areas in a few years from now would provide information on how successful rehabilitation was.

On ash dams and in the natural grassland different resources became available and abundant in different seasons of the year and had met the demands of both winter and summer, autumn and spring active ant species, showing the high temporal diversity in resources on ash dams. Different seasonal activity of ants illustrate not only the temporal and seasonal variation in resource availability, but also resource diversity. Winter active ant species are important, due to the fact it creates temporal diversity on ash dams and in the natural grassland, and also confirms the importance of functional diversity in resources in ecosystems.

From a managerial point of view climate is not a crucial element when rehabilitation is investigated but gives valuable results on the seasonal activity of particular ant species, to determine the time at which particular ant species are active, and also to determine which time of the year is most appropriate for doing ant surveys. This study has demonstrated that summer and autumn is the best time for doing ant surveys. There is however no reason to assume that the results of this study are definitive and more studies are needed in this regard.

5.2 Further predictions and improvement of the study.

Given the lack of functional information regarding the role of ants in ecological succession there is a need for further research in other industrialized parts of South Africa. This particular study was also only conducted in a small part of South Africa's industrialized environment and has to be expanded to other parts of the country, not only on ash dams, but also in other disturbed environments. Such research will not only support current scientific knowledge, but could also provide valuable insight into more effective rehabilitation strategies. Future studies would also give some further insight regarding the resilience of the ash dams at Hendrina Power Station.

Ant surveys on ash dams and in other studies could be improved by the following:

- More replicated grids need to be established in different survey areas, in order to cope with the patchy distribution of species. Available literature also illustrates the importance of replicating various treatments and these replications should sample variables, such as rehabilitation age, aspect, topography, adjoining area, habitat and structural variables. This has to be done in order to sufficiently compare different survey areas with each other, in terms of ant community structure and to limit variation in the data.

- Survey areas also had to be established in areas adjacent to the disturbed environment, in order to determine the possible effect of adjoining areas on the structure of the ant community in disturbed industrialized areas, since Majer (1990) found that potential colonizing ant species must came from the surrounding environment, in which the disturbed area is located.

- The study period has to be extended, in order to gain sufficient data on the change in the structure of the ant community over time.

- At least one survey in the summer and one in the winter have to be conducted in each year of sampling. Surveys should be repeated in the middle of each season and due to the high activity of ants during the warmer parts of the year, it is advisable to do more sampling during these periods.

- Pitfall trapping was effective in this particular study, due to the fact that (1) all survey areas were sampled simultaneously, (2) representative ant species of every survey area were recorded, (3) many specialized and uncommon ant species were caught by means of pitfall traps, (4) it provides quantitative data on the relative abundance of ant species and (5) it provides direct quantitative results suitable for multivariate analysis. Sweepnetting was effective in sampling ant species, associated with vegetation which provided valuable additional data on the relative abundance of ant species on ash dams. However, other survey techniques are needed to catch scarcer, cryptic and nocturnal ant species e.g. day and nighttime hand collections, soil sampling, litter sampling and nest excavations. Cryptic ant species can be sampled by litter extractions. Pitfall trapping, together with hand collecting, litter sampling and nest excavations will provide a complete census of the ant community.

- Additional soil data such as soil moisture content, soil temperature etc. has to be measured in future studies when ecological disturbance is being investigated.

- Seed removal and distribution by ants has to be monitored in future studies.

- More time is needed for identification and classification of ant species. It is necessary to work at the species level when the role of invertebrates in restoration ecology are assessed but due to the great diversity of ants and limited information on their biology, it is quite difficult to interpret the response of ants to disturbance at the species level. These problems could be circumvented by dividing ant species into functional groups, which have distinctive morphologies, habits and distributions. South African ant species could also be divided into functional groups, according to their role, competitive interactions and habitat requirements in South African ecosystems, but more studies are needed in this regard.

- Lastly, Information is needed on the distribution, social biology and role of various ant species in disturbed industrialized ecosystems within South Africa.

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*original not seen

APPENDIX 1

The list below includes the abbreviations used for the survey grids, ant and plant species used in Section 3.2.3.1-3.2.3.3; Section 3.2.4 & Section 3.2.5.

SURVEY GRIDS	
Abbreviation	**Survey grid**
G1	Grid 1
G2	Grid 2
G3	Grid 3
G4	Grid 4
G7	Grid 7
G8	Grid 8
G9	Grid 9
G10	Grid 10
G11	Grid 11
G12	Grid 12

ANT SPECIES	
Abbreviation	**Species name**
Anop cus	*Anoplolepis custodiens*
Camp ves	*Camponotus vestitus*
Card shu	*Cardiocondyla shuckardi*
Crem sp1	*Crematogaster* sp.1
Hypo sp1	*Hypoponera* sp.1
Hypo sp2	*Hypoponera* sp.2
Lepi cap	*Lepisiota capensis*
Lepi lae	*Lepisiota laevis*
Mono alb	*Monomorium albopilosum*

Mono sp1	*Monomorium* sp.1
Mono sp2	*Monomorium* sp.2
Phei sp1	*Pheidole* sp.1
Phei sp4	*Pheidole* sp.4
Sole pun	*Solenopsis punctaticeps*
Tech alb	*Technomyrmex albipes*
Tetr fri	*Tetramorium frigidum*
Tetr ser	*Tetramorium sericeiventre*
Tetr stg	*Tetramorium setigerum*
Tetr stu	*Tetramorium setuliferum*
Tetr vex	*Tetramorium vexator*
Tetr sp1	*Tetramorium* sp.1
Tetr A01	*Tetramorium* sp.A01
Tetr A05	*Tetramorium* sp.A05

PLANT SPECIES

Abbreviation	**Species name**
Agro lac	*Agrostis lachnantha*
Amar hyb	*Amaranthus hybridus*
Aris con	*Aristida congesta*
Bare grd	Bare ground
Bide for	*Bidens formosa*
Bide bip	*Bidens bipinnata*
Cala spp	*Calamagrostis* sp.
Cham bie	*Chamaecrista biensis*
Chen alb	*Chenopodium album*
Chlo gay	*Chloris gayana*
Cirs vul	*Cirsium vulgare*
Comm ben	*Commelina benghalensis*
Cony bon	*Conyza bonariensis*
Cyno dac	*Cynodon dactylon*

Cype esc	*Cyperus esculentus*
Cype usi	*Cyperus usitatus*
Digi eri	*Digitaria eriantha*
Enne cen	*Enneapogon cenchroides*
Erag chl	*Eragrostis chloromelas*
Erag cur	*Eragrostis curvula*
Erag ech	*Eragrostis echinochloidea*
Erag pla	*Eragrostis plana*
Erag tef	*Eragrostis tef*
Erag tri	*Eragrostis trichophora*
Hete con	*Heteropogon contortus*
Hypa hir	*Hyparrhenia hirta*
Hypa tam	*Hyparrhenia tamba*
Impe cyl	*Imperata cylindrica*
Lesp cun	*Lespedeza cuneata*
Oxal spp	*Oxalis* sp.
Penn cla	*Pennisetum clandestinum*
Pseu lut	*Pseudognaphalium luteo-album*
Schk pin	*Schkuhria pinnata*
Sonc ole	*Sonchus oleraceus*
Styl fru	*Stylosanthes fruticosa*
Tage min	*Tagetes minuta*
Verb bon	*Verbena bonariensis*