

**THE POTENTIAL USE OF COLEOPTERA AS BIO-INDICATOR OF
ECOLOGICAL CHANGES ON REHABILITATED ASH DAMS AT
THE HENDRINA POWER STATION IN MPUMALANGA**

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ABSTRACT

This study was conducted on the ash dams of the Hendrina Power Station in Mpumalanga, South Africa and gives an evaluation of the insect order Coleoptera as possible indicators of environmental change associated with rehabilitated ash dams. The study deals with the possibility of using certain Coleoptera species as indicators of environmental changes as well as changes in the composition and diversity of Coleoptera assemblages. A two year sampling period was undertaken during which insects were collected by means of pitfall traps and sweepnets both on ash dams and in natural veld. A total of 191 Coleoptera morphospecies were caught of which 67 were found in natural veld and 175 on the ash dams. From the 191 species 126 morphospecies were only found on ash dams and 19 were only found in natural veld.

The coleopteran families Anthicidae, Chrysomelidae and Tenebrionidae were most abundant on the ash dams while Tenebrionidae, Chrysomelidae and Curculionidae were most abundant in natural veld. Species diversity, equitability and species richness were higher for rehabilitated than for unrehabilitated ash dams and natural veld. The latter is because insects with lower abundance is less trappable in pitfall traps. Because predatory insects are opportunistic, mobile and good hunters they tend to quickly colonise unrehabilitated and newly rehabilitated ash dams to exploit the few prey insects which already colonised these areas. As the areas became more stable (at the older rehabilitated ash dams) the numbers of predators decreased. This tendency was also clear in the succession of individuals of the families Carabidae and Anthicidae. As soon as the area became more stable (stable plant communities occurred with a high organic matter content) the numbers of these families decreased and numbers of

other functional groups such as phytophagous insects increased.

Statistical significant positive correlation was found between Coleoptera species diversity and -richness with the percentage organic matter in the soil. Species richness was negatively correlated with soil pH and percentage clay.

The study therefore proved that certain beetle assemblages, especially those of the families Carabidae and Anthicidae, could be considered as indicators of disturbance. The abundance of individuals in these families tends to increase with an increase in disturbance. Abundance of the predatory beetles generally tend to increase with an increase in disturbance.

OPSOMMING

Die studie is op asdamme van die Hendrina Kragstasie in Mpumalanga, Suid-Afrika uitgevoer en gee 'n evaluasie van die insekorde Coleoptera as moontlike indikatore van omgewingsveranderinge geassosieer met gerehabiliteerde asdamme. Die studie behandel die moontlike gebruik van seker Coleoptera spesies as indikatore van omgewingsveranderinge asook veranderinge in die samestelling en diversiteit van Coleoptera versamelings. Gedurende 'n tweejaar lange opname periode is insekte met beide putvalle en sweepnette versamel op asdamme en in aangrensende natuurlike veld. 'n Totaal van 191 Coleoptera morfospesies is versamel waarvan 67 in die natuurlike veld versamel is en 175 op die asdamme. Van die 191 spesies het 126 spesies slegs op asdamme voorgekom en 19 slegs in natuurlike veld.

Die kewerfamilies Anthicidae, Chrysomelidae en Tenebrionidae is die volopste op asdamme en Tenebrionidae, Chrysomelidae en Curculionidae in die natuurlike veld. Spesiediversiteit, gelykheid en spesierykheid was hoër op gerehabiliteerde asdamme as op nie gerehabiliteerde asdamme en in natuurlike veld. Laasgenoemde kan toegeskryf word aan die feit dat insekte wat minder volop is nie so maklik in valle gevang kan word nie. Omdat predatoriese insekte opportunisties, mobiel en goeie jagters is koloniseer hulle ongerehabiliteerde en nuut gerehabiliteerde asdamme vinnig om sodoende die prooi reeds teenwoordig te benut. Sodra 'n gebied meer stabiel word (ouer gerehabiliteerde damme) verlaag die predatorgetalle. Hierdie tendens was ook duidelik merkbaar in die suksessie van individue van die families Carabidae en Anthicidae. Sodra 'n area meer stabiel is (stabiele plantgemeenskappe met hoë organiese grondinhoud) sal

die aantal individue van hierdie families afneem en die aantal individue van ander funksionele groepe soos fitofage insekte verhoog.

Betekenisvolle positiewe korrelasie is tussen Coleoptera spesiediversiteit en -rykheid met persentasie organiese materiaal in die grond gevind. Spesierykheid toon negatiewe korrelasie met grond pH en persentasie klei.

Hierdie studie het bewys dat sekere kewerversamelings, veral die van die families Carabidae en Anthicidae, moontlike indikatore van versteuring kan wees. Die veelhede van individue van hierdie families verlaag met 'n verhoging in versteuring, wat 'n algemene tendens van predatoriese kewers is.

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CHAPTER 1: INTRODUCTION

"...He treats his mother, the earth, and his brother, the sky, as things to be bought, plundered, sold like sheep or bright beads. His appetite will devour the earth and leave behind only a desert...The earth does not belong to man; man belongs to the earth. This we know: All things are connected like the blood, which unites one family... Whatever befalls the earth, befalls the sons of the earth. Man did not weave the web of life; he is merely a strand in it. Whatever he does to the web, he does to himself..." (Chief Seattle 1854)

In recent years we have come to realize that the world is becoming more crowded, polluted and less ecological stable by the day. We are experiencing a population increase like never before which consequently influences the rates at which we are using resources and modifying natural systems (Fuggle 1992). Waste dumps, tailing dams and ash dams throughout the world are evidence of mining and coal combustion activities. These sites are soon subjected to erosion and leaching which could spread further than just the boundaries of the disposal site (Piha 1995).

A low spatial complexity and the absence of biodiversity characterize degraded land (Majer 1990). This could be the result from a harsh microclimate, including the toxicity of the substrate. The presence of metal ions at toxic levels and salinity, causing unfavorable osmotic effects and extreme levels of acidity or alkalinity are especially problematic (Wei-Chun Ma 1989). The combustion of coal for generating electricity for example produces large amounts of pulverized fly ash (PFA), which has a pH of 8-9 when mixed with water and pumped into a lagoon. The boron toxicity of PFA affects plant growth on the lagoons (Bradshaw & Chadwick 1980). Other factors impeding plant growth on the lagoons includes the formation of impermeable layers of fly ash, which impede drainage and reduce root development (Townsend &

Hodgson 1973), as well as low nitrogen content, impeding plant growth (Townsend & Gillham 1975).

Rehabilitating it to a proper condition can increase the aesthetic and economical value of degraded land. Barnhisel and Hower (1997) states two reasons for rehabilitation: to re-establish a stable landscape and a diversity of native plants (Doll 1988). An ecological system is stable when it has the tendency to return to an equilibrium state following disturbance (Dodd, Silvertown, McConway, Potts & Crawley 1994).

Throughout the world people are taking action against degradation of the environment and policy statements are being issued by governments (Fuggle 1992). The importance of rehabilitation of degraded areas in South Africa is growing and forms a major component of environmental planning and protection. South Africa's mining legislation requires dumps to be rehabilitated (Barnard 1995). The Minerals Act 50 of 1991, Section 40 states that used surfaces should be restored to its natural state. The best way to achieve this is to revegetate the area with appropriate plants for a particular waste and to aim for a self-sustainability (Wells, Meurs & Rabie, 1992).

1.1 IMPORTANCE OF FAUNA IN REHABILITATION

1.1.1 Animals in general

According to Majer (1990) animals are usually considered secondary to plants (if at all) in rehabilitation surveys. Dourojeanni (1990) and di Castri, Vernhes & Younés (1992) also remarked that little attention has been given to the inventory and monitoring of terrestrial arthropods. However fauna plays a very important role in the rehabilitation of exploited lands (Majer 1989a). As a rehabilitated site matures and the percentage of bare ground is reduced, the

microclimate will be buffered and the plant species richness will increase. As a result there will be an increase in litter as well as dead wood and logs (Majer 1990). This will favour colonisation by animals, which in turn could contribute to increasing the aesthetic and economic value of previously disturbed land (Majer 1989a). The diversity and abundance of arthropods can provide useful information regarding planning and management of protected areas (Cassola & Pearson 2000).

Majer (1989b) found positive correlations between animal diversity and richness with plant cover, richness and diversity as well as structural diversity. Animals, especially earthworms, termites and beetles, improve the aeration, drainage and root penetration through their burrowing activities. They also increase the availability of nutrients to plants by bringing soil from lower strata to the surface (Hutson 1989). Recycling of nutrients by animals from leaf litter to the soil, contribute to long term sustainability of the degraded soil, which is usually depleted of nutrients. Bacteria and fungi as well as earthworms, termites and springtails are essential in long term sustainability (Hutson 1989). Ants could contribute to seed dispersal. Fauna can also act as vectors of useful fungi, which could enhance nutrition of plants. They can act as pollinators of various plants as well. Predators and parasitoids can in turn effect plant growth by reducing the herbivore populations. Unfortunately animals don't always have a positive effect on plant productivity. They can reduce growth and seed production while increase mortality. However, most perennial grasses have high tolerance for herbivores, especially on aboveground biomass (Urbanek 1989).

1.1.2 Insects as bio-indicators

Insects are suitable indicators of landscape changes because of their abundance, species richness, ubiquitous occurrence and their importance in the functioning of natural ecosystems (Samways 1994). Kremen, Colwell, Erwin, Murphy,

Noss & Sanjayan (1993) argued that monitoring terrestrial arthropod indicators can provide warnings of ecological changes, they can be surveyed easier and more cost effective than vertebrates and large numbers of individuals can be collected over a short period of time.

McGeoch (1998) proposed three categories of terrestrial insect indicators, which corresponds to differences in application, namely environmental, ecological and biodiversity indicators. **Environmental indicators** are species or groups of species responding predictably, in ways that are readily observed and quantified, to environmental disturbance or to a change in environmental state. Environmental indicators can be used to detect changes in environmental state and to monitor these changes. **Ecological indicators** are species sensitive to habitat fragmentation, pollution, or other stresses that degrade biodiversity (Meffe & Carrol 1994). These indicators are thus “characteristic taxons or assemblages that is sensitive to environmental stress factors, that demonstrates the effect of these stress factors on biota, and whose response is representative of the response of at least a subset of other taxa present in the habitat” (McGeoch 1998). Ecological indicators demonstrate the impact of stressors on biota and can be used to monitor longer-term stressor-induced changes in biota. **Biodiversity indicators** are defined as “a group of taxa (e.g. genus, tribe, family or order, or a selected group of species from a range of higher taxa), or functional group, the diversity of which reflects some measure of the diversity (e.g. character richness, species richness, level of endemism) of other higher taxa in a habitat or set of habitats” (Gaston 1996). This type of indicator can be used in identifying diversity of taxa in specific areas and to monitor changes I biodiversity. A **biological indicator** would therefor be defined as “a species or group of species that readily reflects the abiotic or biotic state of an environment: represents the impact of environmental change on a habitat, community or ecosystem; or is indicative of the diversity of a subset of taxa, or of wholesale diversity, within an area” (McGeoch 1998).

McGeoch (1998) also suggested criteria for the selection of bio-indicators. Because Coleoptera will be evaluated as potential indicator of environmental changes it will be evaluated as an environmental indicator. The following criteria for evaluation of Coleoptera as possible bio-indicator will be used:

1. Cost efficient and effective (Noss 1990)
2. Ease of sampling and sorting (Hellawell 1986)
3. Adequate representation in samples (Hellawell 1986)
4. Abundance (Jenkins 1971)
5. Ease and reliability of storage (Hammond 1994)
6. Should taxonomically be a well-known group, readily identified and taxonomic expertise should be readily available (Stork 1994)
7. Sampled individuals should be expendable (New 1995)
8. Spatial and temporal distribution should be predictable to ensure long-term continuity (Holloway & Stork 1991)
9. Baseline data on biology should be available (New 1995)
10. There should be low genetic and functional variability (Hellawell 1986)
11. The indicator should be sufficiently sensitive to provide early warning (Noss 1990)
12. One should be able to differentiate between natural cycles and trends and those produced by anthropogenic stress factors (Noss 1990)
13. It should be representative of critical components, functions and processes (New 1995)
14. It should replace or be replaced by other species (Jenkins 1971)
15. It should be capable of providing continuous assessment over a wide range of stress (Noss 1990)

1.1.3 The role of Coleoptera as bio-indicators of ecological change

It is impossible to use total biota in assessing the impact of human activities on the environment (Niemelä 2000) because the taxonomic impediment and high species richness interfere with the adequate sampling of the entire fauna

(Kremen *et al.* 1993, Samways 1994). It is therefore useful to use indicator assemblages which are “suites of species that respond readily to environmental change in ways that are easily measured or observed” (Kremen *et al.* 1993).

Taxonomic indicator groups can be used as bio indicators to identify changes in a landscape (Samways 1994). Beetles (especially carabids) were found to be good indicators of environmental change because:

- they are speciose, varied and abundant;
- they can be easily collected with pitfall traps;
- they have fossil records showing them to respond to environmental changes;
- they are well-known indicators of ecological change; and
- they have been used in signalling environmental change (Niemelä 2000).

Numerous studies have been done on the role of Coleoptera (especially Carabidae) in ecosystems (Parmenter & MacMahon 1987, Niemelä 1990, Niemelä 2000). The assemblages of ground beetles are influenced by changes in physical and biotic environments due to rehabilitation (Luff & Woiwod 1995). Ground beetles show strict relations with environmental conditions and are therefore used as indicators of ecosystem stability (Allegro & Sciaky 2002). Neumann (1973) found that density of ground beetles (Carabidae), which were the pioneer colonisers of coal spoil banks, decreased over the ten years following rehabilitation. This parameter could be a good indication of the rate of rehabilitation of the area. Carabidae are evidently good bio-indicators and respond to environmental factors such as soil structure, microclimate, vegetation structure and species composition (Luff *et al.* 1995).

Unfortunately only restricted indicator-related interpretations can be made if a single taxon or assemblage is used. It would be more valuable to demonstrate the representativeness of beetles of other taxa (Noss 1990, McGeogh 1998), but

it is rather time consuming and the urgency of taking conservation measures may demand that decisions be made on the basis of single taxon studies (McGeogh 1998).

The potential value of the ways in which animals reflect different aspects of environmental change will however never be realised if they are not recognised and adopted by conservation management agencies (Mc Geoch 1998).

1.2 THE NEED FOR FURTHER FAUNAL STUDIES IN REHABILITATED AREAS IN SOUTH AFRICA

Environmental changes caused by man are as significant in the Southern Hemisphere as in the North but because the biodiversity per unit area is much richer, the South has a great responsibility with regards to conservation. It is therefore important to monitor changes in population levels of insects in response to environmental changes (Samways 1995). Of all the work on rehabilitation, presented as papers, reports and conference proceedings, on average only 6.3% make some reference to wildlife (Majer 1989a). This emphasises the need to carry out faunal studies in South Africa on the role of animals in rehabilitated land.

1.3 THE GOAL OF THIS STUDY

McGeogh (1998) identified procedural steps in bio-indicator studies involving terrestrial insects as follows:

- 1. Determine the broad objective:** Determine the type of indicator (Environmental, Ecological or Biodiversity). In this study Coleoptera will be used as environmental indicator.

2. **Refine objectives and clarify endpoints:** In this study the potential use of Coleoptera to detect and identify the nature of environmental changes will be evaluated (environmental indicator).
3. **Select potential indicator based on accepted *a priori* suitability criteria:** Criteria set by Niemelä (2000) for the use of Carabidae as bio-indicators of environmental changes were used to evaluate the whole order Coleoptera as possible bio-indicator.
4. **Accumulate data on the indicator:** The response of the indicator to the disturbance (environmental state) will be determined.
5. **Collect quantitative data:** Different altered habitat parameters for example soil pH, soil organic matter content and soil structure will be measured.
6. **Establish statistically the relationship between the indicator and the relational data:** The relationship between the disturbance (environmental state) and the composition, structure or function of the indicator will be established
7. **Accept or reject the species, higher level taxon or assemblage as an indicator**
8. **Establish the robustness of the indicator by developing and testing the hypotheses under different conditions**
9. **If the null hypotheses are rejected make specific recommendations for the use of the indicator**

As mentioned earlier, other insect groups, apart from Carabidae, could be used as indicators of ecological changes (Luff 1995). This study gives an evaluation of the insect order Coleoptera (and not only Carabidae) as possible indicators of environmental changes associated with rehabilitated PFA lagoons (ash dams) at the Hendrina Power Station in Mpumalanga, South Africa.

According to Kremen *et al* (1993) indicator assemblages of arthropods might be examined by monitoring the relative abundance of all members of a taxonomic group or by monitoring functional groups. This study on the

Hendrina ash dams has used both these methods. Not only were the assemblages of the whole Coleoptera order considered, but functional groups were considered as well. The aim of the study was to (1) evaluate Coleoptera communities using relative abundance, species diversity, species equitability and species richness to indicate changes in assemblage structures over time; (2) assess the relationship between the insects and plant variables such as plant diversity, plant species equitability, plant species richness, percentage vegetation cover; (3) investigate the influence of soil variables, such as soil structure, soil pH, electrical conductivity, and percentage organic matter on the distribution of Coleoptera species.

He is the God of man... This earth is precious to Him, and to harm the earth is to heap contempt on its Creator... ” (Chief Seattle 1854)

CHAPTER 2: MATERIAL AND METHODS

2.1 STUDY AREA

2.1.1 Location

The study was conducted between March 1997 and May 1999 at the Hendrina Power Station (26°03'00"S, 29°36'40"E) in Mpumalanga, South Africa. The site consists of a series of four coal ash disposal sites (Fig. 2.1). Ash dam 1 was situated nearest to the power station while ash dam 2 was situated to the south of ash dam 1 and ash dam 3 to the south of ash dam 2.

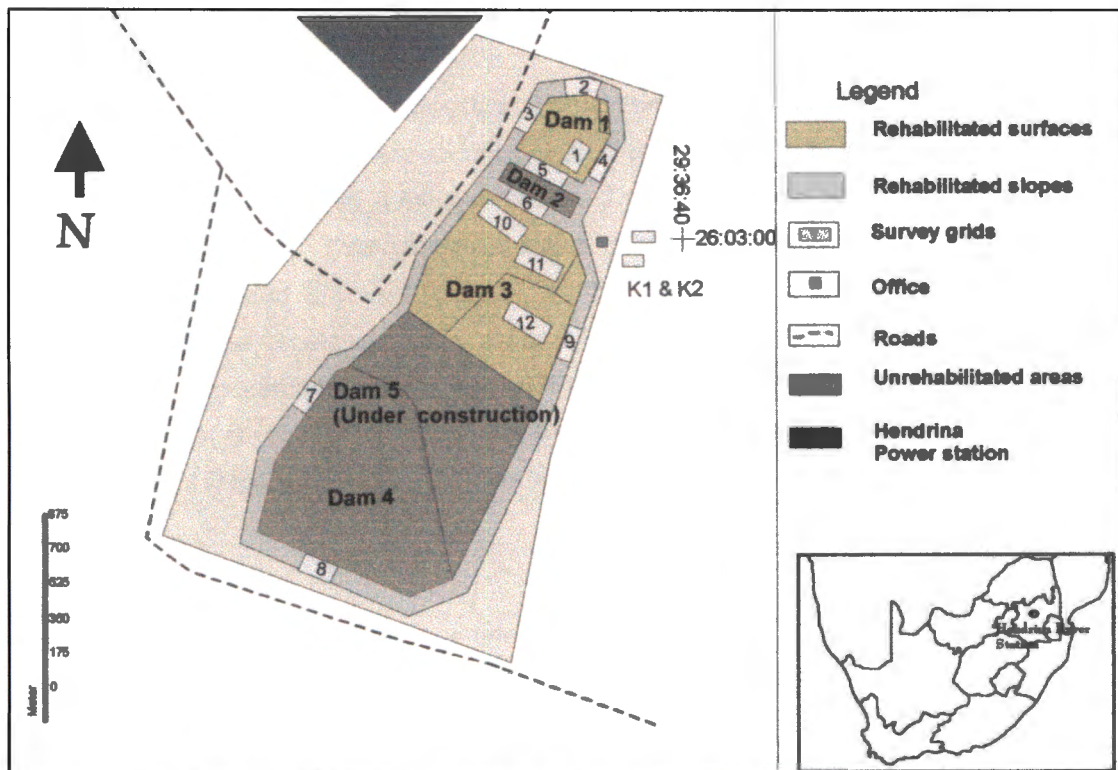


Figure 2.1: A map of the ash disposal site indicating the location of the ash dams. The position of the twelve survey grids (1 to 12) and the control grids (K1, K2) are indicated (from Morgenthal 2000).

The stockpiles of ash dam 2 collapsed and construction was not completed at the time the study started. Ash dam 4 was situated separately from the other three ash dams and was still under construction at the beginning of the study. Construction of a fifth ash dam (E) started late in 1997 and was situated between ash dams C and D (Fig. 2.1). For these reasons only ash dam 1, B and C were used in the study.

The disposal sites are surrounded by land with a number of uses. The northern boundary of the site is bordered by the power station. A railway line and coal loading station form the north-western border. Maize fields form the border on the south western, southern and parts of the eastern side of the ash disposal areas. The north-eastern border of the disposal areas consists of rehabilitated open cast coal mines and severe disturbed and rehabilitated areas due to these mining activities. Natural veld occurred on the eastern parts of the disposal sites.

2.1.2 Rehabilitation history

Ash dams A and C have been rehabilitated to grasslands, but small areas of *Acacia mearnsii* woodland have developed over the years. Dense stands of *Arundo donax* and *Pennisetum clandestinum* occur at ash dam 2 and form part of a semi-wetland.

In the early 1980's the first revegetation started and a *Cortaderia*-species as well as a *Pennisetum clandestinum* were planted (Treatment A, Table 2.1). More rehabilitation work was done in 1990, 1992 and 1996. Seed mixtures sown are given in Table 2.1 where treatment B was used on parts of ash dam 3 in 1990 and treatment C on parts of ash dam 1 in 1992. Ash was covered with a topsoil layer of 10 cm and fertiliser was added before grass was planted. 250kg ha⁻¹ superphosphate (containing 10.5% phosphorus) and 200kg ha⁻¹ 4:3:4:

(30), containing zinc, were used as fertiliser during treatments B, C and D. 150 kg ha⁻¹ LAN were added as well.

Most of the slopes of ash dams A and C were rehabilitated during 1992 and 1994. Treatment C, Table 2.1, was used. *Pennisetum clandestinum* and *Cynodon dactylon* were planted in 450 mm wide strips, 4 m apart to control erosion and stabilise the slopes.

The middle slope of ash dam 4 was revegetated during 1996/1997 (Treatment D, Table 2.1) in a way similar to the 1992 rehabilitation treatment.

2.2 SURVEY SITE SELECTION

Twelve survey grids (Grid 1-12) of standard configuration and layout (Figure 2.2) were established on the Hendrina ash disposal site (Figure 2.1). These grids were established on ash dams 1, 2, 3 and 4. Grids 1,10,11 and 12 were established on plateaux while grids 2,3,4,7,8 and 9 were established on slopes (Fig. 2.1). The grids were established in relative homogenous areas (to reduce background noise).

Two control grids (C1 and C2) were established in bordering grasslands. Although it is impossible to rehabilitate ash dams to the same levels of diversity and complexity as unrehabilitated sites, baseline data is needed of assemblage structure and temporal variability thereof, in order to interpret patterns observed on rehabilitated ash dams.

Grid five and six were only observed once during the initial survey but were omitted from the study because the standard configuration of grid layout could not be fitted on these grids. The rest of the grids, including the control grids were surveyed bi-monthly. The surveys are outlined below.

Table 2.1 Rehabilitation treatments applied on the ash dams at Hendrina PowerStation.

	TREATMENT A: early 1980's	TREATMENT B: 1990-1991	Kg ha⁻¹	TREATMENT C: 1992-1994	Kg ha⁻¹	TREATMENT D: 1996-1997	Kg ha⁻¹
SPECIES	<i>Pennisetum clandestinum</i> sods	<i>Cenchrus ciliaris</i>	2	<i>Chloris gayana</i>	2	<i>Chloris gayana</i>	2
	<i>Cortaderia</i> sp. Young plants	<i>Chloris gayana</i>	1	<i>Chloris virgata</i>	1	<i>Eragrostis teff</i>	3
		<i>Chloris virgata</i>	1	<i>Cynodon dactylon</i>	2	<i>Eragrostis curvula</i>	3
		<i>Cynodon dactylon</i>	1	<i>Digitaria eriantha</i>	2	<i>Eragrostis lehmanniana</i>	2
		<i>Digitaria eriantha</i>	2	<i>Enneapogon cenchroides</i>	2	<i>Enneapogon cenchroides</i>	2
		<i>Enneapogon cenchroides</i>	2	<i>Eragrostis chloromelas</i>	1	<i>Eragrostis echinocloidea</i>	1
		<i>Eragrostis chloromelas</i>	0.5	<i>Eragrostis curvula</i>	3	<i>Themeda triandra</i>	2
		<i>Eragrostis curvula</i>	2	<i>Eragrostis echinocloidea</i>	1	<i>Digitaria eriantha</i>	2
		<i>Eragrostis echinocloidea</i>	2	<i>Eragrostis lehmanniana</i>	1	<i>Cynodon dactylon</i>	1
		<i>Eragrostis lehmanniana</i>	0.5	<i>Eragrostis teff</i>	3	<i>Pogonarthria squarrosa</i>	1
		<i>Eragrostis teff</i>	2	<i>Hyparrhennia hirta</i>	1	<i>Panicum maximum</i>	1
		<i>Fingerhuthia africana</i>	2	<i>Themeda triandra</i>	1		
		<i>Heteropogon contortus</i>	0.5	<i>Pennisetum clandestinum</i> sods		<i>Pennisetum clandestinum</i> sods	
		<i>Hyparrhennia hirta</i>	2	<i>Cynodon dactylon</i> sods			
		<i>Panicum maximum</i>	1				
		<i>Themeda triandra</i>	0.5				
TOPSOIL	50mm Topsoil (1995)	10 cm		10 cm		10 cm	
FERTILISATION		Superphosphate (10.5 % P)	250	Superphosphate (10.5 % P)	250	Superphosphate (10.5 % P)	250
		4:3:4:(30) Zn	200	4:3:4:(30) Zn	200	4:3:4:(30) Zn	200
OTHER	<i>Cortaderia</i> sp. Removed 1995	LAN	150	LAN	150	LAN	150

2.3 VEGETATION CLASSIFICATION OF ASH DAM GRIDS

According to Morgental Cilliers, Kelner, Van Hamburg & Michael (1999) the vegetation of the ash dam grids were classified into three plant communities. Plant community two had two sub communities with three variants each. The vegetation classification is used in Table 2.2, which gives an outlay of the grids at the Hendrina ash dams.

2.3.1 *Brachiaria serrate-Setaria sphacelata* var. *torta* community

This community occurred in the natural veld.

2.3.2 *Eragrostis curvula* and *Cynodon dactylon* community

This community occurred at all the rehabilitation grids and had two sub communities:

2.3.2.1 *Hyparrhenia hirta* and *Eragrostis curvula* subcommunity

This sub community occurred on all grids rehabilitated before 1996 and consisted of three variants:

- Variant 2.3.2.1.1 (*Chamaecrista biensis*) which were found on top of ash dam 3;
- Variant 2.3.2.1.2 (*Lespedeza cuneata-Hyparrhenia hirta*) which occurred on most slopes rehabilitated between 1992 and 1994. This variant did however not occur on grid 7 top and middle and grid 8 top and middle; and
- Variant 2.3.2.1.3 (*Lepidium bonariense-Eragrostis trichophora*) which occurred on grid 1.

2.3.2.2 *Amaranthus hybridus-Cyperus esculentus* sub community

This sub community were found on grid 7 and 8 middle, rehabilitated in 1996.

Three variants occurred:

- Variant 2.3.2.2.1 *Portulaca oleracea-Bidens formosa*;
- Variant 2.3.2.2.2 *Panicum maximum-Digetaria eriantha*; and

- Variant 2.3.2.2.3 *Eragrostis teff-Enneapogon cenchroides*.

2.3.3 Community three is characterised by *Spergularia media*-community that occur on the unrehabilitated transects of ash dam 4 (grid 7 and 8 top).

Table 2.2 Outlay of grids at the Hendrina ash dams showing aspect, topography, rehabilitation treatment (Table 2.1), rehabilitation date and ecological status of bordering areas. Vegetation classification is also included and is explained in the text. Grid 5 and 6 are not included because the surveys at these two grids were stopped. Bordering area codes are as follows: DA = Disturbed Area, NG = Natural Grassland

GRID	ASPECT	TOPOGRAPHY	YEAR REHABILITATED	REHABILITATION TREATMENT	BORDERING AREA	VEGETATION CLASSIFICATION
1	/	Flat	1986, 1995	A	/	/
2	N	Slope	1994	C	DA	/
3	W	Slope	1994	C	DA	2.3.2.1.1
4	E	Slope	1994	C	NG	2.3.2.1.2
7 TOP	W	Slope	Unrehab.	/	DA	2.3.2.1.2
7 MIDDLE	W	Slope	1996	D	DA	2.3.2.1.2
7 BOTTOM	W	Slope	1992	C	DA	/
8 TOP	S	Slope	Unrehab.	/	DA	2.3.2.2.3
8 MIDDLE	S	Slope	1996	D	DA	2.3.2.1.2
8 BOTTOM	S	Slope	1992	C	DA	/
9	E	Slope	1992	C	NG	2.3.2.2.3
10	/	Plateau	1992	B	/	2.3.2.1.2
11	/	Plateau	1992	B	/	2.3.2.1.2
12	/	Plateau	1990	B	/	2.3.2.1.1
C1	/	Plateau	*	*	/	2.3.2.1.1
C2	/	Plateau	*	*	/	2.3.2.1.1

2.4 COLLECTION OF BEETLES

Each of the grids were divided into three transects. The three transects were 30m apart with a total length of 120m. Both pitfalls and sweepnets were used. Fig. 2.2 shows the position of pitfall traps and sweepnet surveys on each of the grids.

2.4.1 Pitfall traps

Plastic specimen jars (120mm deep, 50mm in diameter) were used as pitfall traps. Five pitfall traps per transect were used. The pitfall traps were spaced at 30m intervals (Fig. 2.2). Pitfall traps were placed in holes in the ground made with soil corers without disturbing the natural surroundings too much. Pitfall traps were quarter filled a mixture of water and ten drops of soap. Traps were activated bimonthly for 48 hours, from March 1997 to January 1999. After removal from the ground the traps were filled with 70% ethanol to act as preservative.

After pitfall traps were removed the traps were replaced with a new set of jars for the next survey.

2.4.2 Sweepnet surveys

In addition to the pitfall traps, sweepnet surveys were done. Vegetation sweeping was done between 10:00 and 14:00 with the use of a 300mm in diameter sweepnet. Five sweeps were taken between each pitfall (Fig. 2.2). After the five sweeps the contents of the sweepnet were emptied into a bottle filled with 70% ethanol after each transect was completed.

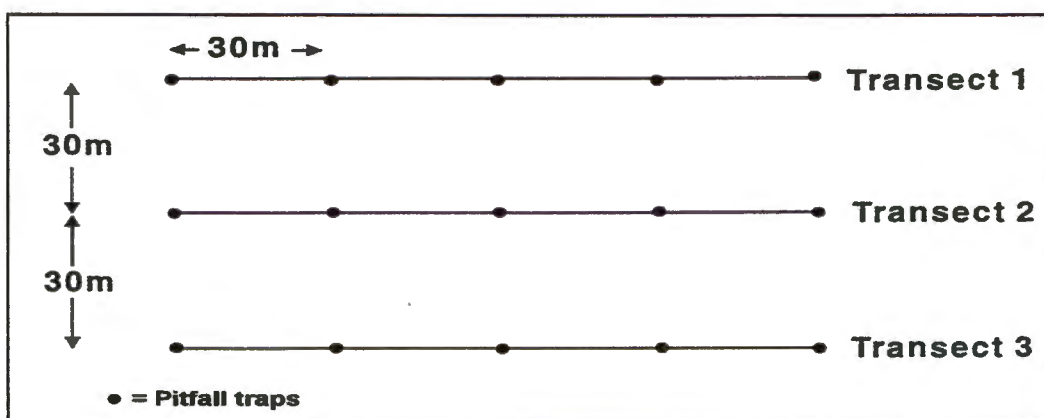


Figure 2.2 Diagram showing the position of pitfall traps and sweepnet surveys on each of the grids. Each grid was divided into three transects, 30m apart. Five pitfall traps per transect were used, spaced at 30m intervals.

2.4.3 Preservation and sorting of insects

Insects were preserved in plastic specimen jars filled with 70% ethanol. The jars were labelled according to the sampling method, the date the survey was undertaken, the grid and transect.

2.4.4 Sorting of Class Insecta, Order Coleoptera

The contents of each jar containing insects were emptied into a petri dish and sorted into the different insect orders. The insects belonging to the order Coleoptera were then sorted into morphospecies. Each morphospecies was given an accession number (e.g. ico221e) which is explained in Fig. 2.3. The accession number corresponds with the number in the accession system (the tables in which the data were documented).

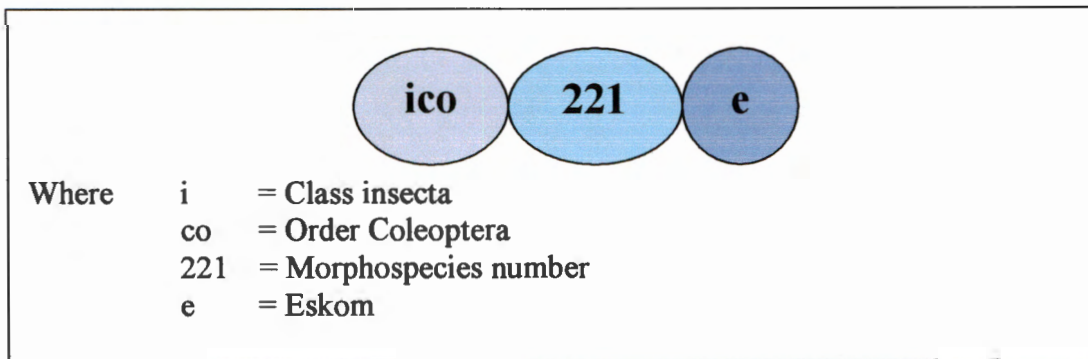


Figure 2.3 Explanation of accession numbers given to each morphospecies

Each morphospecies for each survey were kept separately in a container labelled according to the month of survey, the sampling method (sweepnet or pitfall), the grid and transect (as well as row in the case of pitfalls) and the accession number. The individuals in each container were counted and the numbers documented in tables.

At least one specimen from each morphospecies was mounted directly on pins while the smaller beetles were glued to card points or card platforms. Each insect was supplied with a label with the following information:

- The precise collecting locality, including GPS co-ordinates.
- The date of collection
- The name of the collector
- Accession number, which corresponds with the number in the spreadsheets (Oberprieler, 1996).

The morphospecies were classified to family level. Some of the species were classified to genus and some to species level of classification by R. Stals and E. Grobelaar at the Biosystematics division: Plant Protection Research Institute of the Agricultural Research Council in Pretoria¹.

The mounted specimens were stored in plastic trays lined with pinning substrate. Specimens are kept at the School of Environmental Sciences- and Development, Potchefstroom University for CHE, Potchefstroom².

2.5 SOIL ANALYSIS

Due to the importance of the soil quality in the evaluation of rehabilitation success it was imperative to do a soil analysis. Three substrate samples per grid were taken at depths of 0-10 cm and 10-20 cm. The samples were taken during July 1997 and May 1998 at each of the grids with the aid of a soil sampler. Samples were analyzed by the Research Institute for Reclamation Ecology in Potchefstroom for structure (particle size distribution) as well as macro- and microelements.

¹ Biosystematics Division, Plant Protection Research Institute, Agricultural Research Council, Private Bag X134, PRETORIA, 0001

² School of Environmental Sciences and –Development, Potchefstroom University for CHE, Private Bag X6001, POTCHEFSTROOM, 2520

2.6 VEGETATION SURVEYS

Dr. Theunis Morgenthal from the School of Environmental Sciences and – Development at the Potchefstroom University for CHE² did vegetation surveys on the Hendrina ash dams.

2.7 DATA ANALYSIS

Relative abundance values were calculated by dividing the number of individuals caught at each transect (ni) by the total number of insects caught per transect (N), multiplied by hundred.

Diversity consists of three components, namely the Shannon-Wiener diversity index, species equitability and species richness. These three components were calculated by means of the statistical software package MVSP (Multi-Variate Statistical Package)³.

Shannon-Wiener diversity index (H')

Specific diversity in a community needs a heterogeneity evaluation (distribution of individuals in different species). When all the species are equally represented in the community a maximum theoretical heterogeneity is possible (Allegro & Sciaky 2002). Shannon-Wiener diversity index was used as it emphasizes scarce species, compared to other diversity indices such as the Simpson diversity index (Sheehan 1984).

The formula for the Shannon-Wiener diversity index is:

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

³ Multivariate Statistical Package, Kovach Computing Services, 85 Nont-y-Felin Pentraeth, Isle of Anglesey, LL75 8UY, WALES, U.K.

Where S = total number of species in a sample,
 n_i = total number of individuals in the i th species in a sample
 N = total number of individuals in a sample.

Species equitability (J')

Species equitability is a measure of the evenness of distribution of individuals between species. Equitability is obtained from the ratio between the calculated value of the diversity index and its maximum value with regard to the number of species in the sample (Allegro & Sciaky 2002). Species equitability was calculated with the use of the following formula:

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

Where H' = Shannon-Wiener diversity index
 S = natural log of the number of species within a sample

Species richness (S)

Species richness indices such as the Margalef index overestimates diversity in small samples and underestimates it in large samples (Southwood 1978, Butterfield & Coulson 1983, Rushton Eyre & Luff 1990). According to Georges (1994) species richness indices are not suitable to compare localities and the number of species should be used instead. For this reasons number of species instead of species richness indices were used in this study.

Normality of samples was determined using Shapiro Wilk's test. Samples with $p > 0.05$ were considered normally distributed. Parametric tests such as Analysis of Variance and Pearson's correlation coefficient were used. Analysis

of variance was used to determine statistically significant differences between means. Pearson's product moment correlation coefficient was used to determine the relationship between two variables. It was used to determine significant correlations between components of Coleoptera species diversity and plant species diversity. Non parametric tests included Kruskal-Wallis ANOVA and Spearman R correlation coefficient. A test described by Miller (1981) was used to test statistically significant differences between non-parametric variables such as Mean Shannon diversity index, species equitability and number of species at different stages of rehabilitation. The equation for the test is:

$$|\bar{R}_i - \bar{R}_j| \leq \sqrt{C_{(n-1;0.05)} \cdot \frac{N(N+1)}{12} \left(\frac{1}{n_i} + \frac{1}{n_j} \right)}$$

Where $\bar{R}_i$ = sum of ranks of the i th sample
 $\bar{R}_j$ = sum of ranks of the j th sample
 C = Chi square value
 n_i = Number of repetitions of the i th sample
 n_j = Number of repetitions of the j th sample
 N = Total number of repetitions

A two-way ANOVA was also applied to the Shannon diversity index, species equitability and number of species at different stages of rehabilitation to test for significant differences in values.

Rank abundance graphs were also used to indicate differences between species diversity, at different stages of rehabilitation in comparison to the natural veld. The lognormal model was used during the analysis (Preston 1962, Williams 1964).

Linear regression analysis was used to determine relationships between Coleoptera species and plant parameters as well as between Coleoptera species and different soil parameters. Where data was normally distributed the Pearson correlation coefficient was used to examine the relationship between two variables (Pearson 1896). Where data was not normally distributed the Spearman R correlation method was used.

The use of ordination techniques makes it possible to examine the distribution of many species simultaneously as well as their relationship to environmental parameters (Gauch 1982). Less detailed knowledge of species biology is needed when using these techniques (Kremen 1992).

Detrended Correspondence Analysis (DCA; detrended by polynomials, CANOCO program, Ter Braak & Prentice 1988) was used to determine the patterns of covariation in species distribution. The dimensionality of N species along M samples is reduced to only a few ordination axes, making it easier to interpret (Kremen 1992). Eigenvalues are calculated for each of the axes to indicate the proportion of variation in a sample or species that could be explained by that axis (Gauch 1982). DCA has three advantages to other techniques: 1) it removes artifacts like the arch effect and compression of gradients at ends; 2) it uses reciprocal averaging to ordinate sites and species simultaneously within the same ordination space and 3) it doesn't require a priori assumptions about directions of environmental gradients (Gauch 1982).

Canonical Correspondence Analysis (CCA), a direct gradient analysis was used to analyze Coleoptera species data in relation to plant- and soil parameters. The environmental variables determined the axes along which species are distributed. Monte Carlo Testing (bootstrapping) of the different axes with which different variables was associated was used to determine the significance of that particular environmental variable. The axis Eigenvalue was

used as test statistic (Ter Braak and Prentice 1988).

Forward selection was used to determine which of the environmental variables had significant influence on the distribution of Coleoptera species. Only the environmental variables, which contributed significantly to the distribution of Coleoptera species, were included in the ordination diagram.

Only summer and autumn data were used for the CCA determining the influence of plant parameters on distribution of Coleoptera species. These were the times when both Coleoptera and plant species were abundant. Only soil data for 1997 were available. Because soil data were unlikely to change much in one year's time, Coleoptera data for the whole of 1997 were compared to these soil parameters. Both plant and Coleoptera data with a relative abundance of less than 0.1 were omitted from the analysis.

CHAPTER 3: RESULTS

A total of 191 Coleoptera morphospecies were caught with the use of sweepnets and pitfall traps over a period of two years. Bi-monthly surveys were done at unrehabilitated and rehabilitated ash dams of the Hendrina power station in Mpumalanga. Reference grids were chosen in adjoining Bankenveld Grassland. Of the 191 morphospecies 67 were found in natural veld and 175 on the ash dams. 126 morphospecies were only found on the ash dams while 19 morphospecies were only found in the natural veld. Due to the fact that not all morphospecies could be identified to genus level all species will be referred to by their species code. A species list is supplied in Appendix 1.

3.1 RELATIVE ABUNDANCE OF COLEOPTERA SPECIES ON THE ASH DAM GRIDS AND ON GRIDS IN THE ADJOINING NATURAL VELD

Coleoptera assemblage structures were observed in rehabilitated areas as well as natural veld. According to Fig. 3.1 individuals representative of the families Anthicidae, Chrysomelidae, Tenebrionidae and Scarabaeidae were most abundant on the ash dam grids (values given in Table 3.1). In the natural veld representatives of the families Tenebrionidae, Chrysomelidae and Anthicidae were most abundant (Table 3.2). Fig. 3.1 gives an outlay of relative abundance of Coleoptera families caught on ash dam grids and Fig. 3.2 shows relative abundance of Coleoptera families caught in natural veld. The total relative abundance of each morphospecies was determined and given in Table 3.3. Fig. 3.3A and B gives an outlay of the total relative abundance of the species found on the ash dam grids (values in Table 3.3) while Fig. 3.4 A and B gives total relative abundances of the species found in the natural veld (Values given in Table 3.4). Because of the vast numbers of Coleoptera species caught Fig. 3.3A and Fig. 3.4A shows the relative abundances of all species caught on

both ash dams and in natural veld. Fig. 3.3B and Fig. 3.4B shows rank abundance of species with a relative abundance of more than 0.5% on both ash dams and in natural veld. *Formicomus* cf. *caeruleus* (ico22e), *Notoxus* sp. (ico74e) and *Pseudivongius aeneus* (ico75e) were most abundant on the ash dam grids whereas *Lagria* sp. (ico10e) and *Cryptocephalus bistrripustulatus* (ico160e) dominated in the natural veld (Fig. 3.4A and B). *Pseudivongius aeneus* (ico75e) and *Notoxus* sp. (ico74e) were less abundant and *Formicomus* cf. *caeruleus* (ico22e) was found in low numbers in the natural veld.

Table 3.1 Relative abundance values of the Coleoptera families caught on ash dam grids at the Hendrina Power Station in Mpumalanga.

FAMILY	RELATIVE ABUNDANCE
Anthicidae	31.79
Chrysomelidae	17.20
Tenebrionidae	16.95
Scarabaeidae	8.97
Carabidae	8.35
Coccinellidae	7.60
Curculionidae	5.83
Melyridae	0.72
Cleridae	0.62
Staphylidae	0.53
Elateridae	0.44
Phalacridae	0.28
Brentidae	0.16
Histeridae	0.12
Bostrichidae	0.09
Mordellidae	0.09
Nitidulidae	0.09
Meloidae	0.06
Trogidae	0.06
Cerambycidae	0.03

Table 3.2 Relative abundance values of Coleoptera families caught in natural veld at the Hendrina Power Station in Mpumalanga.

FAMILY	RELATIVE ABUNDANCE
Tenebrionidae	32.18
Chrysomelidae	19.54
Curculionidae	13.79
Anthicidae	13.33
Coccinellidae	5.75
Phalacridae	5.06
Meloidae	3.68
Carabidae	2.07
Scarabaeidae	2.07
Staphylinidae	0.92
Brentidae	0.46
Elateridae	0.46
Melyridae	0.46
Histeridae	0.23

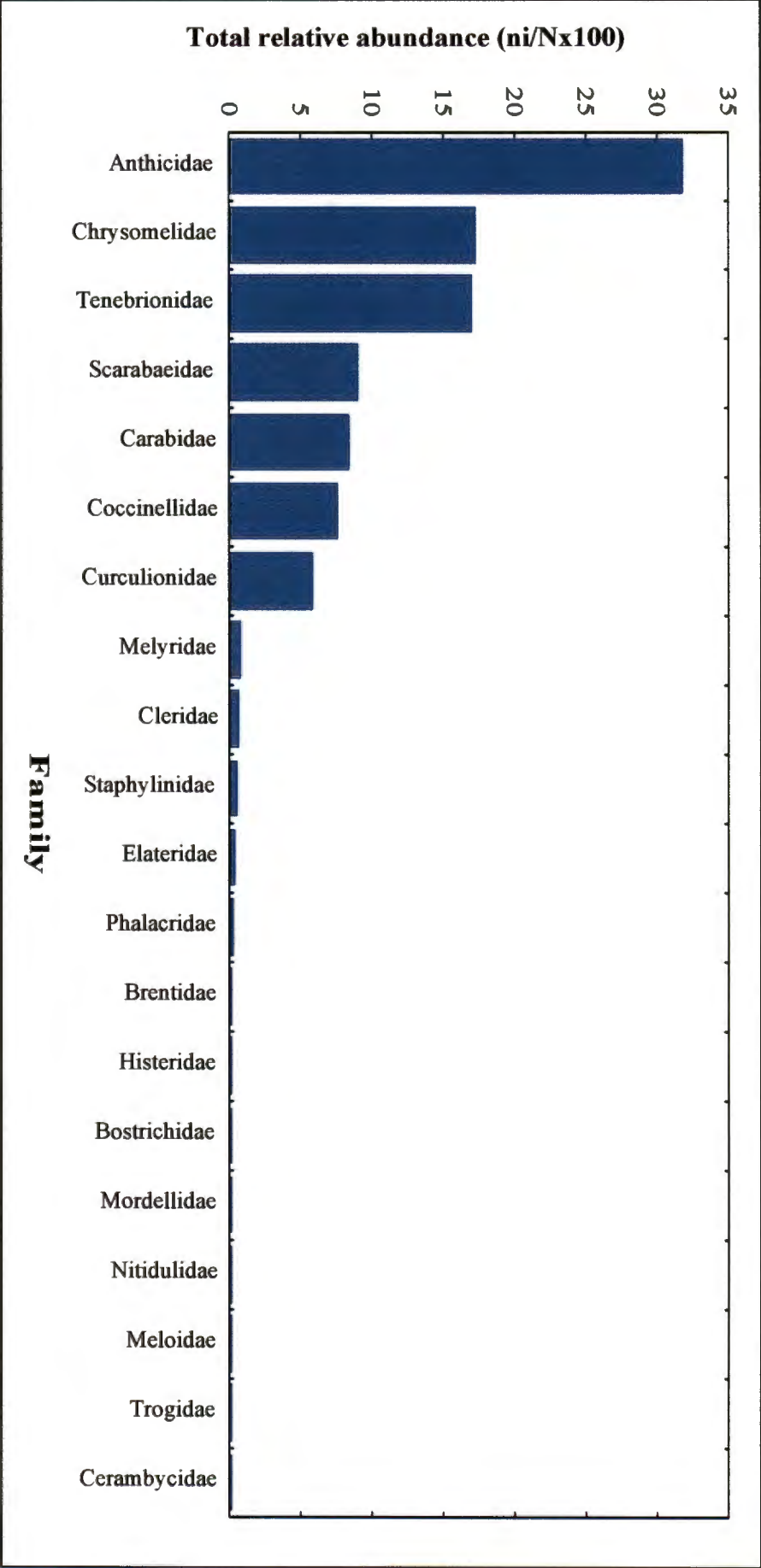


Figure 3.1 Total relative abundance of Coleoptera families caught on ash dam grids. Families are arranged from abundant to scarce.

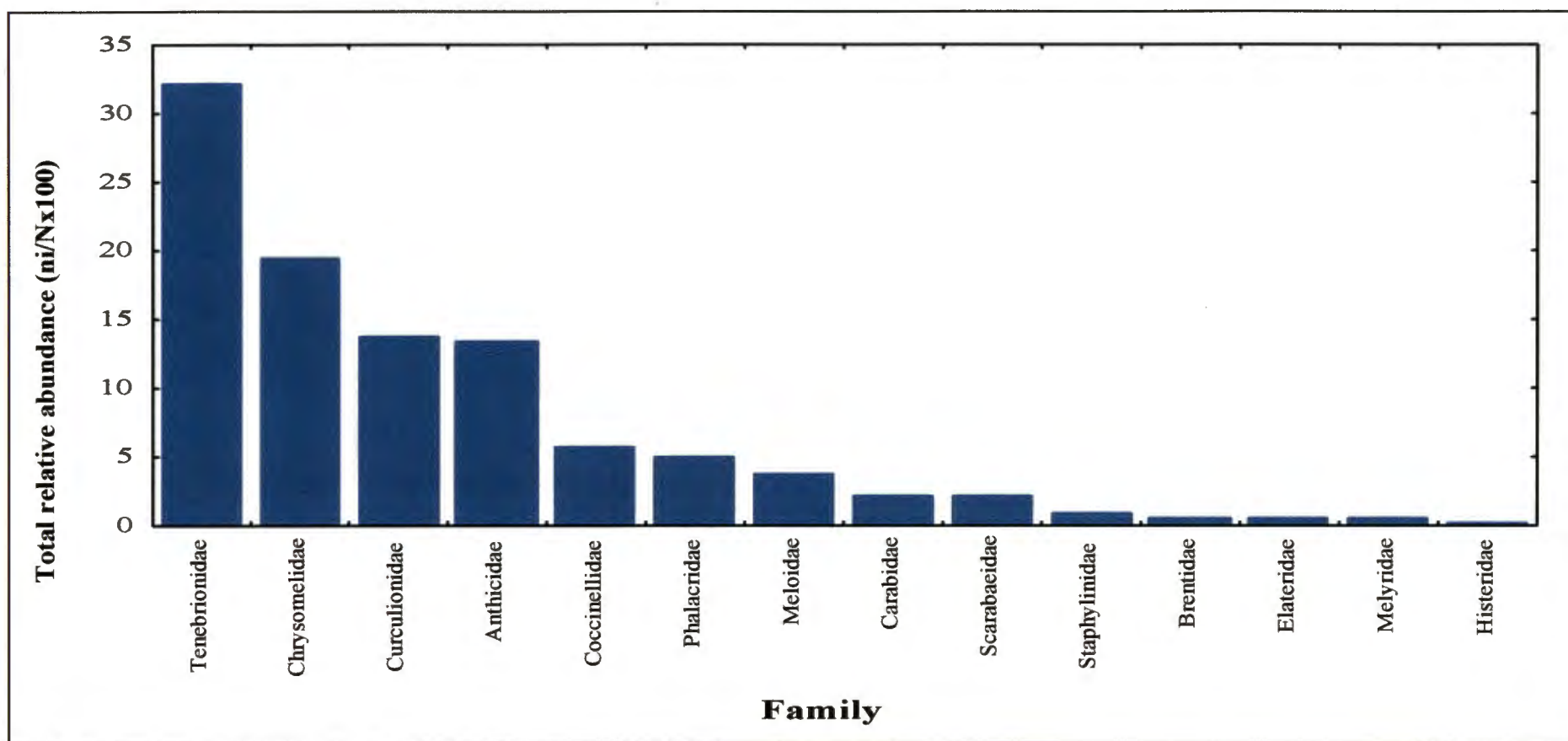


Figure 3.2 Total relative abundance of Coleoptera families caught in natural veld. Families are arranged from abundant to scarce.

Table 3.3 Relative abundance values of the different Coleoptera morpho-species caught on ash dam grids at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
ico22e	Anthicidae (<i>Formicomus</i> cf. <i>caeruleus</i>)	15.02
ico74e	Anthicidae (<i>Notoxus</i> sp.)	11.47
ico75e	Chrysomelidae (<i>Pseudivongius aeneus</i>)	11.00
ico2e	Tenebrionidae (<i>Zophosis</i> sp.)	7.77
ico1e	Scarabaeidae (<i>Rhyssemus</i> prob. <i>atramentarius</i>)	7.10
ico3e	Anthicidae (<i>Hirticomus biplagiatus</i>)	5.63
ico10e	Tenebrionidae (<i>Lagria</i> sp.)	3.46
ico4e	Carabidae (<i>Harpalus</i> sp. 4)	3.43
ico5e	Anthicidae (<i>Anthicus</i> sp.)	3.31
ico47e	Tenebrionidae (<i>Gonocephalum</i> cf. <i>simplex</i> .)	3.08
ico49e	Coccinellidae (<i>Scymnus</i> cf. <i>levaillanti</i>)	3.05
ico71e	Curculionidae (? <i>Lalagetes</i> sp.)	2.85
ico30e	Carabidae (<i>Graphipterus circumcinctus</i>)	1.94
ico7e	Coccinellidae (<i>Hipodamia variegata</i>)	1.38
ico112e	Chrysomelidae (<i>Estcouriana litura</i>)	1.20
ico72e	Curculionidae (<i>Erenmus angustirostris</i>)	1.06
ico19e	Coccinellidae	0.91
ico160e	Chrysomelidae (<i>Cryptocephalus bistrigatus</i>)	0.91
ico45e	Chrysomelidae	0.70
ico109e	Chrysomelidae	0.65
ico25e	Carabidae	0.59
ico82e	Tenebrionidae	0.59
ico134e	Cleridae	0.59
ico190e	Tenebrionidae	0.56
ico113e	Chrysomelidae	0.53
ico144e	Coccinellidae	0.50
ico6e	Scarabaeidae (<i>Aphodius</i> sp.)	0.47
ico61e	Melyridae (<i>Astylus atromaculatus</i>)	0.47
ico110e	Coccinellidae	0.47
ico97e	Staphylinidae	0.44
ico12e	Carabidae	0.38
ico100e	Scarabaeidae	0.35
ico86e	Curculionidae	0.23
ico101e	Scarabaeidae (<i>Heteronychus</i> sp)	0.23
ico48e	Carabidae (Larva)	0.21
ico87e	Chrysomelidae	0.21
ico147e	Curculionidae	0.21

Table 3.3 Relative abundance values of the different Coleoptera morpho-species caught on ash dam grids at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
ico171e	Elateridae	0.21
ico26e	Carabidae	0.18
ico11e	Coccinellidae	0.15
ico15e	Coccinellidae	0.15
ico203e	Chrysomelidae	0.15
ico93e	Histeridae	0.12
ico102e	Curculionidae	0.12
ico115e	Phalacridae	0.12
ico127e	Melyridae	0.12
ico170e	Tenebrionidae	0.12
ico215e	Coccinellidae (Larva)	0.12
ico228e	Carabidae	0.12
ico9e	Chrysomelidae	0.09
ico23e	Carabidae	0.09
ico27e	Carabidae	0.09
ico63e	Curculionidae	0.09
ico64e	Coccinellidae	0.09
ico66e	Carabidae (Larva)	0.09
ico78e	Coccinellidae	0.09
ico92e	Scarabaeidae	0.09
ico114e	Brentidae	0.09
ico142e	Phalacridae	0.09
ico158e	Curculionidae	0.09
ico163e	Chrysomelidae	0.09
ico182e	Bostrichidae	0.09
ico217e	Elateridae	0.09
ico17e	Chrysomelidae	0.06
ico28e	Tenebrionidae	0.06
ico36e	Curculionidae	0.06
ico40e	Carabidae	0.06
ico52e	Carabidae (Larva)	0.06
ico55e	Tenebrionidae	0.06
ico62e	Carabidae (Larva)	0.06
ico80e	Carabidae	0.06
ico85e	Tenebrionidae	0.06
ico88e	Curculionidae	0.06
ico96e	Curculionidae	0.06

Table 3.3 Relative abundance values of the different Coleoptera morpho-species caught on ash dam grids at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
ico103e	Tenebrionidae	0.06
ico111e	Elateridae	0.06
ico117e	Nitidulidae	0.06
ico131e	Chrysomelidae	0.06
ico136e	Chrysomelidae	0.06
ico138e	Anthicidae	0.06
ico152e	Anthicidae	0.06
ico153e	Chrysomelidae	0.06
ico156e	Melyridae	0.06
ico159e	Phalacridae	0.06
ico162e	Chrysomelidae	0.06
ico165e	Mordellidae	0.06
ico176e	Curculionidae	0.06
ico179e	Chrysomelidae	0.06
ico189e	Elateridae	0.06
ico200e	Curculionidae	0.06
ico202e	Curculionidae	0.06
ico206e	Coccinellidae (Larva)	0.06
ico227e	Brentidae	0.06
ico229e	Carabidae (<i>Harpalus</i>)	0.06
ico8e	Carabidae	0.03
ico13e	Coccinellidae	0.03
ico16e	Scarabaeidae	0.03
ico21e	Cerambycidae	0.03
ico32e	Tenebrionidae	0.03
ico33e	Curculionidae	0.03
ico34e	Nitidulidae	0.03
ico35e	Scarabaeidae	0.03
ico37e	Meloidae	0.03
ico41e	Chrysomelidae	0.03
ico44e	Scarabaeidae	0.03
ico50e	Carabidae (Larva)	0.03
ico51e	Trogidae	0.03
ico53e	Carabidae (Larva)	0.03
ico54e	Tenebrionidae	0.03
ico57e	Scarabaeidae	0.03
ico67e	Curculionidae	0.03

Table 3.3 Relative abundance values of the different Coleoptera morpho-species caught on ash dam grids at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
ico76e	Curculionidae	0.03
ico77e	Carabidae	0.03
ico79e	Carabidae (Larva)	0.03
ico81e	Carabidae	0.03
ico83e	Curculionidae	0.03
ico84e	Curculionidae	0.03
ico89e	Carabidae (Larva)	0.03
ico90e	Carabidae	0.03
ico91e	Staphylinidae	0.03
ico95e	Chrysomelidae	0.03
ico98e	Scarabaeidae	0.03
ico104e	Carabidae	0.03
ico105e	Staphylinidae	0.03
ico116e	Coccinellidae	0.03
ico122e	Coccinellidae (Larva)	0.03
ico132e	Chrysomelidae	0.03
ico135e	Curculionidae	0.03
ico137e	Tenebrionidae	0.03
ico139e	Chrysomelidae	0.03
ico141e	Chrysomelidae	0.03
ico143e	Chrysomelidae	0.03
ico145e	Carabidae	0.03
ico146e	Chrysomelidae	0.03
ico149e	Curculionidae	0.03
ico151e	Tenebrionidae	0.03
ico157e	Chrysomelidae	0.03
ico161e	Tenebrionidae	0.03
ico167e	Melyridae	0.03
ico168e	Scarabaeidae	0.03
ico169e	Mordellidae	0.03
ico174e	Carabidae	0.03
ico177e	Coccinellidae	0.03
ico178e	Curculionidae	0.03
ico181e	Chrysomelidae	0.03
ico183e	Curculionidae	0.03
ico184e	Scarabaeidae	0.03
ico185e	Curculionidae	0.03

Table 3.3 Relative abundance values of the different Coleoptera species caught on ash dam grids at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
ico191e	Chrysomelidae	0.03
ico192e	Carabidae	0.03
ico197e	Curculionidae	0.03
ico198e	Curculionidae	0.03
ico204e	Carabidae (Larva)	0.03
ico207e	Carabidae (Larva)	0.03
ico208e	Coccinellidae (Larva)	0.03
ico209e	Carabidae (Larva)	0.03
ico211e	Coccinellidae	0.03
ico216e	Chrysomelidae	0.03
ico219e	Meloidae	0.03
ico221e	Trogidae	0.03
ico222e	Curculionidae	0.03
ico223e	Curculionidae	0.03
ico224e	Curculionidae	0.03
ico225e	Curculionidae	0.03
ico226e	Curculionidae	0.03
ico230e	Carabidae	0.03
ico231e	Carabidae	0.03

Table 3.4 Relative abundance values of the different Coleoptera morphospecies caught in natural veld at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
Ico10e	Tenebrionidae (<i>Lagria</i> sp.)	29.45
Ico160e	Chrysomelidae (<i>Cryptocephalus bistrigatus</i>)	12.33
Ico3e	Anthicidae (<i>Hirticomus biplagiatus</i>)	8.68
Ico72e	Curculionidae (<i>Erenmus angustirostris</i>)	6.85
Ico75e	Chrysomelidae (<i>Pseudovongius aeneus</i>)	3.65
Ico133e	Curculionidae	3.42
Ico74e	Anthicidae (<i>Notoxus</i> sp.)	3.20
Ico115e	Phalacridae	3.20
Ico37e	Meloidae	2.97
Ico7e	Coccinellidae (<i>Hippodamia variegata</i>)	1.83
Ico47e	Tenebrionidae (<i>Gonocephalum</i> sp.)	1.60
Ico40e	Carabidae	1.37

Table 3.4 Relative abundance values of the different Coleoptera morphospecies caught in natural veld at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
Ico19e	Coccinellidae	1.14
Ico142e	Phalacridae	1.14
Ico49e	Coccinellidae (<i>Scymnus cf. levaillanti</i>)	0.91
Ico97e	Staphylinidae	0.91
Ico202e	Curculionidae	0.91
Ico1e	Scarabaeidae (<i>Rhyssalus prob. atramentarius</i>)	0.68
Ico22e	Anthicidae (<i>Formicomus cf. caeruleus</i>)	0.68
Ico41e	Chrysomelidae	0.68
Ico70e	Curculionidae	0.68
Ico159e	Phalacridae	0.68
Ico211e	Coccinellidae	0.68
Ico5e	Anthicidae (<i>Anthicus sp.</i>)	0.46
Ico9e	Chrysomelidae	0.46
Ico43e		0.46
Ico44e	Scarabaeidae	0.46
Ico45e	Chrysomelidae	0.46
Ico73e	Scarabaeidae	0.46
Ico114e	Brentidae	0.46
Ico116e	Coccinellidae	0.46
Ico144e	Coccinellidae	0.46
Ico148e	Chrysomelidae	0.46
Ico150e	Chrysomelidae	0.46
Ico171e	Elateridae	0.46
Ico219e	Meloidae	0.46
Ico4e	Carabidae (<i>Harpalus sp.4</i>)	0.23
Ico38e	Curculionidae	0.23
Ico39e	Tenebrionidae	0.23
Ico42e	Meloidae	0.23
Ico60e	Carabidae (Larva)	0.23
Ico65e	Anthicidae	0.23
Ico67e	Curculionidae	0.23
Ico68e	Curculionidae	0.23
Ico69e	Carabidae	0.23
Ico84e	Curculionidae	0.23
Ico87e	Chrysomelidae	0.23
Ico92e	Scarabaeidae	0.23
Ico98e	Scarabaeidae	0.23

Table 3.4 Relative abundance values of the different Coleoptera morphospecies caught in natural veld at the Hendrina Power Station in Mpumalanga.

MORPHOSPECIES	FAMILY	RELATIVE ABUNDANCE
ico99e	Histeridae	0.23
ico103e	Tenebrionidae	0.23
ico113e	Chrysomelidae	0.23
ico127e	Melyridae	0.23
ico137e	Tenebrionidae	0.23
ico143e	Chrysomelidae	0.23
ico156e	Melyridae	0.23
ico166e	Curculionidae	0.23
ico172e		0.23
ico177e	Coccinellidae	0.23
ico193e	Tenebrionidae	0.23
ico194e	Curculionidae	0.23
Ico200e	Curculionidae	0.23
Ico214e	Chrysomelidae (Larva)	0.23
Ico218e	Curculionidae	0.23

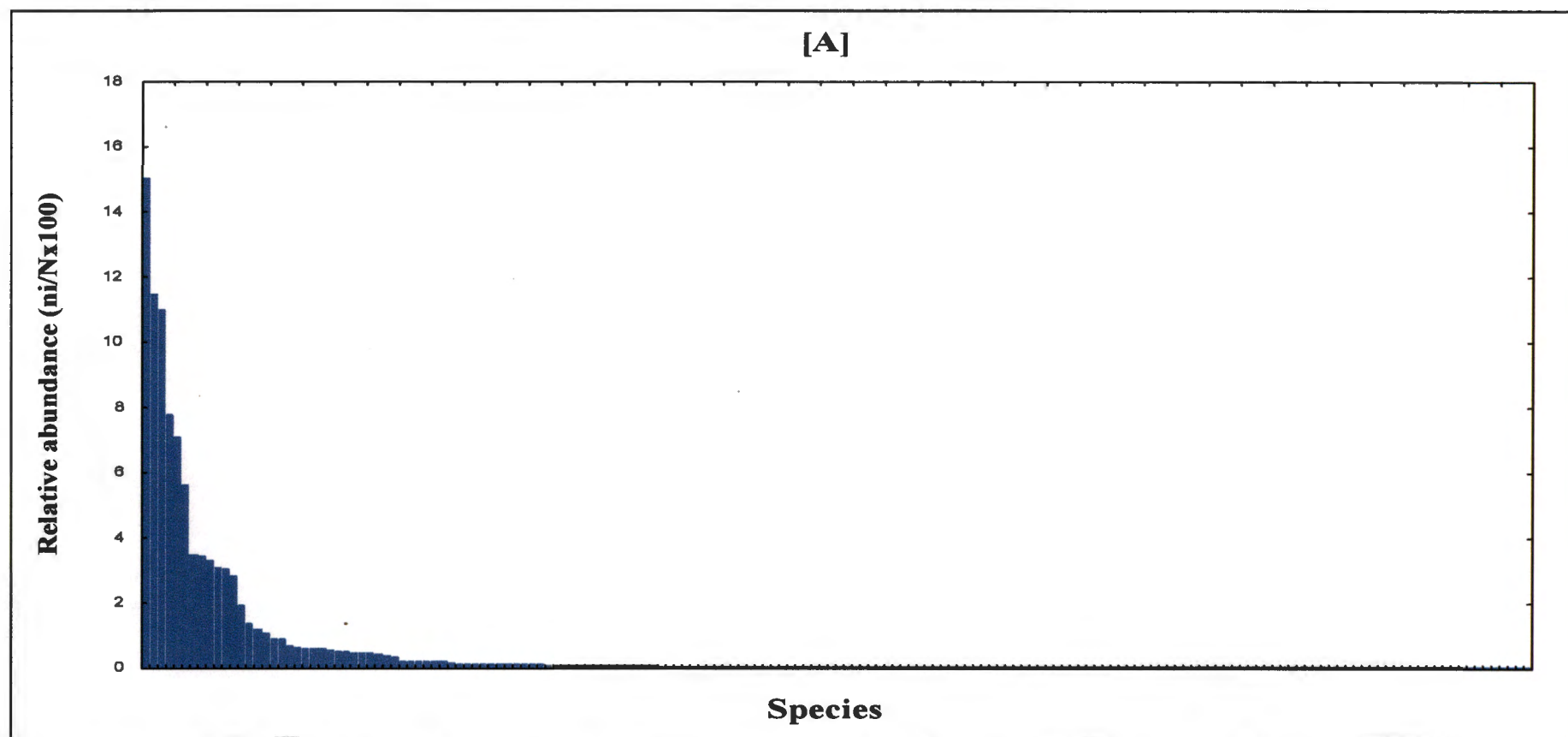


Figure 3.3 A Total relative abundance of Coleoptera morphospecies caught on ash dam grids. All morphospecies are arranged from abundant to scarce.

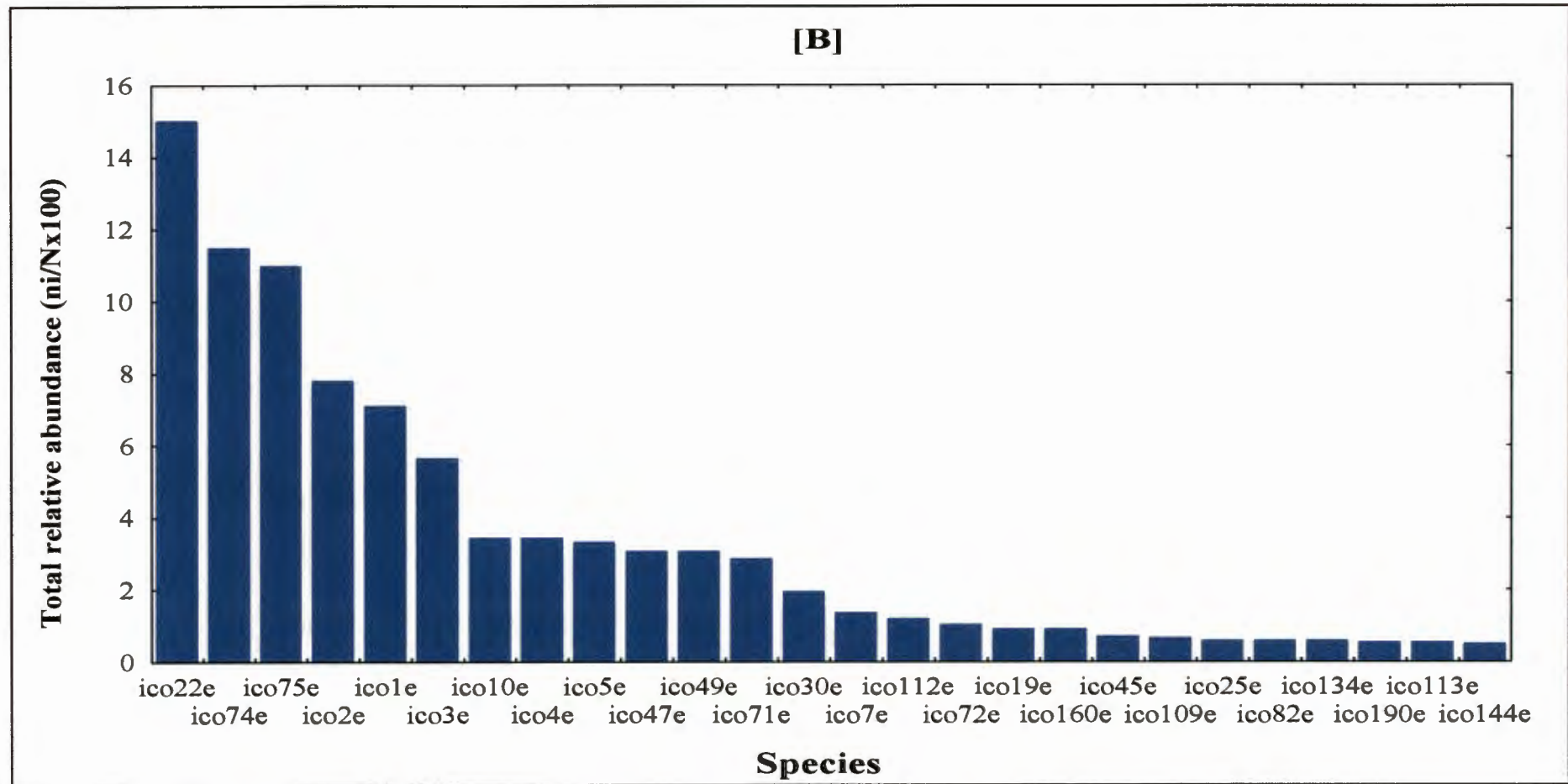


Figure 3.3 B Total relative abundance of Coleoptera morphospecies caught on Ash dam grids. Morphospecies with a relative abundance larger than 0.5% are arranged from abundant to scarce.

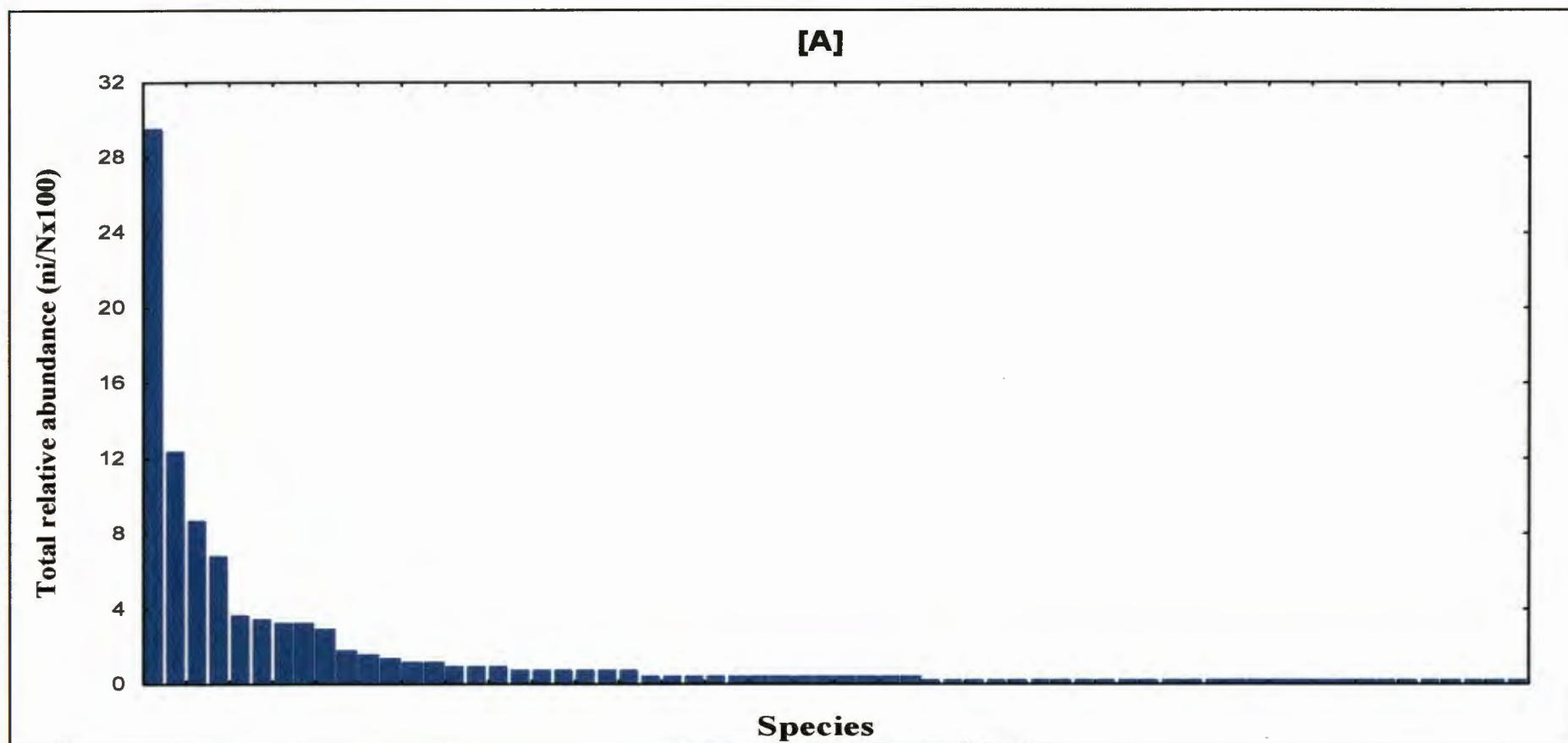


Figure 3.4A Total relative abundance of Coleoptera species caught in natural veld. All morphospecies are arranged from abundant to scarce.

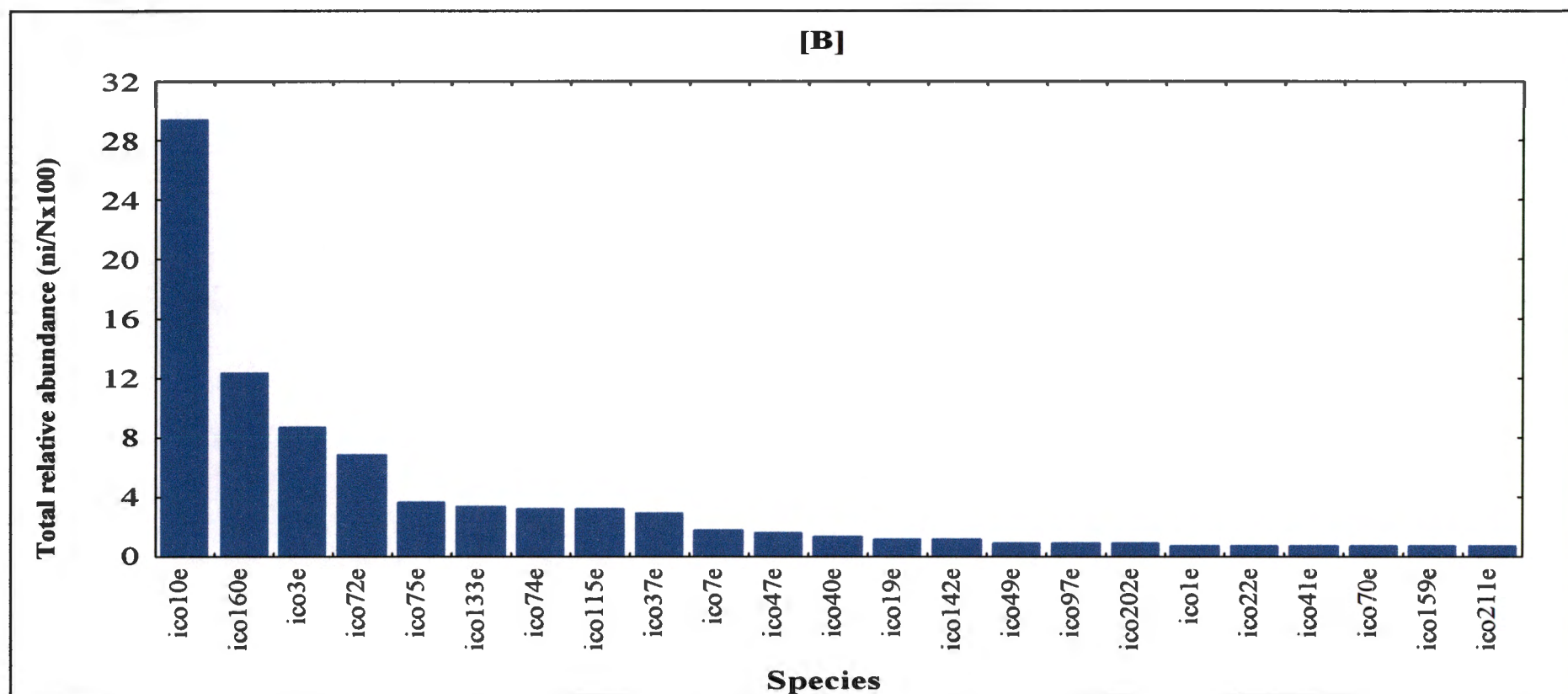


Figure 3.4B Total relative abundance of Coleoptera species caught in natural veld. Morphospecies with a relative abundance of more than 0.5% are arranged from abundant to scarce

3.2 SUCCESSION OF COLEOPTERA SPECIES AT DIFFERENT STAGES OF REHABILITATION AND IN NATURAL VELD

Different Coleoptera species were found during different stages of rehabilitation of the ash dams at the Hendrina power station. Certain species were found to colonise an area before any rehabilitation had taken place. Table 3.5 shows the mean number of individuals per transect of morphospecies of the class Coleoptera during different stages of rehabilitation. The mean number of individuals per species per transect was used to determine the relative abundance.

Representatives of the family Carabidae seem to be early colonisers of the ash dams. Carabidae species were found to be most abundant on both unrehabilitated and rehabilitated ash dams (Table 3.5). Neumann (1973) found Coleoptera species to be early colonisers of coal spoil banks. Some of the species (ico 77, 79 and 104) were only found on unrehabilitated sites and not on any of the rehabilitated sites or in the natural veld. Other Carabidae species (ico 12, 228 and *Harpalus* sp 4(ico4)) as well as some of the Anthicidae species (*Hirticomus biplagiatus* (ico 3), *Formicomus* cf. *caeruleus* (ico22), *Notoxus* sp (ico74) and *Anthicus* sp (ico5)) were found in large numbers on the unrehabilitated and younger rehabilitated sites and decreased in abundance with an increase in rehabilitation age. Very few or none of the individuals from ico 12, 228, 4, 3, 22, 74 and 5 were found in natural veld. Nineteen Coleoptera of the species were found only in natural veld. No representatives of these species occurred in either unrehabilitated or rehabilitated areas. Table 3.6 shows the species that only occurred in natural veld. These species could be parameters of higher levels of succession.

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 1/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico77e	Carabidae			0.50						
ico79e	Carabidae (Larva)			0.50						
ico104e	Carabidae			0.50						
ico12e	Carabidae			1.50	2.50	0.33	0.22	0.09	0.33	
ico228e	Carabidae			0.50	0.50		0.11		0.33	
ico4e	Carabidae		<i>Harpalus</i> sp. 4 ^	4.00	13.50	11.00	2.11	1.91	3.00	0.17
ico3e	Anthicidae		<i>Hirticomus biplagiatus</i>	23.00	54.00	3.00	0.89	1.73	0.67	6.33
ico22e	Anthicidae		<i>Formicomus</i> cf. <i>caeruleus</i>	10.00	5.50	60.33	17.89	9.36	12.00	0.50
ico74e	Anthicidae		<i>Notoxus</i> sp.	6.50	28.00	8.67	20.89	5.64	15.33	2.33
ico5e	Anthicidae		<i>Anthicus</i> sp.	2.00	28.00	10.33	1.11	0.73	1.33	0.33
ico47e	Tenebrionidae		<i>Gonocephalum</i> cf. <i>simplex</i>	1.50	4.50	6.67	4.67	1.73	4.00	1.17
ico1e	Scarabaeidae	Aphodiinae	<i>Rhyssenus</i> prob. <i>atramentarius</i>	1.00	6.50	4.67	6.22	7.82	23.67	0.50
ico144e	Coccinellidae			1.00	0.50	0.67	0.56	0.55	0.33	0.33
ico97e	Staphylinidae			1.00		0.33	0.11	0.91	0.33	0.67
ico9e	Chrysomelidae			1.00			0.11			0.33
ico44e	Scarabaeidae	Scarabaeinae		0.50						0.33
ico49e	Coccinellidae		<i>Scymnus</i> cf. <i>levaillanti</i>		6.00	1.33	3.11	4.36	4.00	0.67
ico7e	Coccinellidae		<i>Hippodamia variegata</i>		3.50	2.00	0.89	1.91	1.67	1.33
ico10e	Tenebrionidae	Lagriinae	<i>Lagria</i> sp.		2.50	10.67	2.56	3.45	6.67	21.50
ico2e	Tenebrionidae		<i>Zophosis</i> sp.		1.00	31.33	4.89	9.64	6.33	0.00
ico19e	Coccinellidae				1.00	1.00	1.33	1.18	0.33	0.83

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 2/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico113e	Chrysomelidae				1.00		1.44	0.18	0.33	0.17
ico72e	Curculionidae		<i>Erenmus angustirostris</i>		0.50	1.67	2.56	0.64		5.00
ico171e	Elateridae				1.00	0.33	0.22		0.67	0.33
ico127e	Melyridae	Malachiinae			0.50		0.11	0.18		0.17
ico30e	Carabidae		<i>Graphipterus circumcinctus</i>		4.00	7.67	1.67	1.09	2.67	
ico25e	Carabidae				1.50	0.67	0.33	1.00	0.33	
ico110e	Coccinellidae				1.50	0.67	0.44	0.27	1.33	
ico71e	Curculionidae		? <i>Lalagetes</i> sp.		0.50	0.33	4.56	1.73	11.67	
ico61e	Melyridae	Dasytinae	<i>Astylus atromaculatus</i>		1.00	0.67	0.67	0.27	1.00	
ico109e	Chrysomelidae				4.00		1.22	0.27		
ico6e	Scarabaeidae	Aphodiinae	<i>Aphodius</i> sp.		2.50		0.78	0.36		
ico15e	Coccinellidae				1.00	0.33		0.18		
ico101e	Scarabaeidae	Dynastinae	<i>Heteronychus</i> sp.		3.00	0.67				
ico78e	Coccinellidae (Larva)				1.00	0.33				
ico17e	Chrysomelidae	Alticinae			0.50	0.33				
ico117e	Nitidulidae				0.50		0.11			
ico176e	Curculionidae				0.50		0.11			
ico52e	Carabidae (Larva)				0.50			0.09		
ico67e	Curculionidae				0.50					0.17
ico62e	Carabidae (Larva)				1.00					
ico206e	Coccinellidae				1.00					

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 3/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico229e	Carabidae		<i>Harpalus</i> sp.		1.00					
icol6e	Scarabaeidae	Aphodiinae			0.50					
icol61e	Tenebrionidae				0.50					
icol74e	Carabidae	Cicindelinae			0.50					
icol81e	Chrysomelidae				0.50					
icol83e	Curculionidae				0.50					
icol84e	Scarabaeidae	Aphodinae			0.50					
icol92e	Carabidae				0.50					
icol204e	Carabidae				0.50					
ico75e	Chrysomelidae		<i>Pseudovongius aeneus</i>			1.67	23.78	5.91	30.33	2.67
icol60e	Chrysomelidae		<i>Cryptocephalus bistrigatus</i>			1.33	1.78	0.82	0.67	9.00
ico100e	Scarabaeidae	Melolonthinae				1.00	0.11	0.55	0.67	
ico48e	Carabidae (Larva)					0.33	0.11	0.36	0.33	
icol90e	Tenebrionidae					5.67	0.11		0.33	
ico27e	Carabidae (Larva)					0.33		0.09	0.33	
icol70e	Tenebrionidae					1.00			0.33	
ico92e	Scarabaeidae	Melolonthinae				0.33	0.22			0.17
ico64e	Coccinellidae					0.33	0.11	0.09		
ico82e	Tenebrionidae					0.33	0.89	1.00		
ico98e	Scarabaeidae	Scarabaeinae				0.33				0.17
icol77e	Coccinellidae					0.33				0.17
icol31e	Chrysomelidae					0.33		0.09		

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 4/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico23e	Carabidae					0.67		0.09		
ico152e	Anthicidae					0.33		0.09		
ico66e	Carabidae (Larva)					0.67	0.11			
ico158e	Curculionidae					0.67	0.11			
ico147e	Curculionidae					0.33	0.67			
ico93e	Histeridae					1.33				
ico55e	Tenebrionidae					0.67				
ico32e	Tenebrionidae					0.33				
ico33e	Curculionidae					0.33				
ico51e	Trogidae					0.33				
ico90e	Carabidae					0.33				
ico91e	Staphylinidae					0.33				
ico146e	Chrysomelidae					0.33				
ico169e	Mordellidae					0.33				
ico185e	Curculionidae					0.33				
ico191e	Chrysomelidae					0.33				
ico231e	Carabidae					0.33				
ico87e	Chrysomelidae						0.33	0.27	0.33	0.17
ico115e	Phalacridae						0.11	0.18	0.33	2.33
ico103e	Tenebrionidae						0.11		0.33	0.17
ico142e	Phalacridae						0.11		0.67	0.83
ico134e	Cleridae						0.11	0.91	3.00	

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 5/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico112e	Chrysomelidae		<i>Estcouriana litura</i>				0.44	2.55	3.00	
ico114e	Brentidae	Apioninae					0.11	0.18		0.33
ico45e	Chrysomelidae						2.67			0.33
ico40e	Carabidae						0.22			1.00
ico200e	Curculionidae						0.22			0.17
ico202e	Curculionidae						0.22			0.67
ico37e	Meloidae						0.11			2.17
ico137e	Tenebrionidae	Alleculinae					0.11			0.17
ico143e	Chrysomelidae						0.11			0.17
ico219e	Meloidae						0.11			0.33
ico136e	Chrysomelidae						0.11	0.09		
ico203e	Chrysomelidae	Hispinae					0.44	0.09		
ico86e	Curculionidae						0.33	0.45		
ico11e	Coccinellidae						0.22	0.27		
ico163e	Chrysomelidae						0.22	0.09		
ico28e	Tenebrionidae						0.11	0.09		
ico36e	Curculionidae						0.11	0.09		
ico88e	Curculionidae						0.11	0.09		
ico96e	Curculionidae						0.11	0.09		
ico153e	Chrysomelidae						0.11	0.09		
ico165e	Mordellidae						0.11	0.09		
ico227e	Brentidae	Apoininae					0.11	0.09		

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 6/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico102e	Curculionidae						0.44			
ico111e	Elateridae						0.22			
ico138e	Anthicidae						0.22			
ico162e	Chrysomelidae						0.22			
ico189e	Elateridae						0.22			
ico34e	Nitidulidae						0.11			
ico35e	Scarabaeidae	Scarabaeinae					0.11			
ico57e	Scarabaeidae (Larva)						0.11			
ico76e	Curculionidae						0.11			
ico95e	Chrysomelidae	Hispinae					0.11			
ico132e	Chrysomelidae						0.11			
ico139e	Chrysomelidae						0.11			
ico141e	Chrysomelidae						0.11			
ico145e	Carabidae						0.11			
ico149e	Curculionidae						0.11			
ico151e	Tenebrionidae	Alleculinae					0.11			
ico157e	Chrysomelidae						0.11			
ico178e	Curculionidae						0.11			
ico198e	Curculionidae						0.11			
ico207e	Carabidae (Larva)						0.11			
ico222e	Curculionidae						0.11			

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 7/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico223e	Curculionidae						0.11			
ico224e	Curculionidae						0.11			
ico225e	Curculionidae						0.11			
ico226e	Curculionidae						0.11			
ico26e	Carabidae							0.45	0.33	
ico85e	Tenebrionidae							0.09	0.33	
ico156e	Melyridae	Malachiinae						0.18		0.17
ico41e	Chrysomelidae							0.09		0.50
ico159e	Phalacridae							0.18		0.50
ico84e	Curculionidae							0.09		0.17
ico211e	Coccinellidae							0.09		0.50
ico63e	Curculionidae							0.27		
ico182e	Bostrichidae							0.27		
ico217e	Elateridae							0.27		
ico80e	Carabidae							0.18		
ico179e	Chrysomelidae							0.18		
ico8e	Coccinellidae							0.09		
ico13e	Coccinellidae							0.09		
ico21e	Cerambycidae							0.09		
ico50e	Carabidae (Larva)							0.09		
ico53e	Carabidae (Larva)							0.09		

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 8/9				Unrehabilitated	3 years rehabilitated (1996)	4 years rehabilitated (1995)	5 years rehabilitated (1994)	7 years rehabilitated (1992)	9 years rehabilitated (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10,11	g12	
ico54e	Tenebrionidae							0.09		
ico81e	Carabidae							0.09		
ico83e	Curculionidae							0.09		
ico89e	Carabidae (Larva)							0.09		
ico105e	Staphylinidae							0.09		
ico121e	Larva							0.09		
ico122e	Coccinellidae (Larva)							0.09		
ico135e	Curculionidae							0.09		
ico167e	Melyridae	Malachiinae						0.09		
ico168e	Scarabaeidae	Rutelinae						0.09		
ico197e	Curculionidae							0.09		
ico208e	Coccinellidae (Larva)							0.09		
ico209e	Carabidae (Larva)							0.09		
ico221e	Trogidae							0.09		
ico116e	Coccinellidae								0.33	0.33
ico215e	Coccinellidae (Larva)								1.33	
ico216e	Chrysomelidae (Larva)	Hispiinae							0.33	
ico230e	Carabidae								0.33	
ico133e	Curculionidae									2.50
ico70e	Curculionidae									0.50
ico73e	Scarabaeidae	Melolonthinae								0.33

Table 3.5 Mean number of individuals per transect caught in grids at different stages of rehabilitation on ash dams as well as in the natural veld during surveys of the Hendrina Power Station in Mpumalanga

Page 9/9				Unrehabili- tated	3 years rehabilita- ted (1996)	4 years rehabilita- ted (1995)	5 years rehabilita- ted (1994)	7 years rehabilita- ted (1992)	9 years rehabilita- ted (1990)	Natural veld
				g7&8t	g7&8m	grid 1	g2,3,4	g7&8b,9,10 ,11	g12	
ico148e	Chrysomelidae									0.33
ico150e	Chrysomelidae									0.33
ico38e	Curculionidae									0.17
ico39e	Tenebrionidae									0.17
ico42e	Meloidae									0.17
ico60e	Carabidae (Larva)									0.17
ico65e	Anthicidae									0.17
ico68e	Curculionidae									0.17
ico69e	Carabidae	Cicindelinae								0.17
ico99e	Histeridae									0.17
ico166e	Curculionidae									0.17
ico193e	Tenebrionidae									0.17
ico194e	Curculionidae									0.17
ico214e	Chrysomelidae (Larva)									0.17
ico218e	Curculionidae									0.17

Assemblages of individuals of Carabidae species and Anthicidae species will be discussed in section 3.3.

Table 3.6 Coleoptera species occurring only in the Natural veld at Hendrina Power station.

MORPHOSPECIES	FAMILY	SUBFAMILY
ico38e	Curculionidae	
ico39e	Tenebrionidae	
ico42e	Meloidae	
ico60e	Carabidae (Larva)	
ico65e	Anthicidae	
ico68e	Curculionidae	
ico69e	Carabidae	Cicindelinae
ico99e	Histeridae	
ico166e	Curculionidae	
ico193e	Tenebrionidae	
ico194e	Curculionidae	
ico214e	Chrysomelidae (Larva)	
ico218e	Curculionidae	

3.3 SPECIES DIVERSITY, EQUITABILITY AND SPECIES RICHNESS AT DIFFERENT STAGES OF REHABILITATION AND IN NATURAL VELD

Species diversity, equitability and species richness were determined for Coleoptera assemblages at different stages of rehabilitation. Species diversity was calculated with the use of the Shannon-Wiener diversity index. The reason why this index is preferred to other diversity indices is because it adds value to rare species (Sheehan 1984). Equitability is a measure of the evenness of distribution of individuals among species. The number of species was used to quantify species richness. The number of species is preferred to the use of an index like Margalef's index because an index over-estimates diversity in small catches and under estimates in large samples (Southwood 1978, Butterfield & Coulson 1983, Rushton *et al.* 1990).

Mean Shannon diversity index per transect, mean species equitability per transect and mean number of species per transect at different rehabilitation stages are given in Fig. 3.5. Actual numbers as well as standard deviation and the results of a one-way ANOVA between the different stages of rehabilitation for Shannon diversity, equitability and number of species are given in Table 3.7.

Mean species diversity increased from unrehabilitated to rehabilitation done in 1996 and remained relative constant regardless of the rehabilitation age (Fig. 3.5, Table 3.7). Species diversity in natural veld seems slightly lower than at rehabilitated ash dams.

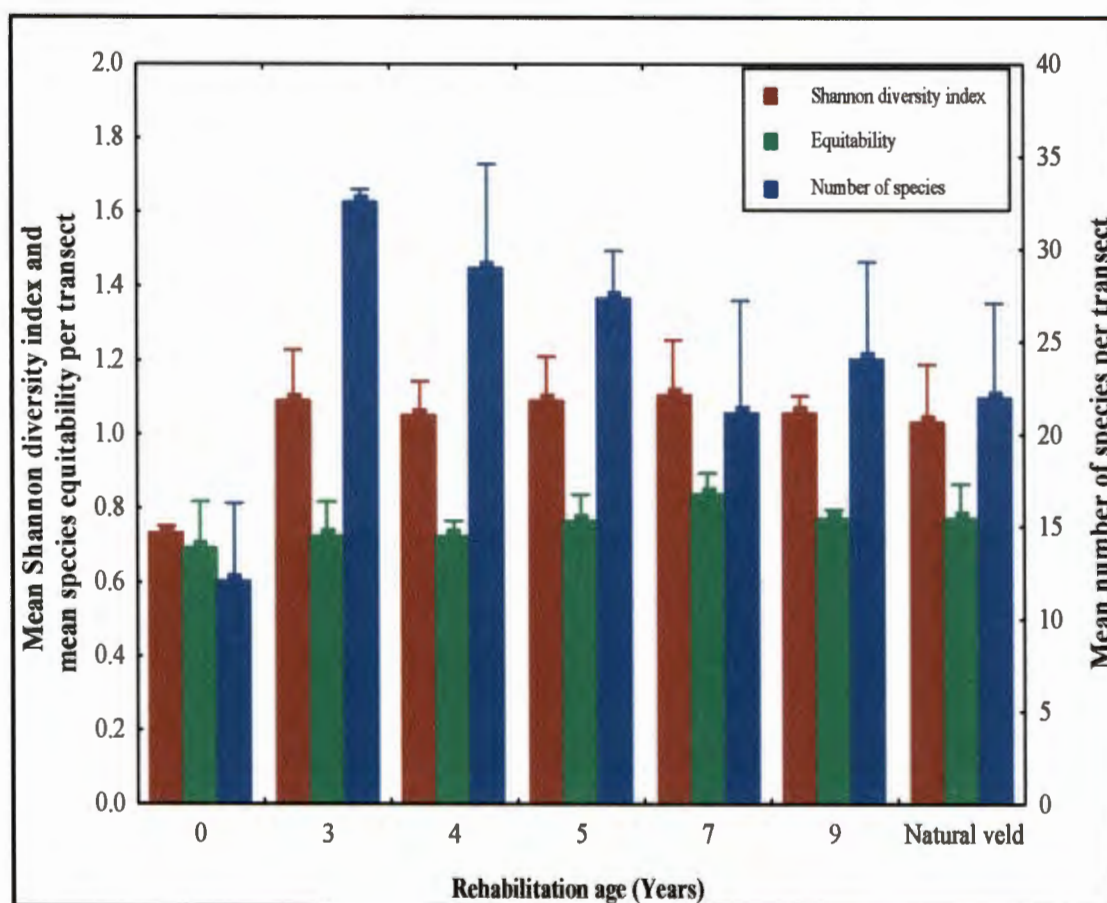


Figure 3.5 Mean Shannon diversity index, mean equitability and mean number of species per transect at different stages of rehabilitation of ash dams at Hendrina Power station.

Equitability increased with increasing rehabilitation age (Fig. 3.5, Table 3.7). The equitability for rehabilitation done in 1990 (9 years old) is slightly lower than for rehabilitation done later on. Equitability for the natural veld is also slightly lower than for rehabilitation done in 1992 (7 years old) (Fig. 3.5, Table 3.7). No statistically significant differences occurred between any of the sites.

The mean number of species caught per transect was used to measure the species richness (Fig. 3.5, Table 3.7). The number of species caught per transect at rehabilitated ash dams was more or less double the number of species caught at unrehabilitated ash dams. Numbers of species per transect decreased with increasing rehabilitation age and the number of individuals caught in the natural veld was lower than at ash dams rehabilitated in 1990 (9 years old), 1994 and 1996. However, the number of species caught in the natural veld is still higher than those caught in unrehabilitated ash dams (Fig. 3.5, Table 3.7). Statistical significance exists between unrehabilitated ash dams and three-year-old rehabilitated ash dams ($P=0.004$), between unrehabilitated ash dams and four-year-old rehabilitated ash dams ($P=0.022$) as well as between unrehabilitated ash dams and five-year-old rehabilitated ash dams ($P=0.0499$).

Rank abundance graphs were drawn to illustrate and compare species diversity at the different rehabilitation ages and natural veld. The relative abundance of species in different grids, rehabilitated at the same time, was grouped. Log relative abundance of species were ranked from high to low (Fig. 3.6)

The slopes and lengths of the curves give an indication of the species diversity. The steeper the slope of the curve, the higher the dominance (i.e. low equitability) and lower diversity while a flatter slope indicates higher species diversity. The longer the curve, the higher the species richness which in turn indicates higher species diversity. According to Fig. 3.6 the area rehabilitated

in 1994 (grid 2,3,4) has the highest species richness, followed by the area rehabilitated in 1992 and then the natural veld. The discrepancy between this and the results from figure 3.5 will be dealt with in Chapter 4.

Table 3.7 Mean Shannon diversity index per transect, Mean Equitability per transect and Mean Number of species per transect in the natural veld and unrehabilitated and rehabilitated ash dams at Hendrina Power Station. The rehabilitated ash dams were rehabilitated at different times. Standard deviation is indicated in brackets.

Rehabilitation age (years)	Mean Shannon diversity index per transect ($\pm$ Std. dev.)	Mean Equitability per transect ($\pm$ Std. dev.)	Mean Number of species per transect ($\pm$ Std. dev.)
0	0.728 ($\pm$ 0.023)	0.693 ($\pm$ 0.124)	12 ($\pm$ 4.243)
3 (1996)	1.092 ($\pm$ 0.135)	0.723 ($\pm$ 0.094)	32.5 ($\pm$ 0.707)
4 (1995)	1.053 ($\pm$ 0.089)	0.722 ($\pm$ 0.043)	29 ($\pm$ 5.568)
5 (1994)	1.093 ($\pm$ 0.116)	0.762 ($\pm$ 0.075)	27.33 ($\pm$ 2.55)
7 (1992)	1.104 ($\pm$ 0.151)	0.841 ($\pm$ 0.053)	21.18 ($\pm$ 6.03)
9 (1990)	1.059 ($\pm$ 0.045)	0.772 ($\pm$ 0.024)	24 ($\pm$ 5.292)
Natural veld	1.036 ($\pm$ 0.153)	0.775 ($\pm$ 0.09)	22 ($\pm$ 5.06)
ANOVA	F ₄₁ = 2.537 P=0.043	F ₄₁ = 2.562 P=0.043	F ₄₁ = 5.104 P=0.001

0 7 NV 9 5 4 3

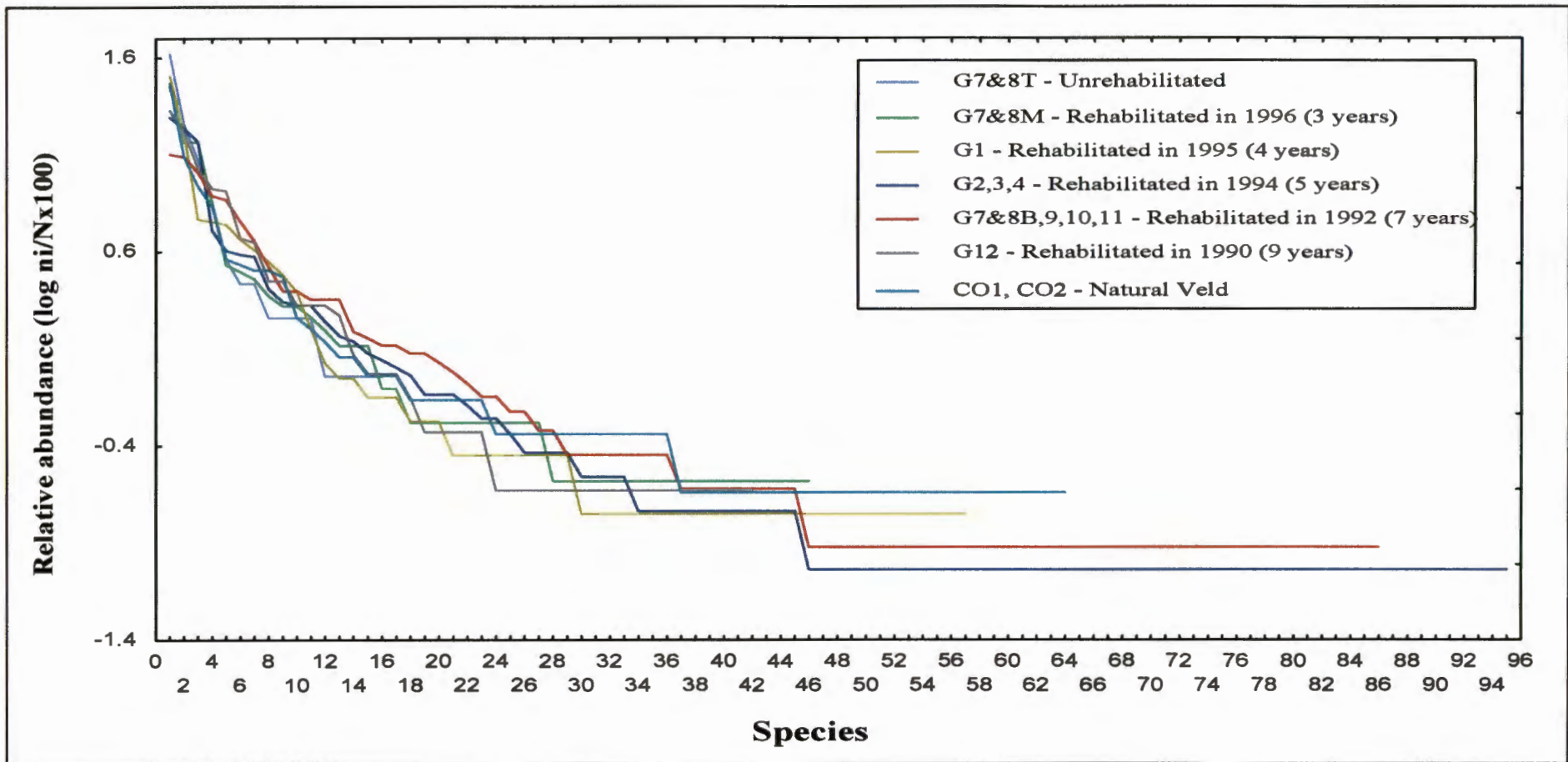


Figure 3.6 Rank abundance curves of Coleoptera species at the various stages of rehabilitation on ash dam grids and natural veld.

3.4 ASSEMBLAGE STRUCTURE OF THE FAMILIES CARABIDAE AND ANTHICIDAE OF THE ORDER COLEOPTERA

Because of the great variation in pooled data the data of two abundant families in the order Coleoptera were separated and analysed. The family Carabidae is a well-researched family and most Coleoptera studies in the Northern Hemisphere are done on this family (Parmenter 1989, Foster 1987, Majer 1989, Majer 1990, Newman 1973, Niemelä 1990, Niemelä 1999, Niemelä, Kotze, Ashworth, Brandmayr, Desender, New, Penev, Samways & Spence 2000). The family Anthicidae tends to show the same tendencies as the family Carabidae and was therefore also included.

3.4.1 Abundance of Carabidae and Anthicidae species at sites in different stages of rehabilitation and abundance in natural veld

Carabidae species were found to be early colonisers of ash dams. Most Carabidae species could be found in the younger rehabilitated areas (ash dams rehabilitated in 1996 and 1995) and few carabid individuals were found in natural veld. Fig. 3.7 illustrates the change in mean number of individuals from the family Carabidae per transect from natural veld to various stages of rehabilitation and shows that few individuals could be found in natural veld. More individuals were found in the unrehabilitated and rehabilitated areas than in natural veld.

After the initial sharp increase in carabid individuals at the start of the rehabilitation process, a steady decrease in individuals was found as rehabilitation progressed. A relatively low number of carabid beetles per grid was characteristic of the natural grassland site. The number of individuals found after three years' rehabilitation is statistical significantly higher than the number found in natural veld ($F_{29}=4.963$, $P=0.014$). Other combinations did not differ significantly.

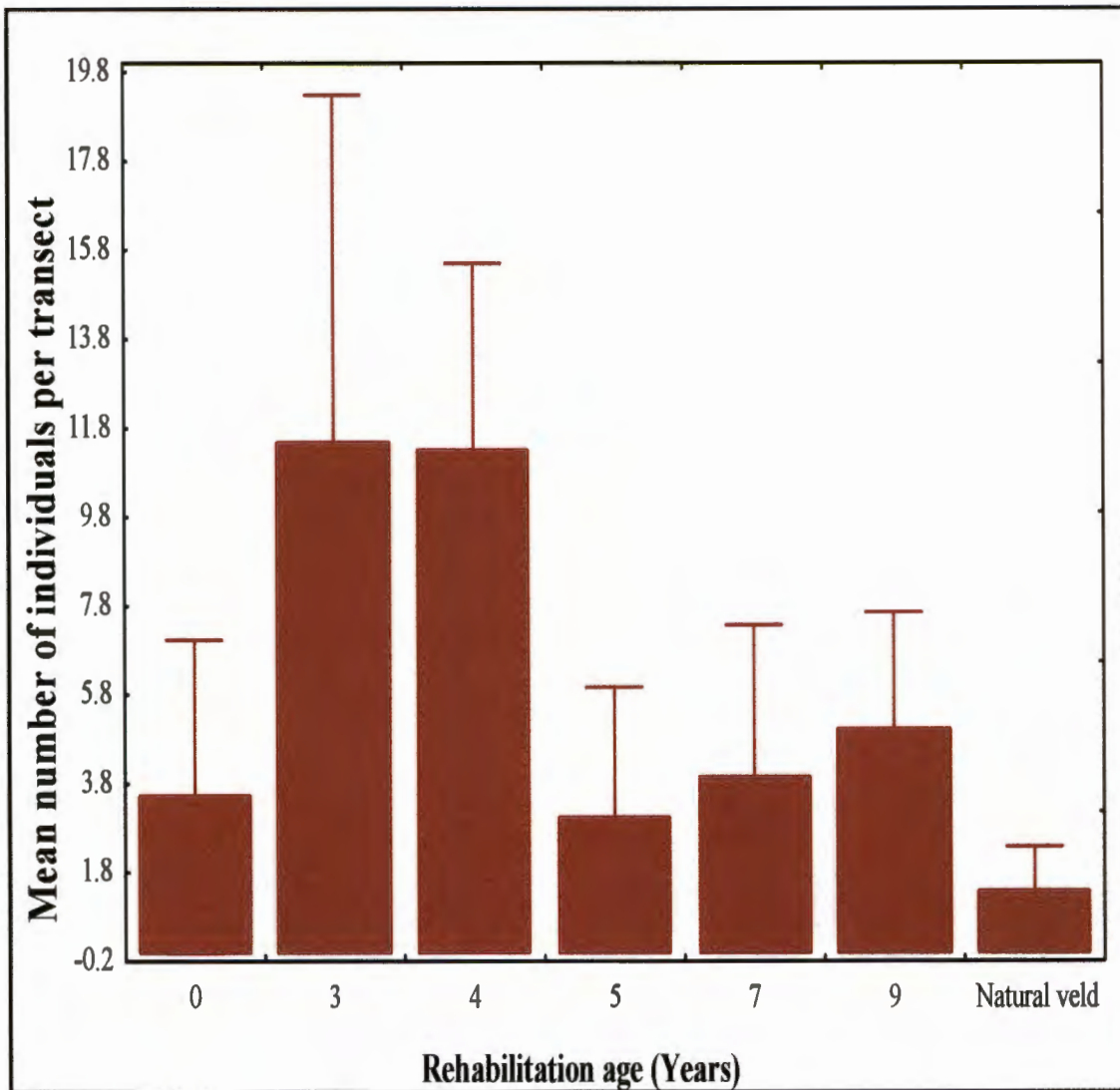


Figure 3.7 Mean number of individuals per transect belonging to the family Carabidae at different ages of rehabilitation of ash dams at Hendrina Power Station.

Individuals of the family Anthicidae show the same colonisation pattern as found for the family Carabidae. The younger rehabilitated areas harbour more individuals per transect than the Natural veld as illustrated by Fig. 3.8. There was a sharp increase in Anthicidae numbers at the younger rehabilitated areas and showed a gradual decrease as rehabilitation aged. Significant differences between abundance of Anthicidae are shown in Table 3.8.

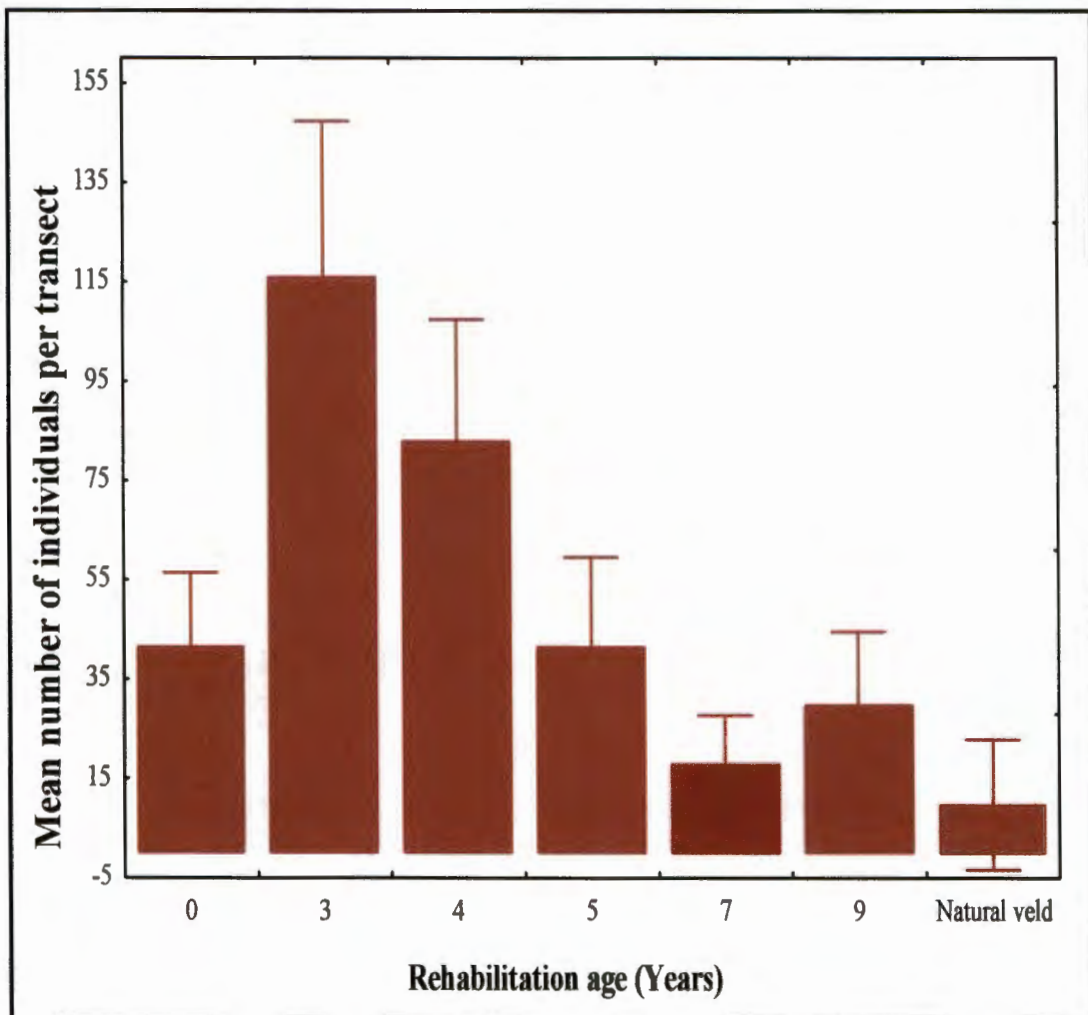


Figure 3.8 Mean number of individuals belonging to the family Anthicidae at different ages of rehabilitation of ash dams at the Hendrina Power Station.

Table 3.8 Statistical significant differences between the mean number of individuals belonging to the family Anthicidae at different ages of rehabilitation of ash dams at the Hendrina Power Station indicated by the P values. Only significant differences ($P < 0.05$) are shown. $F_{29} = 17.75$

Rehabilitation age (Years)	0	3	4	5	7	9	Natural veld
0		0.0014					
3	0.0014			0.0010	0.0002	0.0003	0.0001
4				0.0490	0.0006	0.0060	0.0002
5		0.0010	0.0490				0.0310
7		0.0002					
9		0.0003					
Natural veld		0.0001	0.0002	0.0310			

3.4.2 Species diversity , equitability and number of species of the families Carabidae and Anthicidae at different stages of rehabilitation and in natural veld

Shannon-Wiener diversity index, species equitability and the number of species were calculated for both families at each of the rehabilitation stages. Fig. 3.9 illustrates the Shannon diversity index, equitability and number of species for carabids at each rehabilitation age.

The Shannon diversity index, species equitability and number of species for the family Carabidae at three-year-old rehabilitated ash dams are higher than at unrehabilitated ash dams. With the exception of nine-year-old rehabilitated ash dams, diversity indexes equitability and number of species decreased with an increase in rehabilitation age from thereon and is the lowest in natural veld (Fig. 3.9). Significant differences exists between the Shannon diversity indexes ($P = 0.022$) and mean number of species ($P = 0.002$) at three-year-old

rehabilitated ash dams and natural veld as well as between mean number of species at three-year-old rehabilitated ash dams and five-year-old ($P=0.007$) as well as seven-year-old ($P=0.008$) rehabilitated ash dams.

The mean Shannon diversity index, mean species equitability and mean number of species for the family Carabidae are summarised in Table 3.9.

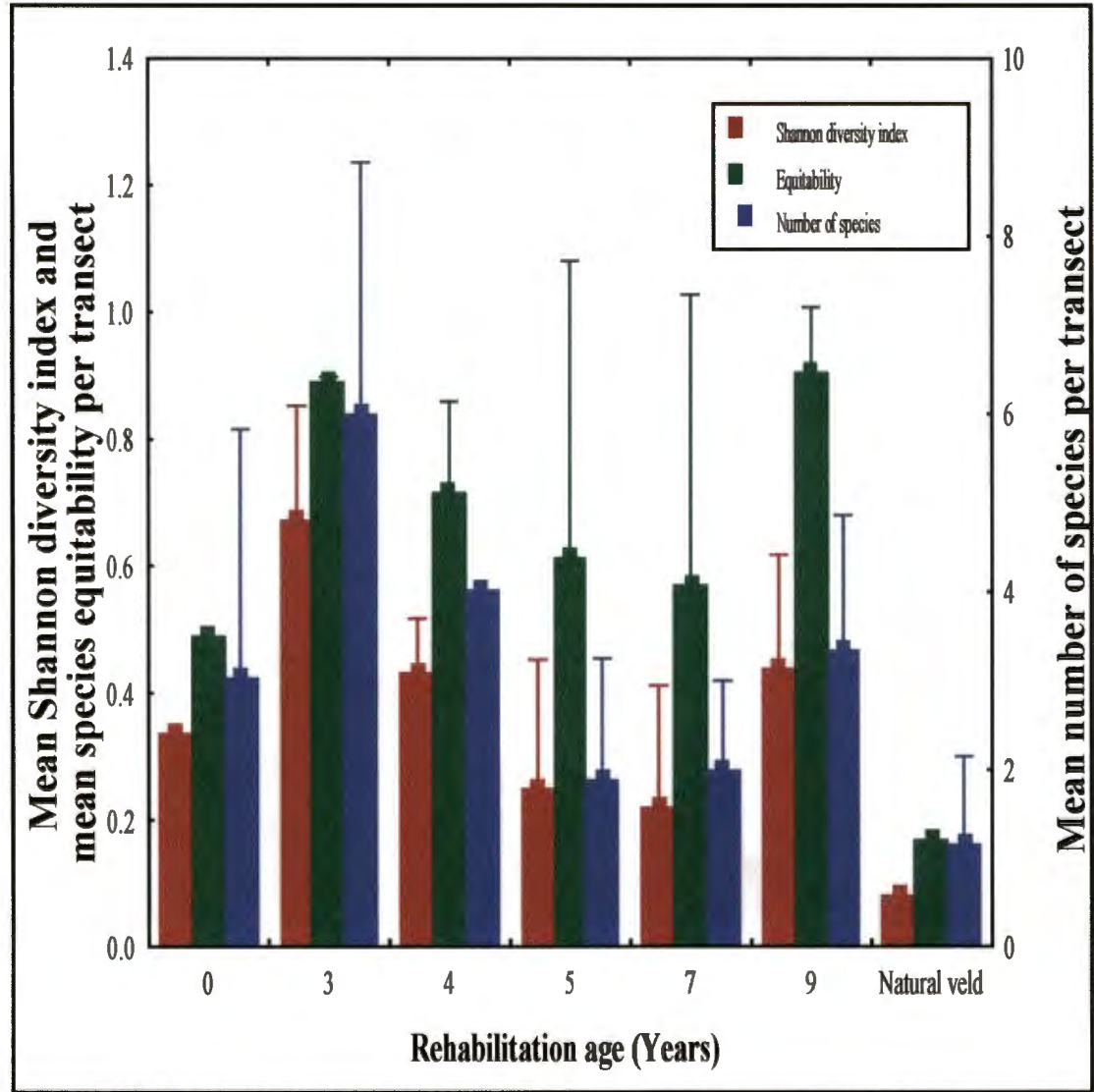


Figure 3.9 Mean Shannon diversity index, mean species equitability and mean number of species per transect for the family Carabidae at different stages of rehabilitation of ash dams at the Hendrina Power station.

Table 3.9 Family Carabidae: Mean Shannon diversity index per transect, Mean Equitability per transect and Mean Number of species per transect in the natural veld and unrehabilitated and rehabilitated ash dams at Hendrina Power Station. The rehabilitated ash dams were rehabilitated at different times. Standard deviation is indicated in brackets.

Rehabilitation age (years)	Mean Shannon diversity index per transect ($\pm$ Std. dev.)	Mean Equitability per transect ($\pm$ Std. dev.)	Mean Number of species per transect ($\pm$ Std. dev.)
0	0.339 (0.479)	0.485 (0.686)	3.000 (2.828)
3	0.670 (0.183)	0.891 (0.008)	6.000 (2.828)
4	0.431 (0.087)	0.715 (0.145)	4.000 (0.000)
5	0.248 (0.204)	0.615 (0.466)	1.889 (1.364)
7	0.221 (0.191)	0.568 (0.460)	2.000 (1.000)
9	0.440 (0.178)	0.902 (0.106)	3.333 (1.528)
Natural veld	0.080 (0.237)	0.167 (0.408)	1.167 (0.983)
ANOVA	$F_{29} = 2.911$ $P=0.024$	$F_{29} = 1.489$ $P=0.217$	$F_{29} = 4.812$ $P=0.0016$

NV 7 5 0 4 9 3
NV 5 7 0 9 4 3

Fig. 3.10 illustrates the Shannon-Wiener diversity index, species equitability and number of species for Anthicidae species at the different rehabilitation ages, including Natural veld.

Shannon diversity index, equitability and number of species for the family Anthicidae remains rather constant regardless of rehabilitation age. However, the values for the Natural veld is slightly lower than those of the ash dam grids (Fig. 3.10). Statistical significant differences exist between 3-year-old rehabilitation and Natural veld.

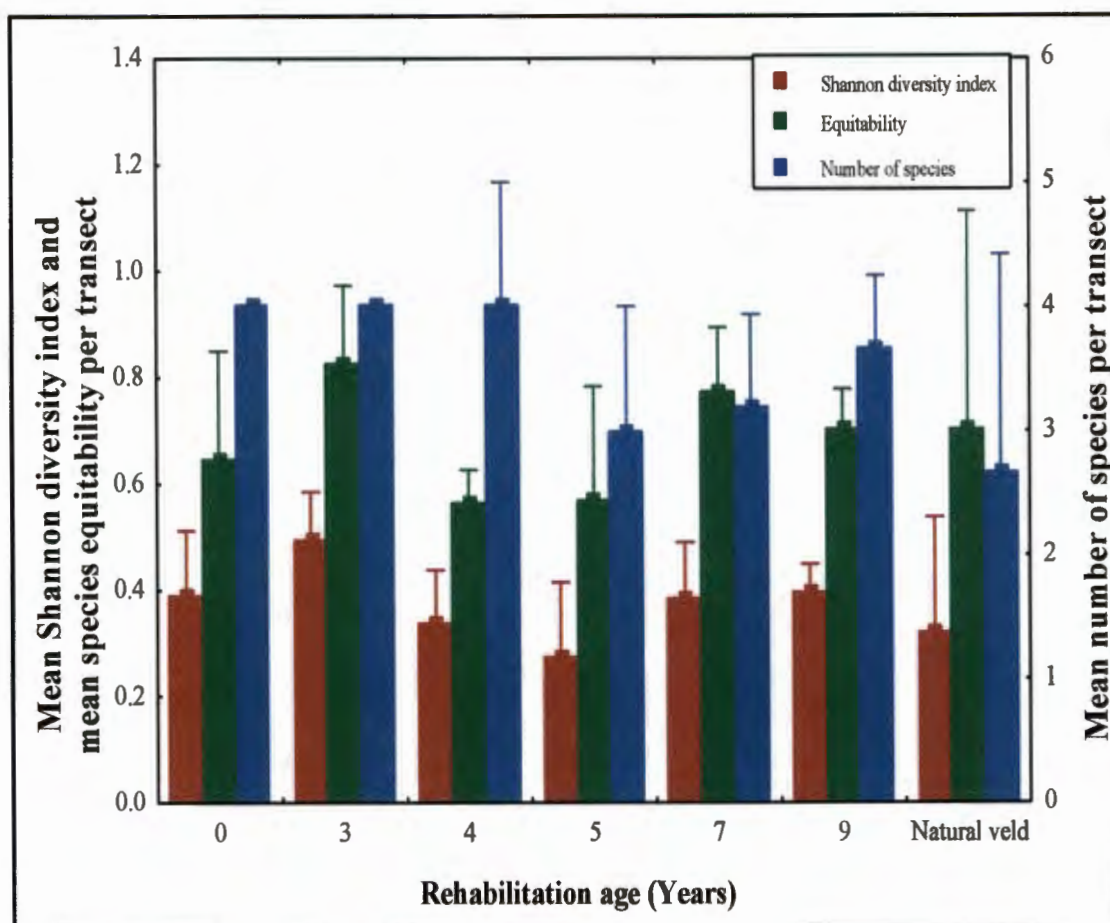


Figure 3.10 Mean Shannon diversity index, mean species equitability and mean number of Anthicidae species per transect at different stages of rehabilitation of ash dams at Hendrina Power station.

The values for mean Shannon diversity index, mean species equitability and mean number of species per transect for the family Anthicidae are summarised in Table 3.10 along with the standard deviations and results of the ANOVA.

Table 3.10 Family Anthicidae: Mean Shannon diversity index per transect, Mean Equitability per transect and Mean Number of species per transect in the natural veld and unrehabilitated and rehabilitated ash dams at Hendrina Power Station. The rehabilitated ash dams were rehabilitated at different times. Standard deviation is indicated in brackets.

Rehabilitation age (years)	Mean Shannon diversity index per transect ($\pm$ Std. dev.)	Mean Equitability per transect ($\pm$ Std. dev.)	Mean Number of species per transect ($\pm$ Std. dev.)
0	0.387 (0.124)	0.643 (0.207)	4.000 (0.000)
3	0.497 (0.088)	0.825 (0.147)	4.000 (0.000)
4	0.339 (0.099)	0.564 (0.062)	4.000 (1.000)
5	0.272 (0.142)	0.571 (0.212)	3.000 (1.000)
7	0.383 (0.107)	0.774 (0.119)	3.182 (0.751)
9	0.394 (0.055)	0.705 (0.072)	3.667 (0.577)
Natural veld	0.320 (0.218)	0.700 (0.412)	2.667 (1.751)
ANOVA	$F_{29} = 1.062$ $P=0.408$	$F_{29} = 0.995$ $P=0.450$	$F_{29} = 1.087$ $P=0.393$

3.5 ASSEMBLAGE STRUCTURE OF THE PREDATORY HERBIVOROUS, DETRITIVOROUS AND SCAVENGER GROUPS IN THE ORDER COLEOPTERA

The different Coleoptera morphospecies were divided into functional groups according to the family to which each morphospecies belong. Table 3.11 gives a summary of the different functional groups and the families belonging to each. Because most species were only in morphospecies level it was assumed that all individuals of a given family belongs to a specific functional group. The species *Harpalus*, belonging to the family Carabidae was grouped as phytophagous instead of a predator like the other individuals belonging to the family Carabidae.

Table 3.11 Coleoptera families caught at the Hendrina power station was grouped in the following functional groups according to feeding behaviour (Clausen 1940).

FUNCTIONAL GROUP	FAMILY
Predators	Anthicidae
	Carabidae (excluding <i>Harpalus</i>)
	Cleridae
	Coccinellidae
	Nitidulidae
Phytophagous	Carabidae (only <i>Harpalus</i>)
	Bostrichidae
	Brentidae
	Cerambycidae
	Chrysomelidae
	Curculionidae
	Elateridae
	Meloidae
	Melyridae
	Mordellidae
Detritivores	Phalacridae
	Scarabaeidae
Scavengers	Trogidae
	Histeridae
	Staphylinidae
	Tenebrionidae

Fig. 3.11 shows the relative number of species of each functional group at different rehabilitation ages. At unrehabilitated ash dams the number of Predator species were the highest of all functional groups, but decreased with an increase in rehabilitation age, increasing again at seven and nine-year-old rehabilitated ash dams. The sudden increase at seven and nine-year-old rehabilitated ash dams could indicate the unsustainability of the rehabilitation. The number of Phytophagous beetle species was low on unrehabilitated ash dams and increased with an increase in rehabilitation age. The number of species decreased at nine year old rehabilitated ash dams.

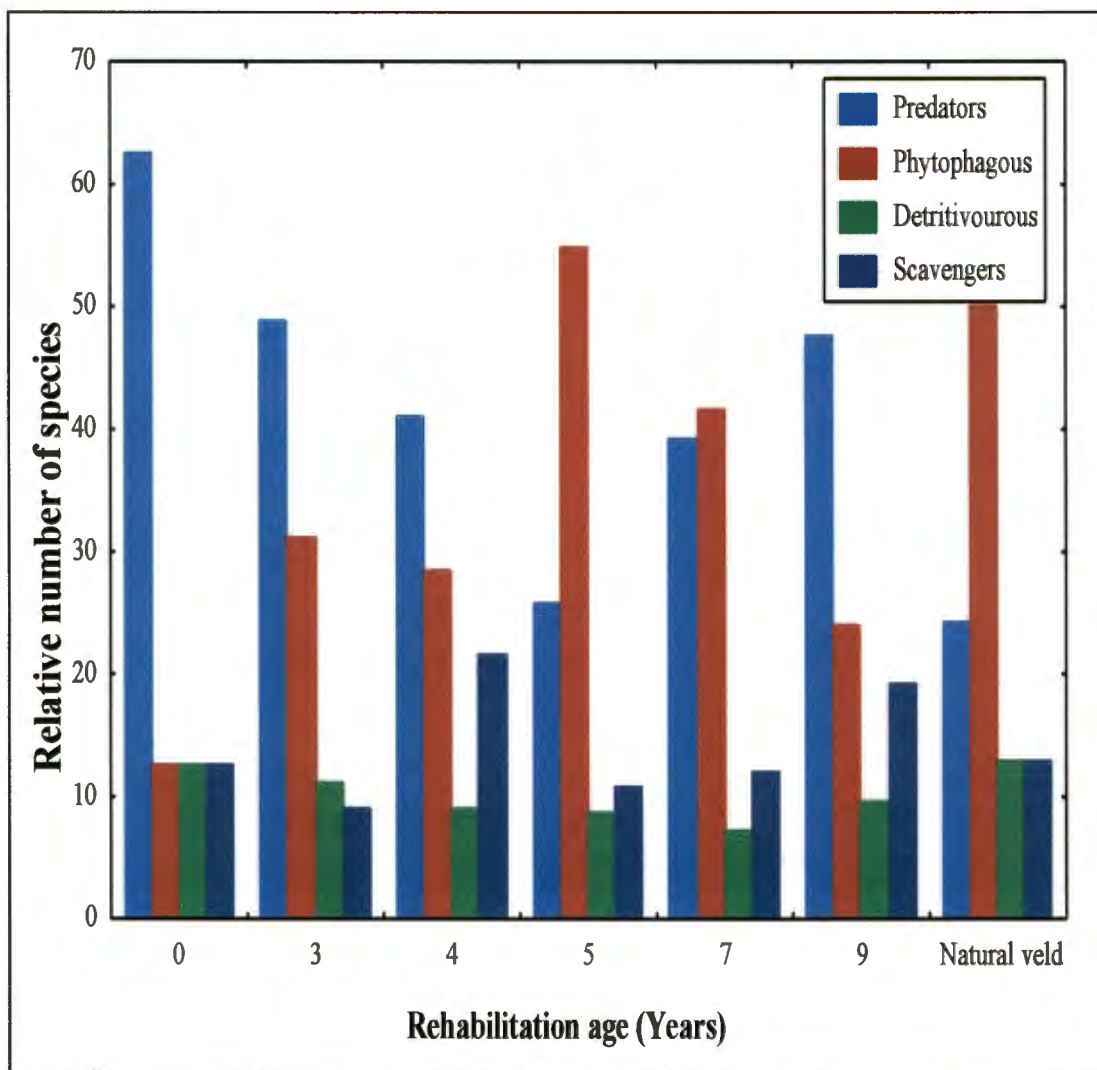


Figure 3.11 Relative number of species of each functional group at different rehabilitation ages of ash dams at Hendrina Power Station.

Mean number of individuals per transect were used to draw graphs to show the difference in numbers of functional groups between the different rehabilitation stages. Predators are shown in Fig. 3.12, phytophagous insects in Fig. 3.13 while detritivores and scavengers are shown in Fig. 3.14 and Fig. 3.15 respectively.

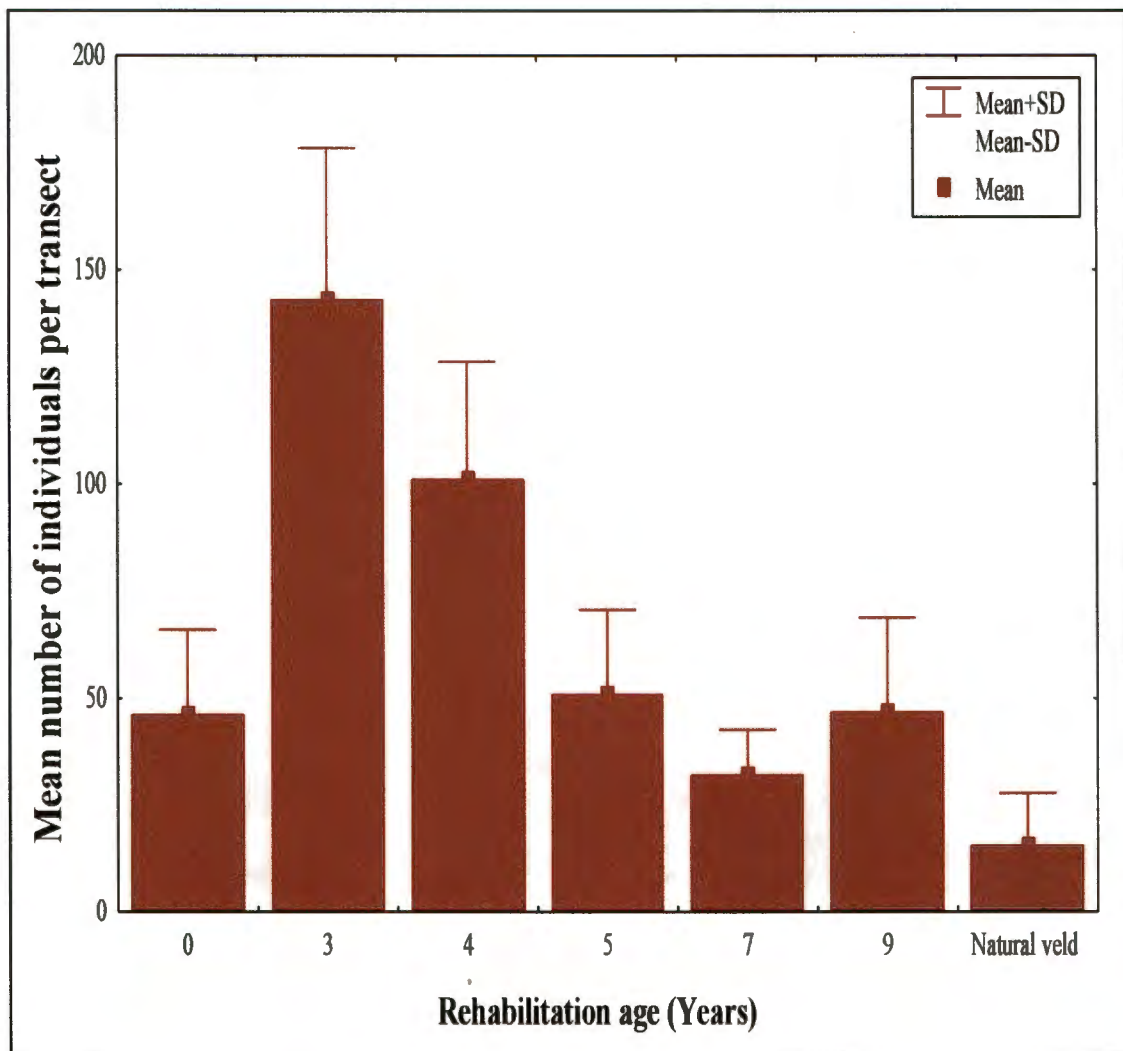


Figure 3.12 Mean number of predaceous coleopteran individuals per transect at different rehabilitation ages on the Hendrina ash dams and in natural veld.

Predaceous beetles are more abundant on newly rehabilitated ash dam grids than on older rehabilitated ash dams. Natural veld has less predaceous beetles individuals per grid than rehabilitated and unrehabilitated ash dam grids. Predators are already found on unrehabilitated ash dam grids, probably to utilise the prey already present. Predators are most abundant on three old rehabilitated fields and decrease with an increase in rehabilitation age from there on except for nine year old rehabilitated ash dams (see also Fig. 3.9). Significant differences are shown in Table 3.12.

Table 3.12 Statistical significant differences between the mean number of predacious coleopteran individuals at different ages of rehabilitation of ash dams at the Hendrina Power Station indicated by the P values. Only significant differences ($P < 0.05$) are shown. $F_{29} = 19.011$

Rehabilit ation age (Years)	0	3	4	5	7	9	Natural veld
0		0.0003					
3	0.0003			0.0004	0.0002	0.0003	0.0001
4				0.0260	0.0010	0.0130	0.0002
5		0.0004	0.0260				0.0230
7		0.0003	0.0010				
9		0.0003	0.0130				
Natural veld		0.0001	0.0002	0.023			

Very low numbers of phytophagous Coleoptera individuals were sampled on unrehabilitated ash dam grids. Thereafter there was a tendency for numbers to increase with an increase of rehabilitation age. There were a drop in phytophagous coleopteran numbers from five to seven year old rehabilitated ash dam grids, but an increase in numbers from the seven to nine year old rehabilitated ash dam grids. Natural veld had higher numbers of individuals than unrehabilitated and younger rehabilitated ash dam grids, but lower than five and nine year old rehabilitated grids (Fig. 3.13). Significant differences are shown in Table 3.13.

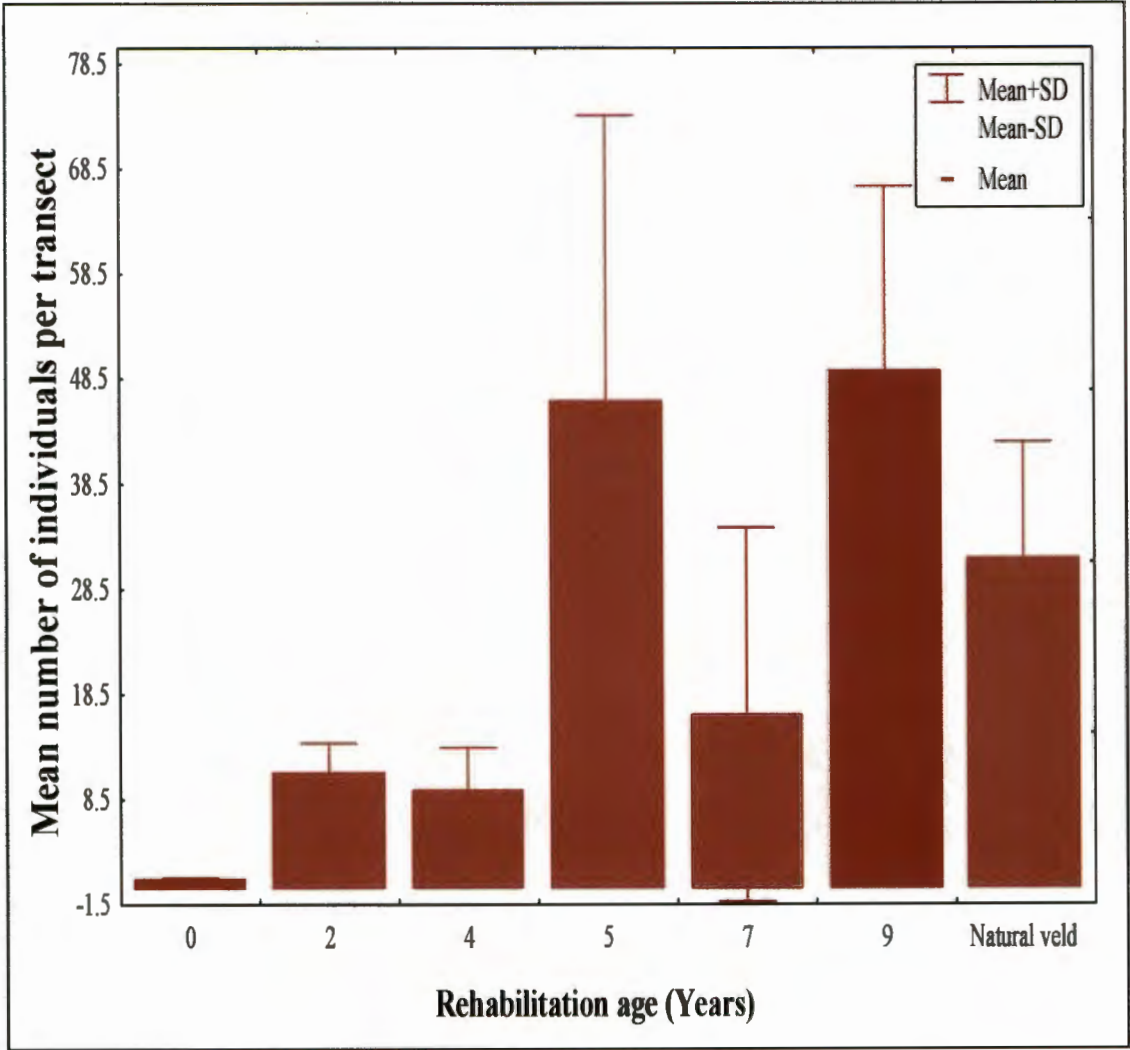


Figure 3.13 Mean number of phytophagous coleopteran individuals per transect at different rehabilitation ages on the Hendrina ash dams and in natural veld.

Table 3.13 Statistical significant differences between the mean number of phytophagous coleopteran individuals at different ages of rehabilitation of ash dams at the Hendrina Power Station indicated by the P values. Only significant differences ($P < 0.05$) are shown. $F_{29} = 4.184$

Rehabilitation age (Years)	0	3	4	5	7	9	Natural veld
0				0.005		0.009	
3				0.024		0.034	
4				0.006		0.015	
5	0.005	0.024	0.006		0.002		
7				0.002		0.013	
9	0.009	0.034	0.015		0.013		
Natural veld							

Very low numbers of detritivorous Coleoptera individuals were sampled on unrehabilitated ash dam grids and in the Natural veld (Fig. 3.14). Higher numbers were found on two year old rehabilitated grids and decreases again at four year old grids. From then on it gradually increased with an increase in rehabilitation age. Significant differences are shown in Table 3.14.

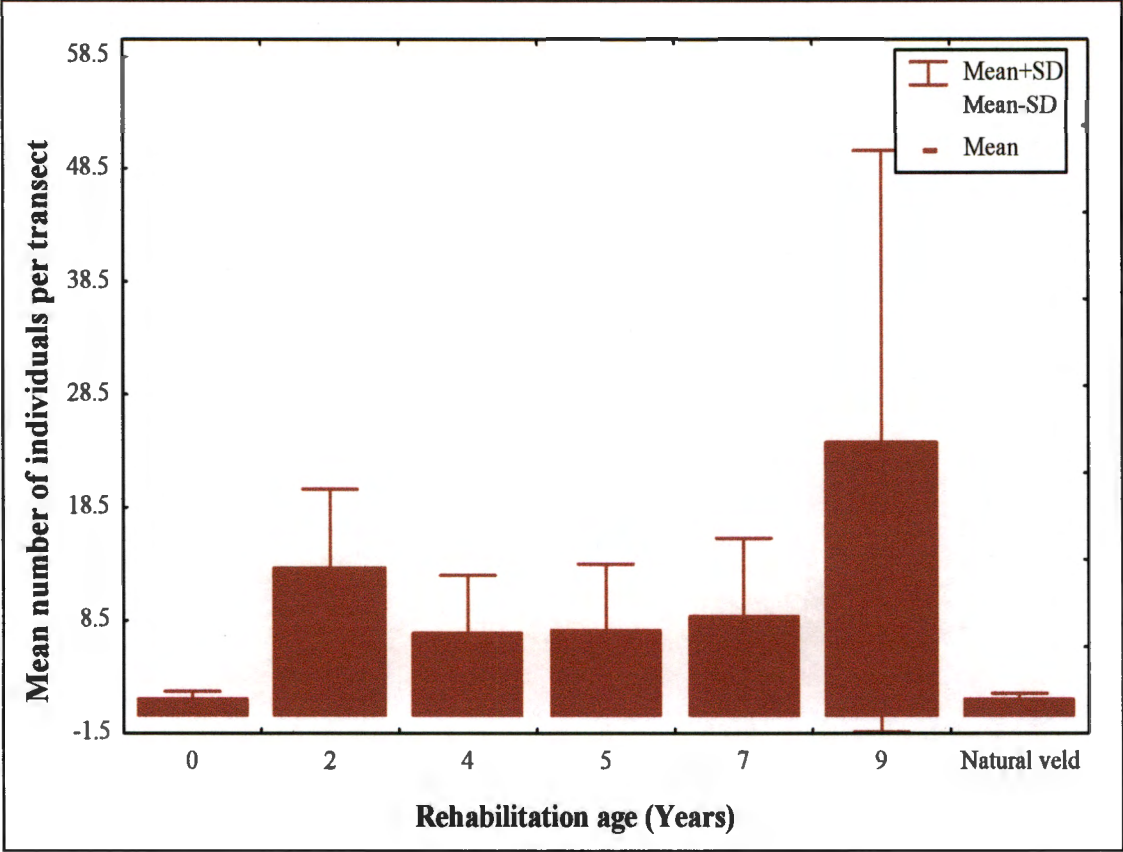


Figure 3.14 Mean number of detritivorous coleopteran individuals per transect at different rehabilitation ages on the Hendrina ash dams and in natural veld.

Table 3.14 Statistical significant differences between the mean number of detritivorous coleopteran individuals at different ages of rehabilitation of ash dams at the Hendrina Power Station indicated by the P values. Only significant differences ($P < 0.05$) are shown. $F_{29} = 2.656$

Rehabilitation age (Years)	0	3	4	5	7	9	Natural veld
0						0.007	
3							
4						0.023	
5						0.007	
7						0.011	
9	0.007		0.023	0.007	0.011		0.001
Natural veld						0.001	

Low numbers of scavenger individuals occurred on unrehabilitated ash dam grids and increases with an increase in rehabilitation age (Fig. 3.15). Four year old rehabilitated grids had a large number of individuals. Significant differences is shown in Table 3.15.

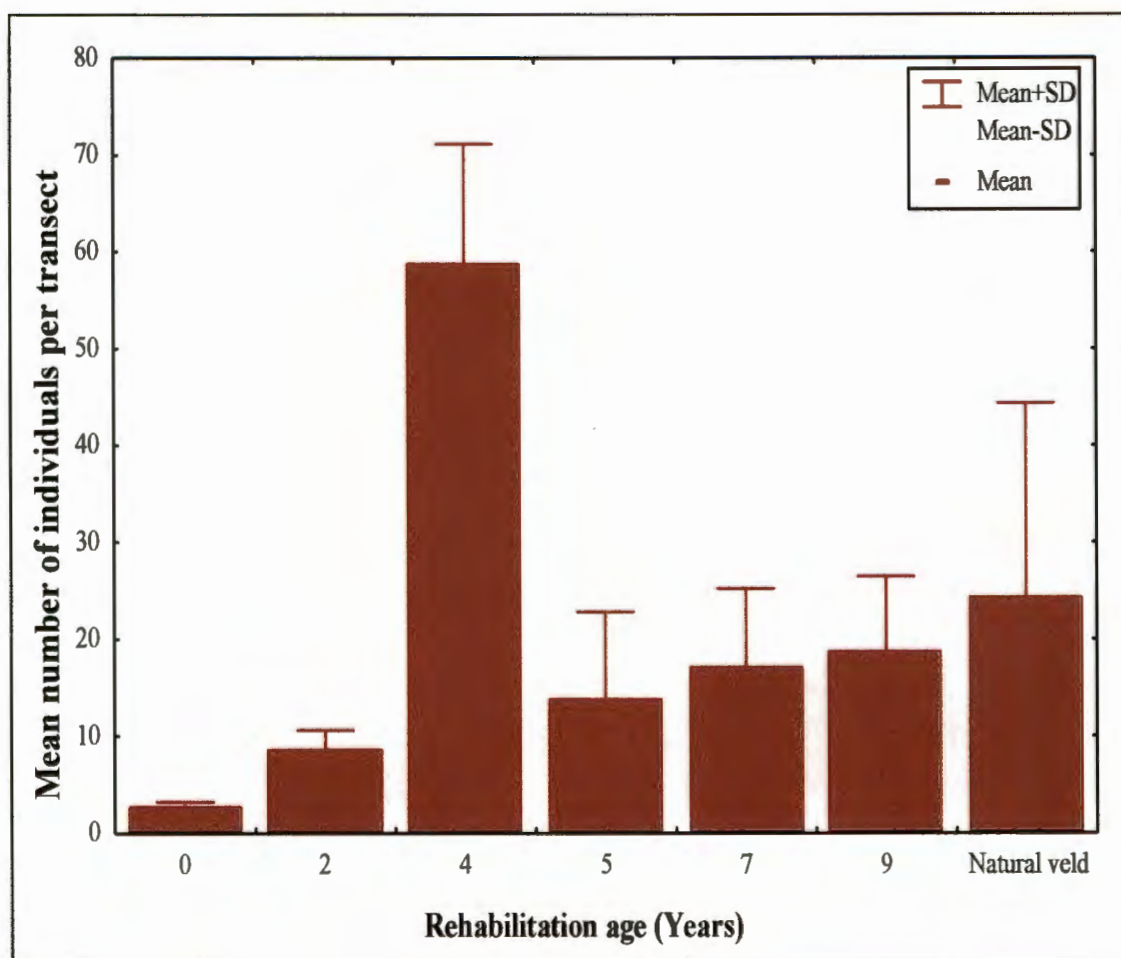


Figure 3.15 Mean number coleopteran scavenger individuals per transect at different rehabilitation ages on the Hendrina ash dams and in natural veld.

Table 3.15 Statistical significant differences between the mean number of scavenger coleopteran individuals at different ages of rehabilitation of ash dams at the Hendrina Power Station indicated by the P values. Only significant differences ($P < 0.05$) are shown. $F_{29} = 7.558$

Rehabilitation age (Years)	0	3	4	5	7	9	Natural veld
0			0.0007				
3			0.0025				
4	0.0007	0.0025		0.0009	0.0020	0.0030	0.0140
5			0.0009				
7			0.0020				
9			0.0030				
Natural veld			0.0140				

3.6 THE INFLUENCE OF SELECTED BIOTIC AND ABIOTIC VARIABLES ON COLEOPTERA ASSEMBLAGE STRUCTURE

The aim of this analysis is

- (1) to identify correlation between Coleoptera species diversity and different plant variables, including plant species diversity and percentage vegetation cover;
- (2) to identify correlation between Coleoptera species diversity and soil structure. Soil structure includes percentage gravel, percentage sand, percentage silt and percentage clay. Coleoptera species diversity was compared with physical soil variables such as electrical conductivity and percentage Carbon content; and
- (3) to determine if any relationships exist between Coleoptera species and plant species in the various grids

3.6.1 Ordination of Coleoptera species to determine distribution in relation to different environmental factors

With the use of ordination techniques the distribution of species and their relationship to environmental parameters could easily be determined (Gauch 1982, Ter Braak 1987, Peet, Knox, Case & Allen 1988).

The following ordination diagrams were constructed: 1) DCA (Detrended Correspondence Analysis, by segments) to illustrate the Coleoptera species distribution in relation to rehabilitation status and –age, 2) a CCA (Canonical Correspondence Analysis) to show the influence of plant species on the distribution of Coleoptera species and 3) a CCA to show the influence of soil parameters on the distribution of Coleoptera species.

3.6.1.1 Ordination of Coleoptera species to determine the distribution of species in relation to rehabilitation status

DCA, an indirect gradient analysis based on distribution of species abundance values, were used to determine the distribution of species between unrehabilitated ash dams, rehabilitated ash dams and the natural veld.

Eigenvalues of 0.439 and 0.171 respectively were obtained for the first two axis. The gradient length for the first ordination axis was 2.388, which indicates that no statistical significant gradient existed between the different sites (Fig. 3.16). A gradient length of 4 is considered to show statistically significant gradient between sites. This means that there were no variables, which had a meaningful influence on the distribution of the species. No sites could therefore be treated separately from the others when environmental factors are considered.

3.6.1.2 Ordination of Coleoptera species in relation to plant species on rehabilitated ash dams

CCA (Canonical Correspondence Analysis) techniques were used to determine the relationship between species distribution and various environmental parameters such as plant parameters (Kremen 1992).

A CCA was done on the Coleoptera data in relation to plant data. Only summer and autumn data were used when both Coleoptera and plant species were abundant.

The significance of plant data on the Hendrina ash dams in relation to the Coleoptera species distribution was determined by means of the Monte Carlo testing (bootstrapping) of the axis associated with the specific variables. The axis eigenvalue was used as the test statistic (Ter Braak & Prentice 1988). Only those plant parameters that had a statistically meaningful influence on the distribution of species were considered.

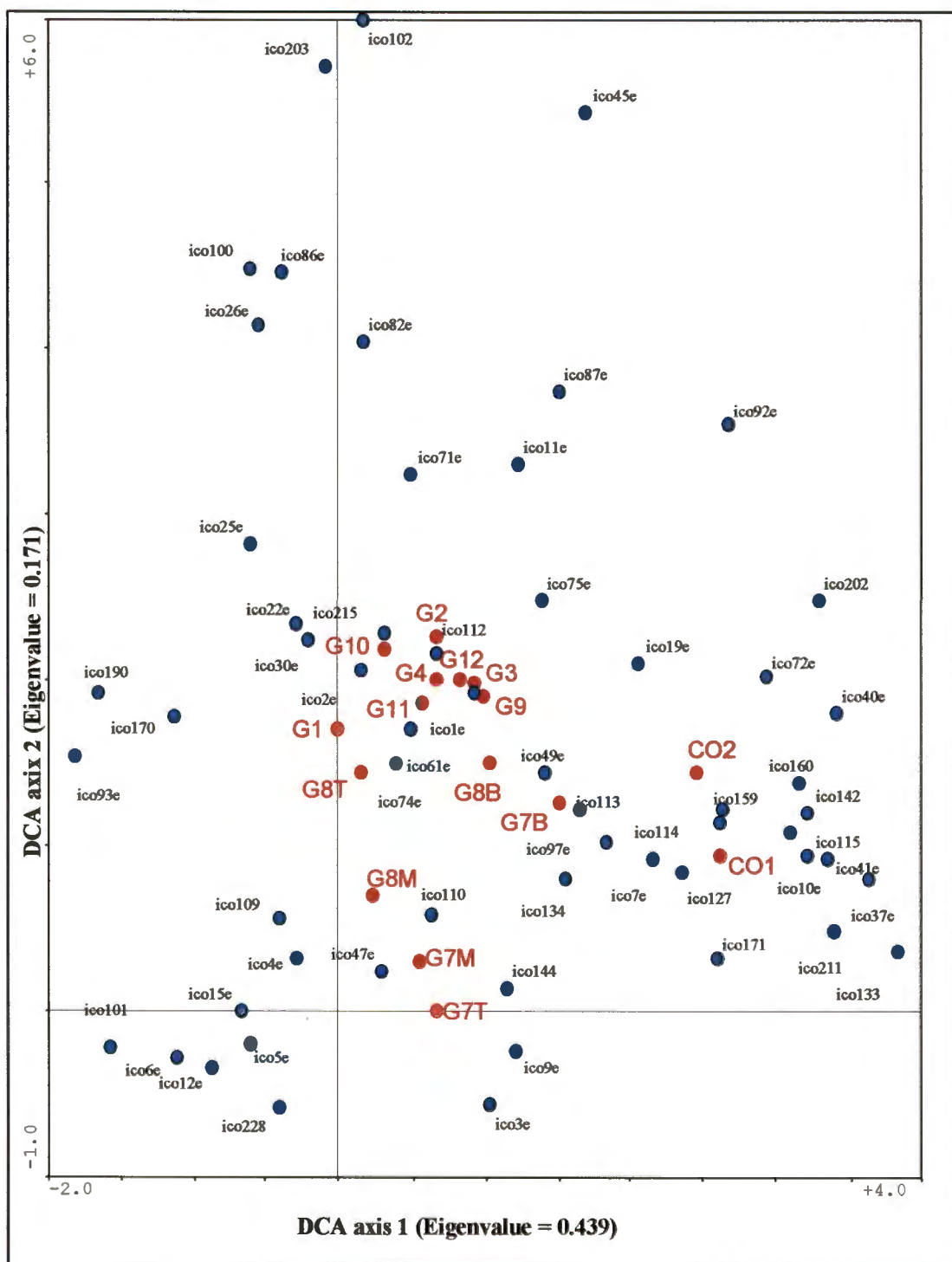


Fig. 3.17 shows the distribution of Coleoptera species in relation to the plant species that had a significant influence on the distribution on the beetles.

Bidens formosa had the largest influence on the distribution of Coleoptera species, followed by *Tagetes minuta*, *Schkuria pinnata* and *Conyza bonariensis*. The P- and F-values of these plant species are summarised in Table 3.16.

Table 3.16 Significant relationship between distribution of different plant species on the distribution of Coleoptera species

VARIABLE	CONDITIONAL EFFECTS	
	P	F
<i>Tagetes minuta</i>	0.010	3.260
<i>Bidens formosa</i>	0.060	2.460
<i>Schkuria pinnata</i>	0.005	2.460
<i>Conyza bonariensis</i>	0.050	2.090

There is a significant relationship between the distribution of *Schkuria pinnata* and Coleoptera species on Grids 1, 3, 9, 11 and 12. Species in association with *Schkuria pinnata* are *Zophosis* sp. (ico2e), *Erenmus angustirostris* (ico72e), *Lalagetes* sp. (ico71e), *Astylus atromaulatus* (ico61e), *Pseudivongius aeneus* (ico75e), *Estcourtiana litura* (ico112e).

A significant relationship exists between the distribution of *Tagetes minuta* and beetles on the sites rehabilitated in 1996, grids 7 and 8 middle. Morphospecies that occurred in association with *Tagetes* are ico109e (Family Chrysomelidae) and ico110e (Family Coccinellidae)

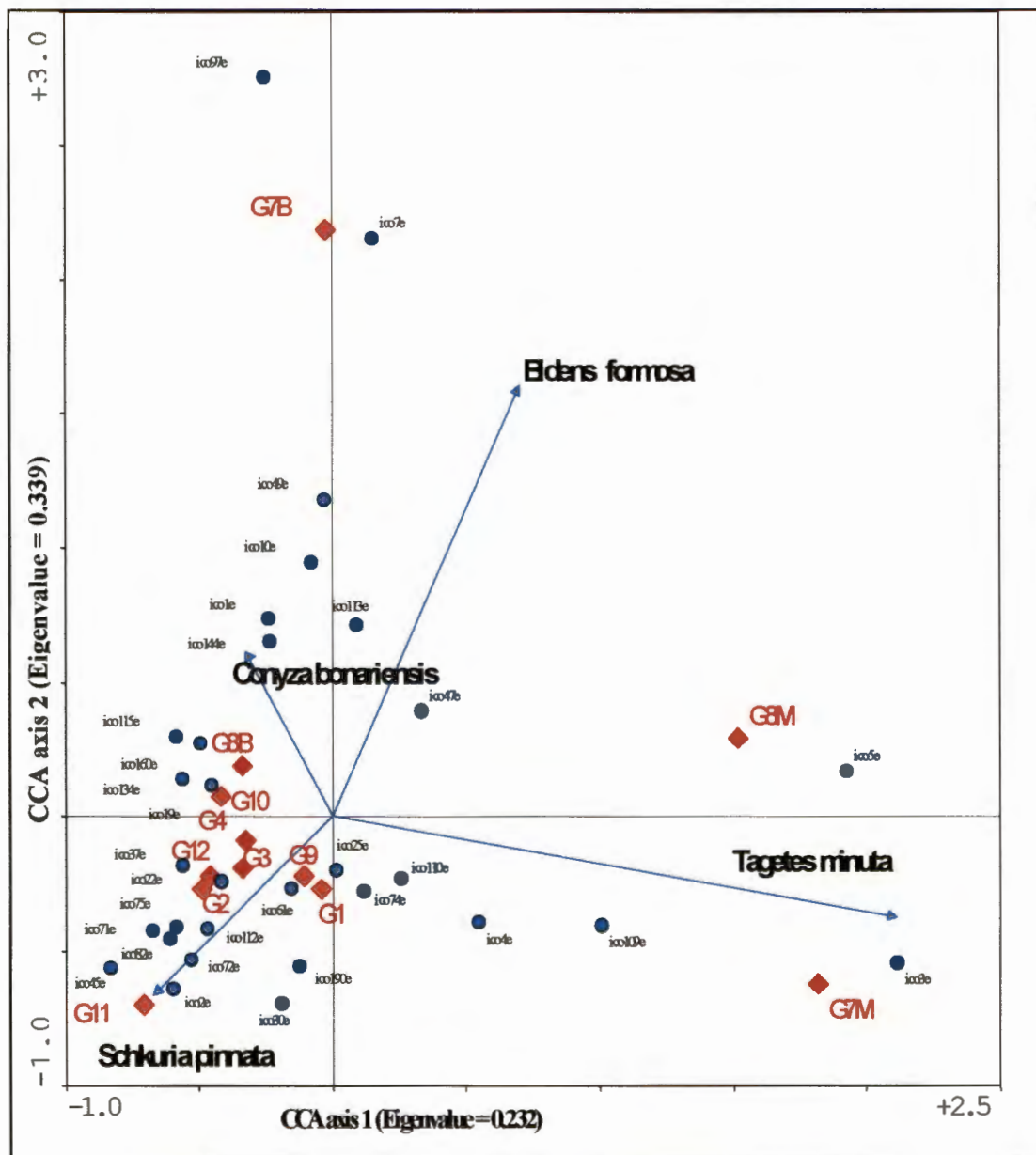


Figure 3.17 Ordination diagram for CCA showing the distribution of Coleoptera species in relation to the plant species which had a significant influence on the distribution of Coleoptera species. The length of the gradient is 2.388 units indicating that no statistically meaningful gradient exist between the distribution of Coleoptera species between the different sites.

The distribution of Coleoptera species on grids 4, 10 and grid 8 bottom were significantly associated with *Conyza bonariensis*. Beetles that occurred together with *Conyza* are *Rhyssalus atramentarius* (ico1e), *Chrysocephalus bistrigatus* (ico160e), ico144e (Family Coccinellidae) and ico115e (Family Phalacridae).

The distribution of *Gonocephalum simplex* and ico113e (Family Chrysomelidae) were mostly associated with *Bidens formosa*

The distribution of most of the Coleoptera species were associated with *Schizura pinnata* followed by *Tagetes minuta*.

3.6.1.3 Ordination of Coleoptera species in relation to soil parameters on rehabilitated ash dams

A CCA was done on the Coleoptera data in relation to soil parameters. Only soil data for 1997 were available. Because soil data were unlikely to change much in one year's time, Coleoptera data for the whole of 1997 were compared to these soil parameters.

Only soil parameters that showed a statistically meaningful influence on the distribution of Coleoptera species were used in the CCA diagram (Fig. 3.18). P- and F-values of the influence of soil variables on the distribution of Coleoptera species are summarised in Table 3.17.

Table 3.17 Significant influence of soil variables on the distribution of Coleoptera species

VARIABLE	CONDITIONAL EFFECTS	
	P	F
pH	0.010	2.270
Electrical Conductivity	0.025	1.920
Percentage Carbon	0.070	2.050
Percentage Sand	0.520	0.940
Percentage Clay	0.445	1.010
Percentage Gravel	0.660	0.780
Percentage Silt	0.750	0.530

Electrical conductivity showed the largest influence on the distribution of Coleoptera species, followed by pH, percentage gravel, percentage sand, percentage silt, percentage carbon and percentage clay.

pH had a significant effect on the distribution of species on grid 2 and grid 7 bottom. Species of which the distribution was influenced by pH included *Lalagetes* sp. (ico71e), *Notoxus* sp. (ico74e) and *Pseudivongius aeneus* (ico75e).

The Carbon composition of the soil had a significant influence on the distribution of the following species: *Rhyssemus atramentarius* (ico1e), *Gonocephalum simplex* (ico47e), *Formicomus caeruleus* (ico22e), *Chryptocephalus bistrupustalatus* (ico160e), *Erenmus angustirostris* (ico72e), *Lagria* sp. (ico10e), *Zophosis* sp. (ico2e) and *Graphipterus circumcinctus* (ico30e).

Electrical conductivity had a significant influence on *Scymnus levaillanti* (ico49e), ico9e, ico113e and ico 109 (Family Chrysomelidae), ico97e (Family Staphylinidae), ico7e, ico110e and ico19e (Family Coccinellidae), *Harpalus* sp4 (ico4e) and ico12e (Family Carabidae).

Because other species could conceal the direct effects of soil parameters on ground dwelling Coleoptera species, a CCA were done where only ground beetle (Carabidae and Anthicidae) data were used.

According to the Monte Carlo permutation test applied to the ground beetle data and soil parameters there were no statistical significant influence of soil parameters on the distribution of ground beetles. Table 3.18 summarises the P- and F-values of the influence of soil parameters on the distribution of ground beetles.

Table 3.18 Significant influence of soil variables on the distribution of ground dwelling Coleoptera species

VARIABLE	CONDITIONAL EFFECTS	
	P	F
PH	0.055	1.65
Percentage Sand	0.080	1.73
Percentage bare ground	0.17	1.24
Percentage Silt	0.19	1.24
Percentage Clay	0.205	1.4
Electrical conductivity	0.235	1.4
Percentage Carbon	0.39	0.71
Percentage Gravel	0.575	0.65

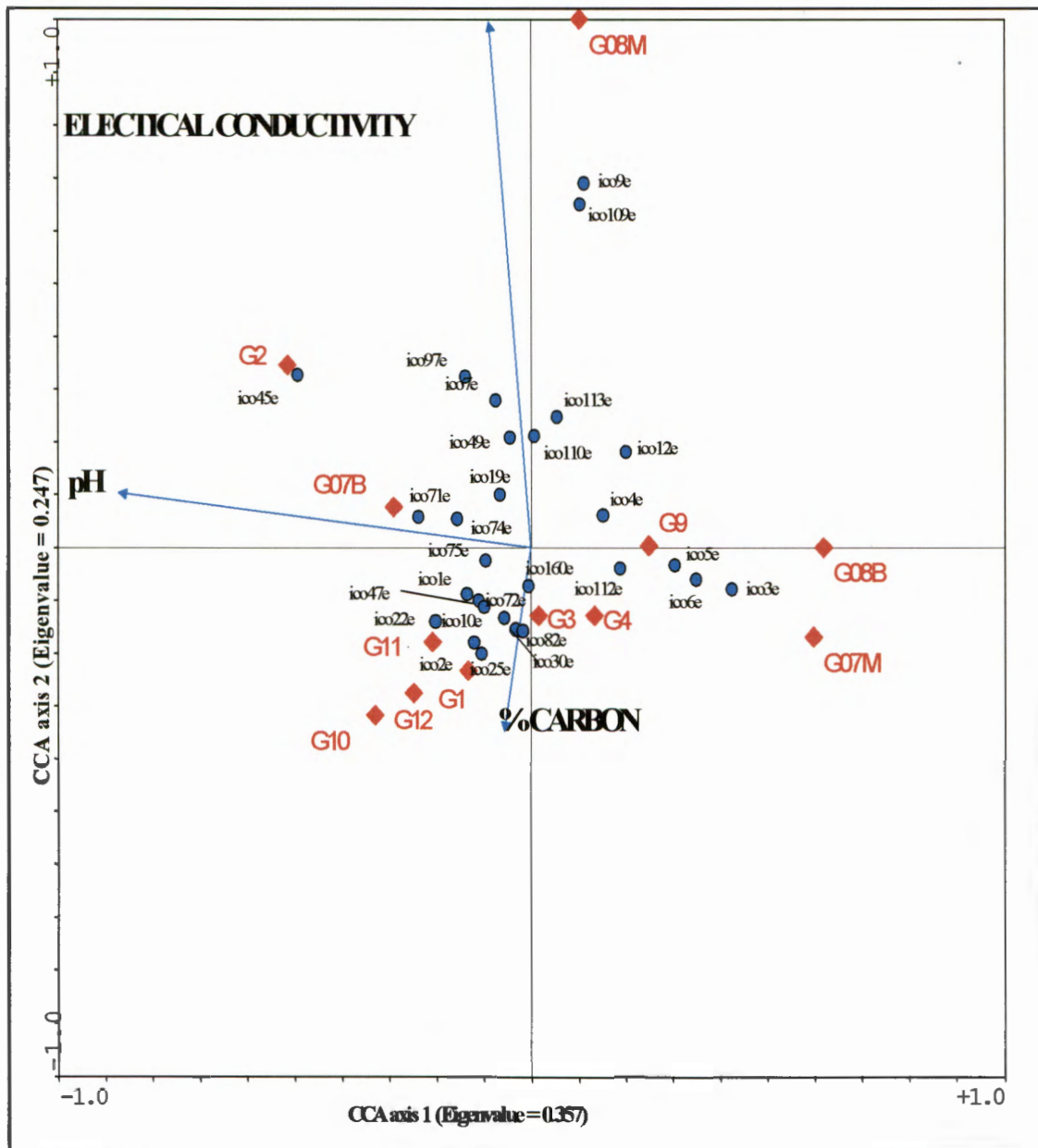


Figure 3.18 Ordination diagram for CCA showing the distribution of Coleoptera species in relation to soil factors which had a significant influence on the distribution of Coleoptera species. The length of the vector indicates how significant the relationship

3.6.2 The relationship between Coleoptera species diversity and plant species diversity as well as percentage vegetation cover

The term species diversity includes both equitability and species richness. The use of species diversity would therefore in future include the terms equitability and species richness. Because plant communities in the natural veld were rather constant throughout the study period, these data was omitted during the analysis. Winter Coleoptera data was omitted as well because of the huge variation in winter data.

The relationship between Coleoptera species diversity on the ash dams and plant species diversity and percentage vegetation cover was investigated. Results of the linear regression analysis are summarised in Table 3.19.

Significant correlation is given $P < 0.05$ while $r^2 \times 100$ shows the percentage variation explained by the parameters.

No significant relationships between any of the Coleoptera and plant parameters were found. Only a small percentage of the variation in Coleoptera data could be explained by the plant parameters by means of regression analysis.

Most variation in Coleoptera species richness is explained by plant species richness (11.9%).

Table 3.19: Regression analysis on data at Hendrina Power Station between Coleoptera species diversity, -species equitability and -species richness and Plant species diversity, -species equitability, -species richness and percentage vegetation cover on rehabilitated ash dams. The correlation coefficient (r) and the coefficient of determination (r^2) are given. $P < 0.05$ indicate significant relationships.

SOURCE OF VARIANCE	COLEOPTERA SHANNON DIVERSITY			COLEOPTERA SPECIES EQUITABILITY			COLEOPTERA SPECIES RICHNESS		
	p	r	r^2	p	r	r^2	p	r	r^2
Plant Shannon diversity	0.963	0.009	0.000	0.520	0.127	0.016	0.994	-0.001	0.000
Plant species equitability	0.978	-0.027	0.000	0.371	0.176	0.031	0.171	-0.266	0.071
Plant species richness	0.527	0.125	0.016	0.556	-0.116	0.013	0.072	0.345	0.119
Vegetation cover (%)	0.173	0.265	0.070	0.700	0.076	0.006	0.335	0.189	0.036

3.6.3 The relationship between Coleoptera species diversity and soil variables

Soil structure affects the microclimate of soil and may affect decomposition and mineralization of the soil (Adriano *et al.* 1980). Coleoptera species diversity is influenced by soil structure (Georges 1994). For this reason Coleoptera species diversity were correlated with soil structure and physical soil variables. Soil structure variables included percentage gravel, percentage sand, percentage clay and percentage silt. The relationship between Coleoptera species diversity and physical soil variables such as pH, electrical conductivity and Carbon content were investigated. Electrical conductivity can be used as a measure of salinity of the soil while pH plays a role in determining availability of nutrients (Grunwald, Iverson & Szafoni 1995).

3.6.3.1 The relationship between Coleoptera species diversity (with all Coleoptera species included) and soil variables

Soil parameters were only measured in the winter survey of 1997. Due to the fact that it is unlikely for the soil parameters to change during the course of a year, soil variables were applied to the Coleoptera data for the whole of 1997. Natural grassland and unrehabilitated areas were also excluded from the data.

Table 3.20 gives a summary of the results from the linear regression done between Coleoptera species data and soil parameters obtained from the Hendrina power station during 1997.

Significant contributions of each soil variable to each of the components of species diversity is given by the coefficient of determination (r^2) while $r^2 \times 100$ shows the percentage variation.

Most components of Coleoptera species diversity were not significantly correlated with soil parameters. However, species richness and species diversity was negatively correlated with the percentage clay as well as soil pH and positively correlated with the percentage organic matter (represented by the percentage Carbon). Species diversity was also positively correlated with percentage organic matter.

14.4 % of the variation in species richness could be explained by the percentage clay, 14.7 % by the soil pH while 22.8 % of variation could be explained by the percentage organic matter. Percentage organic matter could explain 16.5% of the variation in Coleoptera species diversity.

Table 3.20: Regression analysis on 1997 data of Hendrina Power Station between Coleoptera species diversity, -species equitability and –species richness and soil characteristics on rehabilitated ash dams. The correlation coefficient (r) and the coefficient of determination (r²) are given. P<0.05 show significant relationships.

SOURCE OF VARIANCE		COLEOPTERA SHANNON DIVERSITY			COLEOPTERA SPECIES EQUITABILITY			COLEOPTERA SPECIES RICHNESS		
		p	r	r ²	p	r	r ²	p	r	r ²
Percentage gravel	Fraction of particle size	0.548	-0.119	0.014	0.229	-0.235	0.055	0.569	0.112	0.013
Percentage sand		0.216	0.241	0.058	0.743	0.065	0.004	0.458	0.146	0.021
Percentage silt		0.787	-0.053	0.003	0.733	-0.067	0.004	0.828	0.043	0.002
Percentage clay		0.053	-0.369	0.136	0.808	0.482	0.232	0.047	-0.379	0.144
pH		0.315	-0.197	0.039	0.442	-0.151	0.023	0.044	-0.383	0.147
Electrical conductivity		0.134	0.290	0.084	0.702	0.076	0.006	0.175	0.264	0.070
Organic matter (%C)		0.032	0.406	0.165	0.942	0.015	0.000	0.010	0.478	0.228

The regression between Coleoptera species richness and percentage clay composition, soil pH and percentage Carbon composition are illustrated in Fig. 3.19, Fig. 3.20 and Fig. 3.21. The regression between Coleoptera species diversity and percentage Carbon composition is illustrated in Fig. 3.22.

3.6.3.2 The relationship between Coleoptera species diversity (only ground beetles) and soil variables

To determine the relationship between soil parameters and ground dwelling beetles (Family Carabidae and Family Anthicidae) correlation were drawn

between soil parameters and the different components of ground beetle species diversity. Only ground beetle data were used.

The results of a linear regression analysis on components of ground beetle diversity and soil parameters are summarised in Table 3.21.

Table 3.21 Regression analysis on 1997 data of Hendrina Power Station between ground beetle species diversity, -species equitability and -species richness and soil characteristics on rehabilitated ash dams. The correlation coefficient (r) and the coefficient of determination (r^2) are given. $P < 0.05$ show significant relationships.

SOURCE OF VARIANCE		COLEOPTERA SHANNON DIVERSITY			COLEOPTERA SPECIES EQUITABILITY			COLEOPTERA SPECIES RICHNESS		
		P	r	r ²	P	r	r ²	P	r	r ²
Percentage gravel	Fraction of particle size	0.479	-0.140	0.020	0.376	-0.174	0.030	0.515	0.128	0.016
Percentage sand		0.631	-0.095	0.009	0.418	-0.159	0.025	0.745	-0.064	0.004
Percentage silt		0.856	0.036	0.001	0.916	0.021	0.0004	0.419	0.159	0.025
Percentage clay		0.782	-0.054	0.003	0.327	0.192	0.037	0.490	-0.136	0.018
pH		0.592	-0.106	0.011	0.890	0.027	0.0007	0.082	-0.334	0.112
Electrical conductivity		0.768	0.058	0.003	0.941	0.015	0.0002	0.764	0.059	0.003
Organic matter (%C)		0.550	-0.118	0.014	0.979	-0.005	0	0.692	0.078	0.006
Percentage bare ground		0.332	0.190	0.036	0.641	0.092	0.008	0.547	0.119	0.014

None of the components of ground beetle species diversity shows correlation with soil parameters. Not much of the variation in ground beetle species diversity, equitability or species richness could be accounted for by the different soil parameters. 11.2% of ground beetle species richness could be explained by the pH of the soil.

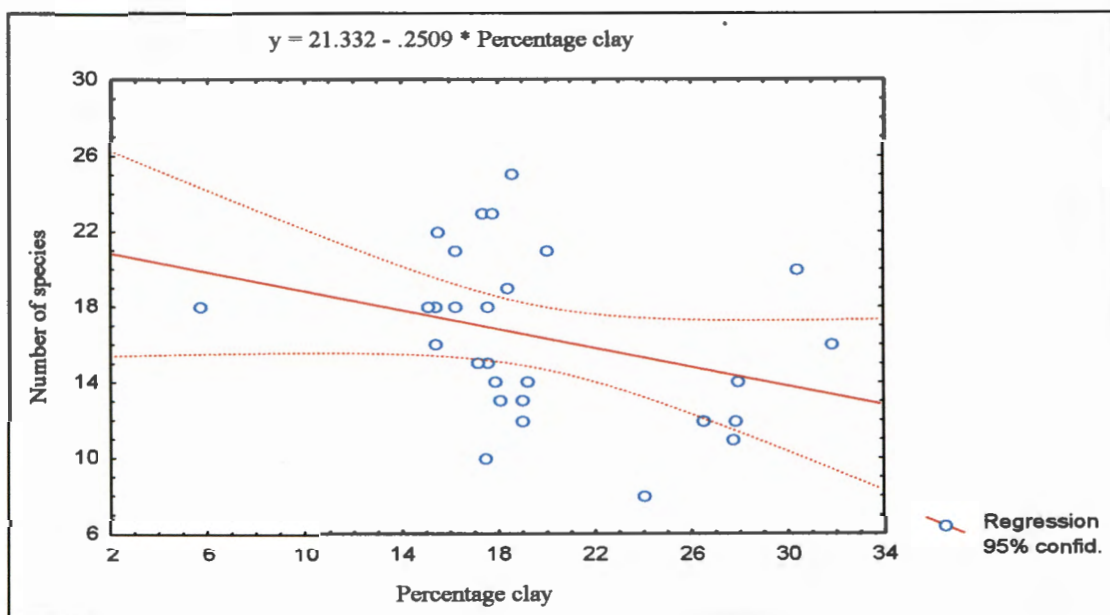


Figure 3.19 Linear relationship between Coleoptera species richness and percentage clay composition on rehabilitated ash dams at Hendrina Power Station

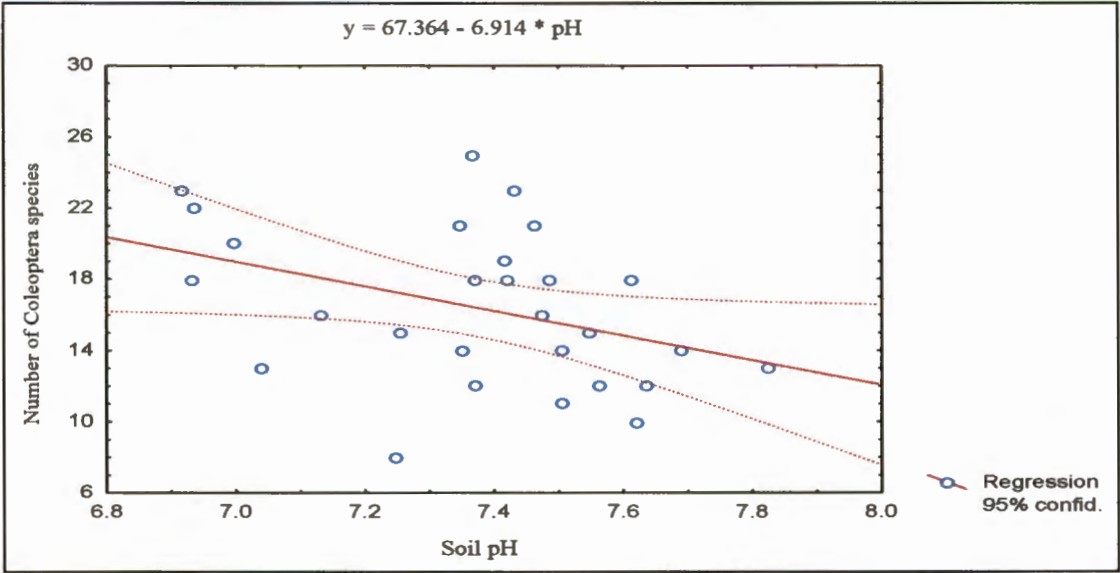


Figure 3.20 Linear relationship between Coleoptera species richness and soil pH on rehabilitated ash dams at Hendrina Power Station.

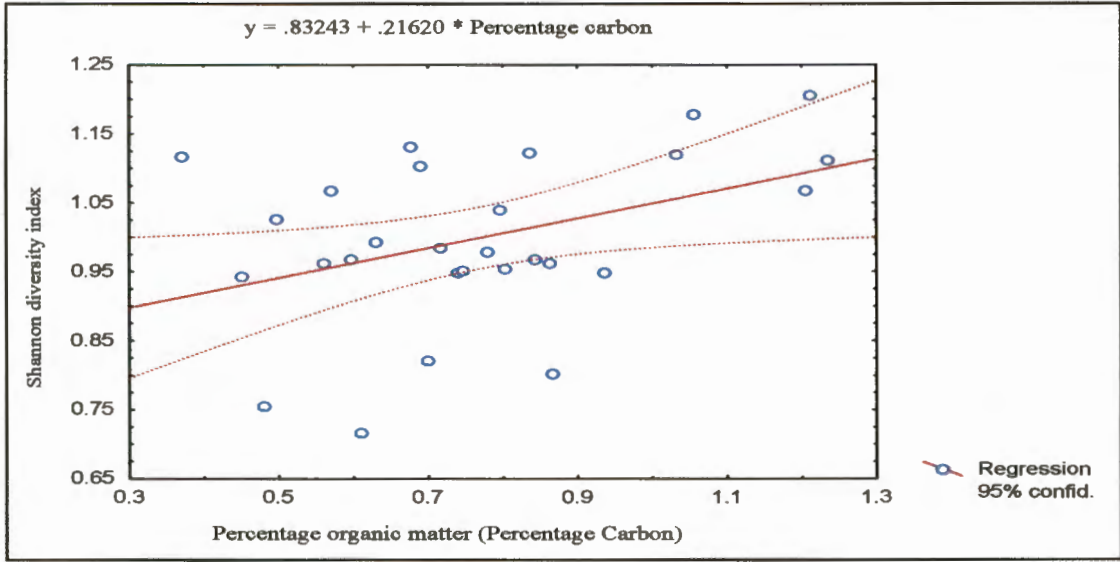


Figure 3.21 Linear relationship between Coleoptera Shannon diversity index and percentage organic content of rehabilitated ash dams at Hendrina Power Station.

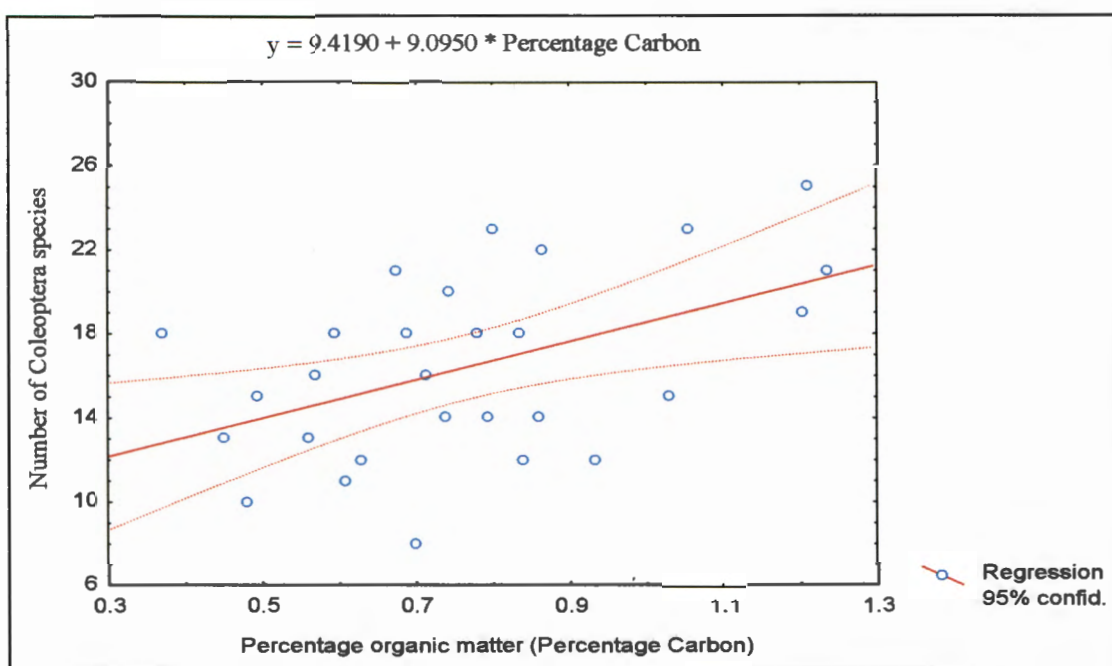


Figure 3.22 Linear relationship between Coleoptera species richness and percentage organic content of rehabilitated ash dams at Hendrina Power Station.

CHAPTER 4: DISCUSSION

4.1 ASSEMBLAGE STRUCTURE IN SUCCESSION STUDIES OF ASH DAM REHABILITATION

4.1.1 Relative abundance and succession of Coleoptera species at the unrehabilitated and rehabilitated ash dams and in the adjoining natural veld

Changes in resource availability and the nature of the habitat could influence the succession of species (Majer 1990). Although individuals of *Formicomus* cf. *caeruleus* (ico22e) were dominant in rehabilitated grids (relative abundance of 15,02%) it represented only 0.68% of the total amount of individuals caught in natural veld (Fig. 3.3 and 3.4, Table 3.3 and 3.4). *Lagria* sp. (ico10e), *Cryptocephalus bistrigatus* (ico160e) and *Hirticomus biplagiatus* (ico 3e) occurred in abundance in the natural veld (Fig. 3.4). The ranking of families according to abundance (Fig. 3.1) showed that the families Anthicidae, Chrysomelidae, Tenebrionidae and Scarabaeidae were most abundant on the ash dams. In the natural veld representatives of the families Tenebrionidae, Chrysomelidae and Anthicidae were most abundant (Fig. 3.2). Salgado (1996) found that arthropods in general were much more abundant on more contaminated areas of coal-fired power plants. Parmenter & Macmahon (1987) also found Tenebrionidae to be one of the dominant families in undisturbed areas and Anthicidae to be one of the dominant families in disturbed areas. Because Anthicidae are mostly predaceous, they can, like Carabids move fast and can quickly colonise an area. The sample size in natural veld is much smaller than in ash dams. This could have an effect on the number of species caught especially since numbers of individuals caught were so low.

In studies done by Neumann (1973) it was concluded that Carabidae were pioneer colonisers of coal spoil banks and tended to leave the area by about ten year's after colonisation. Incidence of Carabidae on the ash dams of the Hendrina Power station shows a similar pattern. Carabid species were found to be dominant on unrehabilitated and newly rehabilitated ash dams and became less dominant as rehabilitation progressed (Fig. 3.7). There are phytophagous, detritivorous and scavenger species present, but only in small numbers (Fig. 3.13 - Fig. 3.15). Many of the carabids are very good hunters and their mobility enables them to colonise rapidly to prey on a variety of organisms and to exploit new niches rapidly. Carabids are able to feed on small and very scattered food items. Both this and the fact that most of them are generalist feeders enable Carabidae beetles to effectively colonise open areas (Hammond 1990). Becker (1975) and Janzen (1973) found that islands are more likely to be colonised by predators at first because of their polyphagy. Predaceous Coleoptera species generally followed the same tendency in this study, to be more abundant on more disturbed areas (Fig. 3.11, Fig. 3.12). Janzen (1973) also emphasised that islands don't necessarily only implicate oceanic islands. Host plants, plant crops and other natural areas on the continent could be regarded as islands (Janzen 1968) thus island biogeography principles are important to mainland situations as well (Price 1894). Fewer herbivores will be established because they accept a narrower range of food species. This could explain why Carabidae species colonised the unrehabilitated areas before many of the herbivorous insects could colonise it (Fig 3.11, Fig. 3.13). Janzen (1973) believed that carnivory might enhance the colonising success of predacious Coleoptera. Janzen (1973) also found that predacious Coleoptera species could survive longer without food in the laboratory than phytophagous ones. Detritivorous and scavenger species will colonise the area much later than predacious and phytophagous beetles because of their feeding habits. This was also found in this study (Fig. 3.11, Fig. 3.14, Fig. 3.15). These insects feed on dead and decaying matter. Parmenter (1987) found that colonising species

were mostly generalistic feeders and Carabids were found to rapidly disperse into disturbed areas (Rivard 1965, Neumann 1971). In all functional groups (with the exception of Scavenger species there was an increase in beetle abundance between the seven and nine year old ash dams. One explanation for this could be that this ash dam, which is the oldest rehabilitated ash dam, was returning to an unstable state.

Although most of the literature (Parmenter 1989, Foster 1987, Majer 1989, Majer 1990, Newman 1973, Niemelä 1990, Niemelä 1999) refer to the use of Carabidae as indicators of changes in environmental factors, some of the Anthicidae species could possibly also be used as indicators of rehabilitation success. Members of the family Anthicidae were found in large numbers in the unrehabilitated and newly rehabilitated sites and decrease in numbers with an increase in rehabilitation age (Figure 3.8). Most Anthicidae species are predators and occur on the ground (Endrödy-Younga 1985). Members of Anthicidae seem to be good colonisers of disturbed areas as opportunistic feeders.

4.1.2 Species Diversity, Equitability And Species Richness at different stages of rehabilitation and in Natural veld

Diversity has two components (Sheehan 1984):

1. Species richness (Number of species present)
2. Equitability (The distribution of individuals among species present).

The more disturbed an area becomes, the lower the species diversity should be (Sheehan 1984). Species diversity increased from unrehabilitated areas to rehabilitation done in 1996 and remained relatively constant regardless of the rehabilitation age (Fig. 3.5, Table 3.7). Species diversity and species richness in natural veld is slightly lower than on rehabilitated ash dams. Salgado (1996) found arthropods to be more abundant on more contaminated areas of coal-fired power plants.

Sheehan (1984) found equitability to be lower for more disturbed areas. In this study however equitability increased with increasing rehabilitation age but is slightly lower in the natural veld than for rehabilitation done in 1992 (Fig. 3.5, Table 3.7).

The mean number of species caught per transect on rehabilitated ash dams is much higher than on unrehabilitated sites. According to Sheehan (1984) the species richness should increase with an increase in rehabilitation age. However, the older rehabilitated ash dams had a lower species richness than younger ones.

Sheehan (1984) states that it could be possible that diversity and the number of taxa (species) present are only indicative of severe stress on the environment. This could explain the huge differences in diversity and number of species between unrehabilitated and rehabilitated areas and not much difference between the ash dams in different stages of rehabilitation (Fig. 3.5). However, Parmenter & Macmahon (1989) found that the number of species increased with rehabilitation age and then decreased again after a few years. The number of species in the natural veld were less than the highest number of species found at rehabilitated sites which could be contributed to the fact that the assemblage reached the climax species complement (Parmenter & Macmahon 1989). According to Wilson (1969) there are four stages in the organisation of a community namely noninteractive, interactive, assortative and evolutionary. During the noninteractive stage number of species rise. No competition for resources exists because numbers are too low and there is insufficient biomass for effective exploitation by predators. During the interactive equilibrium, species compete for resources and some species become extinct while others will colonise the area. The number of species will theoretically drop during the interactive stage. It could be possible that the unrehabilitated ash dams and ash dams rehabilitated two to four years previously is still in the noninteractive

stage, where the biomass is still too small for competition and effective exploitation by predators. Ash dams rehabilitated five to nine years previous to the survey could be in the interactive stage, which explains why the number of species is lower than those of two to four year old rehabilitation sites.

The fact that species richness and in effect species diversity is lower for the natural veld than for the earlier rehabilitated areas could be also attributed to the chance that some species are less trappable and do occur in much lower abundance. Species, which are caught more frequently, are usually considered most abundant while species that move slower could be more abundant, but are not trapped that easily or frequently (Skuhavy, 1959). In the rehabilitated grids, the species diversity should be lower, with more individuals per species, than in the natural veld. In stable, natural environments however there should be more specialists but in lower numbers. This should affect their catchability.

According to Fig. 3.6 five-year-old rehabilitated ash dams has the highest number of species. When numbers in Fig. 3.5 is considered the highest mean number of species per transect occurs at 3 year old rehabilitated sites. There is a huge discrepancy between mean number of species per transect and total number of species probably because of the low frequency of these species and is therefore a sampling artefact. The mean number of species per transect is needed for comparison between the rehabilitation ages. This is however not an indication of the total number of species present. When total number of species is considered, Fig. 3.6 should be used.

4.2 ORDINATION OF COLEOPTERA SPECIES TO DETERMINE DISTRIBUTION IN RELATION TO DIFFERENT ENVIRONMENTAL FACTORS

4.2.1 Ordination of Coleoptera species to determine the distribution of species in relation to rehabilitation status

The gradient length of 2.388 for the first ordination axis of the DCA (Figure 3.15 shows that no single variable had a meaningful contribution to the distribution of Coleoptera species between research sites. A gradient length of 4 SD is considered as a statistically significant gradient. The fact that the possibility exists that only severe stress could influence the Coleoptera species assemblages (Sheehan 1984) could mask the influence of disturbance on the distribution of the Coleoptera species. The already rehabilitated areas could be similar enough for the disturbance not to have a large enough gradient effect on the distribution of the Coleoptera species. Another reason could be the opportunistic nature of some of these insects and the pioneer status of the population.

On the first ordination axis of Fig. 3.16 unrehabilitated areas (G7T & G8T) and areas rehabilitated for three years (G7M & G8M) tended to separate from areas rehabilitated for four to nine years (G1-G4, G7B, G8B, G9-12). Natural veld (CO1 & CO2) is situated on the right of the diagram with areas rehabilitated five to nine years situated in the middle.

The CCA of Coleoptera species in relation to the distribution of plant species showed that *Tagetes minuta* had the largest influence on the distribution of Coleoptera species. Only four plant species had a significant influence on the distribution of Coleoptera species. These species are *Tagetes minuta*, *Bidens formosa*, *Schkuria pinnata* and *Conyza bonariensis* (Table 3.16). High

frequency of these plants was encountered at the sites where they had the largest influence on the distribution of Coleoptera species (Fig. 3.17).

Species influenced by *Schkuria pinnata* are *Zophosis* sp. (ico2e), *Erenmus angustirostris* (ico72e), *Lalagetes* sp. (ico71e), *Astylus atromaculatus* (ico61e), *Pseudivongius aeneus* (ico75e), *Estcourtiana litura* (ico112e).

Morphospecies that occurred in association with *Tagetes minuta* are ico109e (Family Chrysomelidae) and ico110e (Family Coccinellidae)

Beetles that occurred in association with *Conyza bonariensis* are *Rhyssalus atramentarius* (ico1e), *Chrysocephalus bistrigatus* (ico160e), ico144e (Family Coccinellidae) and ico115e (Family Phalacridae).

The distribution of *Gonocephalum simplex* and ico113e (Family Chrysomelidae) were mostly influenced by *Bidens formosa*

The CCA of Coleoptera species in relation to soil parameters showed that electrical conductivity had the largest influence on the distribution of Coleoptera species. The other soil parameters, which had a significant influence on the distribution of Coleoptera species, are pH and percentage carbon content of the soil (Fig. 3.18). This corresponds with results of the linear regression between components of Coleoptera species diversity and soil parameters, where statistically meaningful correlations were found with soil pH and percentage organic matter (Fig. 3.19).

Soil pH influenced the distribution of *Lalagetes* sp. (ico71e), *Notoxus* sp. (ico74e) and *Pseudivongius aeneus* (ico75e).

The Carbon composition of the soil had a significant influence on the distribution of the following species: *Rhyssalus atramentarius* (ico1e),

Gonocephalum simplex (ico47e), *Formicomus caeruleus* (ico22e), *Chryptocephalus bistripustalatus* (ico160e), *Erenmus angustirostris* (ico72e), *Lagria* sp. (ico10e), *Zophosis* sp. (ico2e) and *Graphipterus circumcinctus* (ico30e).

Electrical conductivity had a significant influence on *Scymnus levaillanti* (ico49e), ico9e, ico113e and ico 109 (Family Chrysomelidae), ico97e (Family Staphylinidae), ico7e, ico110e and ico19e (Family Coccinellidae), *Harpalus* sp4 (ico4e) and ico12e (Family Carabidae).

4.3 THE INFLUENCE OF EDAFIC VARIABLES ON COLEOPTERA ASSEMBLAGE STRUCTURE

4.3.1 The relationship between Coleoptera species diversity and plant species diversity as well as percentage vegetation cover

No statistically significant correlation exists between Coleoptera species diversity and plant species diversity or between Coleoptera species diversity and percentage vegetation cover (Table 3.18). A possible explanation could be that beetles are opportunistic and tend to quickly colonise areas before any plants are present. By the time plants start to grow there are already numerous insect species present.

4.3.2 The relationship between Coleoptera species diversity and soil structure as well as physical soil variables

No statistically significant correlation exists between Coleoptera species equitability and soil variables. However significant correlation was found between Coleoptera species diversity and the percentage organic matter present in the soil. Coleoptera species richness is correlated with the percentage clay, pH and the percentage organic matter present (Table 3.19).

Negative correlation is observed between Coleoptera species richness and percentage clay composition. The poor drainage of clay soils and the high level of waterlogging results in low biomass and thus low species assemblages. Clay soils also adsorb some of the proteins derived from organic matter and protect these proteins against microbial exploitation. Some of these proteins can also be caught in the pores between clay particles, protecting it against microbial exploitation (White 1997) and are not available to plants and other organisms. For these reasons the Coleoptera species richness could possibly decrease with an increase in clay composition of the soil as illustrated in Fig. 3.19A.

Soil pH decreased with rehabilitation age. This could explain the negative correlation between the Coleoptera species richness and soil pH.

coleopteran species diversity and species richness were both positively correlated with the organic matter content in soil which corresponds with results found by Ings (1999). Luff *et al.* (1989) and Gardner (1991) found that Carabidae assemblages are positively correlated with organic matter content in grassland habitats. The lack of organic matter contributes to creating a harsher environment and could. Organic litter could create shelter, protecting the insects from predation and desiccation (Parker 1989) while some species feed saprophytically on organic litter (White 1997). Organic matter could possibly also constitute food for prey items of predaceous beetles.

Correlation was drawn between the different components of ground beetle species diversity (Table 3.20). No significant correlation was found. This may be attributed to the possibility that sample sizes were too small to get clear tendencies.

CHAPTER 5: CONCLUSION

5.1 VALUE OF COLEOPTERA AS INDICATORS OF ECOLOGICAL CHANGE

Although animals are usually considered secondary to plants in rehabilitation surveys this study provides evidence that animals could also prove to be useful in studying rehabilitation success.

In Chapter 1 (section 1.1.2 and section 1.1.3) criteria for using insects as bio indicators were defined (McGeogh 1998 and Niemelä). The following arguments could indicate Coleoptera as suitable candidates for use as bio indicators:

- they can be easily collected with pitfall traps and is easily sorted;
- they are speciose, varied and abundant. They were abundant in both pitfalls and sweepnets in natural veld and disturbed areas. Tenebrionidae, Chrysomelidae and Anthicidae were the most abundant families at the Hendrina Power station sites.
- They are easily stored;
- Some baseline data on biology is available;
- It seems that some families and functional groups are sensitive to environmental change and could provide early warnings;
- Most species, families and functional groups are replaced by others as rehabilitation matures.
- they have fossil records showing them to respond to environmental changes;
- they are well-known indicators of ecological change and have been used in signalling environmental change. In this study certain Coleoptera

assemblages (Carabidae and Anthicidae) indicate environmental changes in terms of rehabilitation age.

The following criteria set by McGeogh (1998) and Niemelä (2000) still pose to be problematic when using Coleoptera:

- beetles should be readily identifiable: Unfortunately identification of South African beetle species is a problem at the moment. The taxonomic impediment when trying to use beetles as indicators of ecological change within a limited time frame is problematic. The classification in functional groups (i.e. families) may be an alternative. The division of the different families into functional groups based on the feeding habits of the families proved to be quite useful in determining changes in assemblage structure with change in rehabilitation age.
- Long-term data is needed in order to determine if sample individuals should be expendable, spatial and temporal distribution is predictable and to differentiate between natural cycles and trend and those produced by anthropogenic stress factors.

Certain Coleoptera groups can be used to indicate rehabilitation success. Predaceous Coleoptera species are most abundant during early stages of rehabilitation and decreases as the state of the environment improves while phytophagous, detritivorous and scavenger species occur in low numbers during early stages of rehabilitation and abundance increase with a decrease in disturbance.

Carabidae and Anthicidae groups should also be considered as possible indicators of environmental change. Carabidae is used with great success in the Northern Hemisphere as indicators of disturbance. Anthicidae shows the same colonisation patterns as Carabidae and is more abundant as well and should therefore be considered as a possible bio indicator. The cause for the

change in colonisation patterns is unfortunately not clear and indicate a further research priority.

5.2 RECOMMENDATIONS TO IMPROVE THE STUDY OF COLEOPTERA AS BIO-INDICATORS

Although certain groups in the order Coleoptera could be used as bio-indicators, a few problems should be addressed:

- Data should be collected over a larger time scale to get a clear picture of Coleoptera assemblage structure. More environmental parameters must be monitored. It could be useful to measure soil moisture and soil temperature to determine the correlation between beetles and these parameters as well.
- According to Majer (1990) the rate of recolonisation after disturbance differs between animal taxa and between recolonised areas. Baseline data should therefore be collected to act as a benchmark for after disturbance data.
- Only 5-10% of all insect species have been described compared to 80% of the vertebrates (Samways 1994). The taxonomy of the beetles, especially Carabidae, is still a great impediment. Local expertise is limited and the taxonomies of some beetles are ill developed. Information on the biology of beetles in South Africa and their relationship to plants is very limited.
- It takes a lot of time and (unavailable) expertise to sort and identify the different beetle species. For this reason the beetles were only sorted into morphospecies. This has its own restrictions, as the biology of single species could not be used in discussing the results. Functional groups according to feeding behaviour of the different families were used with

great ease although one still can't use these groups as indicators and only the relative abundance of the functional groups could serve a purpose.

- Sorting and identifying the insects is a great obstacle in doing a quick assessment of rehabilitation status. Therefore, certain groups should be identified and only those groups should be used for analysis. Unfortunately much more research is needed before relevant groups could be identified. Although Carabidae is used extensively in the Northern Hemisphere, it is difficult to use groups of which the local taxonomy is still ambiguous. It becomes time consuming and expensive if specimens should first be sent abroad for identification. Local expertise in beetle taxonomy must therefore be developed.

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<http://www.barefootsworld.net/seatile.html>

APPENDIX 1: SPECIES LIST

Table A.1 List of morphospecies codes, families, sub families and species names (where available) of Coleoptera species caught at the Hendrina Power Station

SPECIES NUMBER	FAMILY	SUB FAMILY	SPECIES NAME
ico1e	Scarabaeidae	Aphodiinae	<i>Rhyssenus prob. atramentarius</i> Perringuey
ico2e	Tenebrionidae		<i>Zophosis</i> sp.
ico3e	Anthicidae		<i>Hirticomus biplagiatus</i> (Laferté)
ico4e	Carabidae	Harpalini	<i>Harpalus</i> sp 4
ico5e	Anthicidae		<i>Anthicus</i> sp.
ico6e	Scarabaeidae	Aphodiinae	<i>Aphodius</i> sp.
ico7e	Coccinellidae	Coccinellinae	<i>Hippodamia (Adonia) variegata</i> (Goeze)
ico8e	Coccinellidae		
ico9e	Chrysomelidae		
ico10e	Tenebrionidae	Lagriinae	<i>Lagria</i> sp.
ico11e	Coccinellidae		
ico12e	Carabidae		
ico13e	Coccinellidae		
ico15e	Coccinellidae		
ico16e	Scarabaeidae	Aphodiinae	
ico17e	Chrysomelidae	Alticinae	
ico19e	Coccinellidae		
ico20e	unknown		
ico21e	Cerambycidae		
ico22e	Anthicidae		<i>Formicomus cf. caeruleus</i> (Thunberg)
ico23e	Carabidae		
ico25e	Carabidae		
ico26e	Carabidae		
ico27e	Carabidae (Larva)		
ico28e	Tenebrionidae		
ico30e	Carabidae	Graphipterini	<i>Graphipterus circumcinctus</i> Boheman
ico32e	Tenebrionidae		
ico33e	Curculionidae		
ico34e	Nitidulidae		
ico35e	Scarabaeidae	Scarabaeinae	
ico36e	Curculionidae		
ico37e	Meloidae		
ico38e	Curculionidae		
ico39e	Tenebrionidae		
ico40e	Carabidae		
ico41e	Chrysomelidae		
ico42e	Meloidae		
ico43e	unknown		
ico44e	Scarabaeidae	Scarabaeinae	
ico45e	Chrysomelidae		

SPECIES NUMBER	FAMILY	SUB FAMILY	SPECIES NAME
ico47e	Tenebrionidae		<i>Gonocephalum cf. simplex</i> (Fabricius)
ico48e	Carabidae (Larva)		
ico49e	Coccinellidae	Coccinellinae	<i>Scymnus cf. levaillanti</i> (Mulsant)
ico50e	Carabidae (Larva)		
ico51e	Trogidae		
ico52e	Carabidae (Larva)		
ico53e	Carabidae (Larva)		
ico54e	Tenebrionidae		
ico55e	Tenebrionidae		
ico57e	Scarabaeidae (Larva)		
ico60e	Carabidae (Larva)		
ico61e	Melyridae	Dasytinae	<i>Astylus atromaculatus</i>
ico62e	Carabidae (Larva)		
ico63e	Curculionidae		
ico64e	Coccinellidae		
ico65e	Anthicidae		
ico66e	Carabidae (Larva)		
ico67e	Curculionidae		
ico68e	Curculionidae		
ico69e	Carabidae	Cicindelinae	
ico70e	Curculionidae		
ico71e	Curculionidae	Peritelini	? <i>Lalagetes</i> sp.
ico72e	Curculionidae	Tanyrhynchini	<i>Erenmus angustirostris</i> Marshall
ico73e	Scarabaeidae	Melolonthinae	
ico74e	Anthicidae		<i>Notoxus</i> sp.
ico75e	Chrysomelidae	Eumolpinae	<i>Pseudivongius aeneus</i> Jacoby
ico76e	Curculionidae		
ico77e	Carabidae		
ico78e	Coccinellidae (Larva)		
ico79e	Carabidae (Larva)		
ico80e	Carabidae		
ico81e	Carabidae		
ico82e	Tenebrionidae		
ico83e	Curculionidae		
ico84e	Curculionidae		
ico85e	Tenebrionidae		
ico86e	Curculionidae		
ico87e	Chrysomelidae		
ico88e	Curculionidae		
ico89e	Carabidae (Larva)		
ico90e	Carabidae		
ico91e	Staphylinidae		
ico92e	Scarabaeidae	Melolonthinae	
ico93e	Histeridae		
ico95e	Chrysomelidae	Hispinae	
ico96e	Curculionidae		
ico97e	Staphylinidae		
ico98e	Scarabaeidae	Scarabaeinae	
ico99e	Histeridae		
icol100e	Scarabaeidae	Melolonthinae	
icol101e	Scarabaeidae	Dynastinae	<i>Heteronychus</i> sp.

SPECIES NUMBER	FAMILY	SUB FAMILY	SPECIES NAME
icol02e	Curculionidae		
icol03e	Tenebrionidae		
icol04e	Carabidae		
icol05e	Staphylinidae		
icol09e	Chrysomelidae		
icol10e	Coccinellidae		
icol11e	Elateridae		
icol12e	Chrysomelidae	Galerucinae	<i>Estcourtiana litura</i> (Gerstaecker)
icol13e	Chrysomelidae		
icol14e	Brentidae	Apioninae	
icol15e	Phalacridae		
icol16e	Coccinellidae		
icol17e	Nitidulidae		
icol21e	Larva		
icol22e	Coccinellidae (Larva)		
icol23e	unknown		
icol27e	Melyridae	Malachiinae	
icol31e	Chrysomelidae	Chrysocephalinae	
icol32e	Chrysomelidae		
icol33e	Curculionidae		
icol34e	Cleridae		
icol35e	Curculionidae		
icol36e	Chrysomelidae		
icol37e	Tenebrionidae	Alleculinae	
icol38e	Anthicidae		
icol39e	Chrysomelidae		
icol41e	Chrysomelidae		
icol42e	Phalacridae		
icol43e	Chrysomelidae		
icol44e	Coccinellidae		
icol45e	Carabidae		
icol46e	Chrysomelidae		
icol47e	Curculionidae		
icol48e	Chrysomelidae		
icol49e	Curculionidae		
icol50e	Chrysomelidae		
icol51e	Tenebrionidae	Alleculinae	
icol52e	Anthicidae		
icol53e	Chrysomelidae		
icol56e	Melyridae	Malachiinae	
icol57e	Chrysomelidae		
icol58e	Curculionidae		
icol59e	Phalacridae		
icol60e	Chrysomelidae		<i>Cryptocephalus bistrigatus</i> Suffrian
icol61e	Tenebrionidae		
icol62e	Chrysomelidae		
icol63e	Chrysomelidae		
icol65e	Mordellidae		
icol66e	Curculionidae		
icol67e	Melyridae	Malachiinae	
icol68e	Scarabaeidae	Rutelinae	

SPECIES NUMBER	FAMILY	SUB FAMILY	SPECIES NAME
ico169e	Mordellidae		
ico170e	Tenebrionidae		
ico171e	Elateridae		
ico172e	unknown		
ico174e	Cicindelinae		
ico176e	Curculionidae		
ico177e	Coccinellidae		
ico178e	Curculionidae		
ico179e	Chrysomelidae		
ico181e	Chrysomelidae		
ico182e	Bostrichidae		
ico183e	Curculionidae		
ico184e	Scarabaeidae	Aphodinae	
ico185e	Curculionidae		
ico187e	unknown		
ico189e	Elateridae		
ico190e	Tenebrionidae		
ico191e	Chrysomelidae		
ico192e	Carabidae		
ico193e	Tenebrionidae		
ico194e	Curculionidae		
ico197e	Curculionidae		
ico198e	Curculionidae		
ico200e	Curculionidae		
ico202e	Curculionidae		
ico203e	Chrysomelidae	Hispinae	
ico204e	Carabidae		
ico206e	Coccinellidae		
ico207e	Carabidae (Larva)		
ico208e	Coccinellidae (Larva)		
ico209e	Carabidae (Larva)		
ico211e	Coccinellidae		
ico214e	Chrysomelidae (Larva)		
ico215e	Coccinellidae (Larva)		
ico216e	Chrysomelidae (Larva)	Hispinae	
ico217e	Elateridae		
ico218e	Curculionidae		
ico219e	Meloidae		
ico221e	Trogidae		
ico222e	Curculionidae		
ico223e	Curculionidae		
ico224e	Curculionidae		
ico225e	Curculionidae		
ico226e	Curculionidae		
ico227e	Brentidae	Apojininae	
ico228e	Carabidae		
ico229e	Carabidae	Harpalini	<i>Harpalus</i> sp.
ico230e	Carabidae		
ico231e	Carabidae		