THE EPIGEAL AND EPIPHYTIC HEMIPTERAN ASSEMBLAGES AS INDICATORS OF REHABILITATION SUCCESS ON ASH DISPOSAL SITES AT HENDRINA POWER STATION

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ABSTRACT

Hemiptera portrays many of the characteristics of successful bioindicators, however hemipterans have also shortcomings in this regard. Few studies have been conducted on the bio-indicative value of hemipteran species in South Africa. This study was conducted at Hendrina Power Station (Mpumalanga, South Africa) and entails a preliminary study on the possible indicative value of hemiptera as possible bioindicators during succession on rehabilitated ash dams.

On the ash dams 61 species in 13 families were recorded compared to the 47 species in 16 families recorded in natural grassland. The natural grassland represented the most advanced succesional stage. The early stage of rehabilitation was characterized by low vegetation cover, low organic matter and high gravel content within the soil. Mainly pioneer hemipteran species were recorded during the first stages of rehabilitation probably utilizing pioneer vegetation as herbivores. Relatively low species diversity was also evident during this stage. The second stage of rehabilitation was characterized by more stable plant communities, high vegetation cover and high organic matter content resulting in higher hemipteran species diversity.

Although lower species diversity was expected on the rehabilitated ash dams than in the natural veld, this was not confirmed from the results. This was discussed in this study and indicated further research opportunities.

Multivariate ordinations were used to investigate possible correlations of hemipteran assemblages with edaphic characteristics. Significant correlations were found between hemipteran species richness and clay content, pH and organic matter.

Keywords: Hemiptera, bioindicators, rehabilitation, ash dams.

OPSOMMING

Hemiptera vertoon goeie eienskappe as suksesvolle bioindikatore, maar so ook eienskappe dat die groep terkortkominge het in die verband. Min studies is egter al gedoen oor die waarde van hemiptera as bioindikatore in Suid-Afrika. Hierdie studie is gedoen by Hendrina-kragstasie (Mpumalanga, Suid-Afrika) en behels 'n voorlopige studie op die waarde van hemiptera as moontlike bioindikatore tydens suksessie op gerehabiliteerde asdamme.

Daar is 61 spesies Hemiptera in 13 families op die asdamme versamel terwyl daar 47 spesies in 16 families in die natuurlike kontrole veld versamel is. Die natuurlike veld was verteenwoordigend vir die mees gevorderde stadium van suksessie. Die vroeë stadium van rehabilitasie was gekenmerk deur lae plantegroei bedeking, lae hoeveelhede organiese materiaal en hoë gruis inhoud in die grond. Pionier spesies van hemiptera was versamel tydens die begin stadium van rehabilitasie, waar hierdie spesies waarskynlik op pionier plante voed. Lae spesie diversiteit was ook opmerkend in die vroeë stadium. Die tweede stadium van rehabilitasie was gekenmerk deur meer stabiele plant gemeenskappe, hoë plantegroei bedekking en hoër organiese materiaal, wat hoër hemiptera spesie diversiteit tot gevolg het.

Alhoewel daar 'n laer spesiediversiteit verwag was op die gerehabiliteerde asdamme in vergelyking met die natuurlike veld het resultate anders daarop gedui. Hierdie resultate was bespreek in die studie en verdere navorsings geleenthede was uitgewys.

Meerveranderlike ordinasies is gebruik om moontlike korrelasies van Hemiptera spesiesamestellings met edafiese faktore te bepaal. Betekenisvolle korrelasies is gevind vir Hemiptera spesierykheid en pH, Klei-inhoud en organiese materiaal.

Sleutelwoorde: Hemiptera, bioindikatore, rehabilitasie, asdamme.

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MICHAEL

CHAPTER 1

INTRODUCTION

1.1 Rehabilitation and possible end use of ash disposal sites.

To imagine the world without electricity is impossible. Since the start of the industrial period in the early 1900's the need for electricity increased exponentially. This demand for more electricity impacted on the utilization of natural resources such as coal, to satisfy the demands. Utilization of these resources by man seriously impacted on ecosystems in ways such as pollution and destruction of species and habitats (Kelly & Harwell 1987). Man only realized very recently that utilization could be very destructive to ecosystems and that the damage caused is irreparable. Action had to be taken to ensure the survival and sustainability of important species and ecosystems.

According to Harris et.al. 1996 there are three possible solutions to damaged or unusable land. The first is reclamation a process by which previously unusable land is returned to a state whereby some use may be made of it. The second is rehabilitation a process often applied to areas, which formerly had no growth at all, but with careful fertilization works may be used to grow a limited number of plant species. Thirdly restoration can be divided in two parts: ecological restoration, this is the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems; land restoration is the process by which an area is returned to its original state or as close to the original state as possible prior to degradation of any sort.

Rehabilitation is also stated as the establishment of a community that is similar to but not identical to the original community (Bradshaw 1983).

To restore a disturbed ecosystem to exactly the same state it was before is impossible, because no two conditions will be exactly the same in either of the ecosystems (Bradshaw 1983; Louda 1995). The mission of ecological restoration is to reestablish a functional ecosystem of a designated type that contains sufficient biodiversity to continue the ecosystem's maturation by natural processes and to evolve over longer time spans in response to changing environmental conditions (Clewel, Rieger & Munro 2000). If restoration cannot be fully achieved, then the project should be redesigned as rehabilitation, which is defined as any ecologically beneficial treatment short of full restoration.

Rehabilitation requires a lot of managerial involvement, finance and legal understanding. If a concept is not applied in law, the concept does not need a legal definition. Rehabilitation, however, is required in our mining legislation laws, to create or authorize environmental management systems and to ensure that rehabilitation must be done where development has taken place. The rehabilitated area must be restored to a proper condition or state that will meet the demands of sustainability, as stated in South Africa's national and environmental management act (Act No. 107 of 1998) (Begon, Harper & Townshend 1990). The act also states that loss of biological diversity and destruction of ecosystems has to be prevented or at least diminished and mitigated (Barnard 1995).

Rehabilitation can be divided in three important phases (Higgs 1997):

- **Structural or compositional replication:** where a self-sustainable and functional ecosystem is established. This phase mainly consist of replacing soil and vegetation of the desirable ecosystem. It can take considerable amount of time.

- **Functional success:** this is restoration or establishment of ecological processes within the disturbed areas.
- **Sustainability:** where the rehabilitated area must be self-sustainable and must be able to survive unfavourable conditions such as fire or droughts.

The definition for environmental impact assessment is that EIA is a process of doing predictive studies on a proposed development, analysing and evaluating the results of this development (Lash, Maasland, Filteau & Larkin 1974). To determine if rehabilitation of a disturbed area was successful, monitoring and assessment must take place during and on completion of rehabilitations (Rosenberg, Danks & Lehmkuhl 1986). In order to perform a successful impact assessment there must be a predictive phase, to determine what effect the development might have on the environment. There must be the monitoring and assessment phase to determine what the effect of the development was and what the effect of rehabilitation is or should be (Rosenberg & Snow 1981). Ecological studies are usually neglected during rehabilitation due to its difficulty and complexity (Bradshaw 1983; Louda 1995).

1.2 Insects as possible bioindicators.

Questions concerning the protocols that should be used to identify indicator taxa and whether or not they can be designated objectively have been raised (Stork & Samways 1995). Terrestrial systems tend to be more complex compared to aquatic systems (Steele 1991). The Oxford Dictionary of Zoology defines an indicator species as a species that is of narrow amplitude with respect to one or more environmental factors and when present is therefore indicative of a particular environmental condition (Allaby 1992). McGeoch (1997) states that there are three main applications of bioindicators. These three main applications are environmental-, ecological- and biodiversity indicators.

Characteristics of a good bioindicator are determined by the objectives of the environmental issue being addressed and the temporal scale of the latter. According to McGeoch 1997 the two most important criteria for an effective bioindicator are:

- Economic and Logistic suitability (Financial cost, time efficiency and personnel requirements).
- Biological efficacy (taxonomic, distributional, reliability, representation and sensitivity criteria).

For the selection of a potential bioindicator the two most important criteria can be divided into the following:

- Cost efficient and effective (Noss 1990).
- Sampled and sorted easily (Hellawell 1986).
- Adequate representation (Hammond 1994).
- Should be abundant (Jenkins 1971).
- Ease and reliability of storage (Hammond 1994).
- Taxonomically well known (Stork 1994).
- Sampled individuals must be expendable (New 1995).
- Baseline data on biology available (New 1995).
- Abundant Autecological data (Hellawell 1986).
- Low genetic and functional variability (Hellawel 1986).
- Be a non-target species if used to monitor pesticides (Jenkins 1971).
- Easily cultured in laboratory.
- Recognised importance to agricultured environment (Stork 1994).

- Economic importance as resource or pest (Hellawell 1986).
- Full range of body sizes and growth forms (Stork 1994).
- Tend to be distributed over range of habitats or environments (Faith & Walker 1996).
- Group should have species that are distinct and environmentally dispersed in their distributions (Ryti 1992).
- Representatives from low-, medium-, and high diversity groups (Stork 1994).
- Wide range of host-specificities (Stork 1994).

Insects comply fairly well with the criteria of good bioindicators, but there are also a few shortcomings. Insects constitute a substantial proportion of terrestrial species richness and biomass and play a significant role in ecosystem functioning (McGeoch 1997). The use of invertebrate indicators has only gained momentum within the last two decades (Holloway 1990). Insects are perhaps well suited to be bioindicators because of the enormous amount of species available to work with. Insects can also be found in almost any habitat on earth and are usually so abundant that they can be sampled with ease.

Unfortunately there is also a downside to the use of terrestrial insects as bioindicators. There are still many problems regarding the taxonomy of insects, as well as the lack of attention given to their ecological and economic importance. Their usefulness as indicators must also be addressed (Resh & Grodhaus 1983). Publications on the utility of terrestrial insects as bioindicators are largely anecdotal or prescriptive (McGeoch 1997). Many instances have been recorded where insects were not good indicators of rehabilitation (Majer 1989; Abensperg-Traun, Arnold, Steven, Smith, Viveen & Gutter 1996). Possible reasons for insects not being good bioindicators are that the insect's diversities and quantities differ from sampling season to season due to the huge fluctuations in resources for insects during the seasonal changes (Abensperg-Traun *et al* 1996). Another reason could be that one habitat contains a large quantity of a specific resource but not a low diversity of resources. Such instances could have a tremendous impact on the presence of insects in a specific habitat. Insects have multiple adaptations to assist in the ability to maintain widespread geographical ranges and to occupy various types of habitats to try to overcome the stresses of seasonal changes.

There are many other aspects and factors that play a role during the rehabilitation process. These types of disturbances could also have an effect on the possible bio-indicator species. Plant species, soil pH, rainfall, climate fire, etc. are but a few other environmental aspects that could have an effect on insect species. Insects are usually not seen as an important factor in rehabilitation of disturbed areas; however insects play an important role in a disturbed ecosystem in more than one way. They influence soil through decomposing, grazing, pollination, plant predation and seed distribution (Majer 1984). Insects play an important role in plant communities, they can disperse seeds faster and thus increase plant diversity and richness or they can restrict seed dispersal and can also affect growth and seed production due to predation (Miller, 1993). Anderson (1997) stated that insects and other invertebrates are better bioindicators than plants on the state of a rehabilitated ecosystem.

There are few cases where ecologists can provide decision-makers with tested terrestrial insect indicators as tools for conservation assessment and planning (McGeoch 1997). Not enough research has been done though and ecologists should therefore keep on trying and invest in long term research projects such as this project to find possible terrestrial insect bio-indicators.

1.3 Role of hemipterans during rehabilitation

Very little is known about the effect of fauna in general on plant life in rehabilitated areas, not even to mention insects or the order Hemiptera specifically (Majer 1989). Hemiptera is the largest order of exopterygote insects. Hemiptera divides in two suborders Homoptera (Phytophagous) and Heteroptera (Phytophagous or predacious) (McGavin 2000). Hemipterans comply with most of the criteria to serve as a possible terrestrial insect bioindicator. Hemipterans are abundant, very diverse and can be found in almost every ecosystem (Majer 1984). Hemipteran species can also be easily sampled, sorted, stored and counted. There is baseline data on biology available and the hemipterans are recognized as important to agriculture and the environment. Hemipterans also have representatives from low-, medium-, and high diversity groups with a wide range of host-specificities.

Hemipteran species are known for their piercing and sucking mouthparts. Hemipterans obtain food from seeds, vegetation stems, or nectar some are predacious and have various ways to catch and utilize their prey. All of the hemipterans have specialized feeding habits (McGavin 2000). Many hemipterans are agricultural pest such as *Nezara viridula.* Due to hemipteran feeding habits they could possibly play an important role in rehabilitation, the enzymes released during feeding brakes down plant cell walls or dissolves seed contents, thus preventing growth or inhibiting seed dispersal. The feeding habits can also have a positive effect on vegetation; enzymes can stimulate growth and or seed dispersal (Solbrek & Pehrson 1979).

Food quality and quantity could play an important role in the migration of some hemipteran species. Low food quality and quantity causes a stronger migratory tendency in the hemipteran species, while high food quality and quantity causes some of the hemipteran species to lose all flight ability (Solbrek & Pehrson 1979).

Migration of hemipterans takes place to maximize population stability (May 1975). The question that comes to mind is, will an insect stay where conditions are unsuitable or unstable? Hemipterans also have an effect on other species, predating on various Coleoptera, Diptera and other hemipteran species. Predators and parasitoids can indirectly affect plant productivity by reducing plant-feeding insects (Majer 1989). Some homopterans also have close interactions with ants (Jackson & Fox 1996). Various factors such as the above mentioned tendencies by hemipterans can play a major role in the quantitative or qualitative explanation of data on rehabilitated grasslands.

Effects of hemipterans on grasses are difficult to observe because the insects feeding on grass are usually small. Damage is also less visible as the insects feeding on grass are usually sap or root feeders (Majer 1989). Yield losses of over 30% have been found on the grass species *Cynodon dactylon* due to damage caused by Delphacidae species feeding on grass (Hawkins, Wilson, Mondart, Nelson, Farlow & Schilling 1979). No hemipteran pests have yet been noticed on rehabilitated surface mines. Looking at the arthropods as a group it is noted that the Carabidae beetles, spiders (Araneae) and hemipterans are known as the early colonizers (Majer 1989). Hemipterans can thus be important in the succession of rehabilitated areas. There is a strong possibility that hemipterans can be dispersal agents or inhibiting agents on vegetation growth. Hemipterans have been shown to be early successional species and it appears that they decrease in late successional stages of rehabilitation and are then replaced by other insect orders (Majer 1983, 1989).

Publications on the order Hemiptera as indicators of any sort are almost non-existent with only three entries in the form of books, journals and articles noted in Africa, Europe, and Australia (Majer 1989). Papers on hemipterans as agricultural pests are more readily available and conclusive evidence has been found that hemipterans migrate from natural grassland to agricultural areas and vice versa (Majer 1984, Villet & Capitao 1996). The migration of hemipterans from natural grassland to rehabilitated areas is highly possible, which opens the possibility that hemipterans could be used as bioindicators of environmental change due to rehabilitation success. However, this possibility is not sustained by supporting case studies (Majer 1983). Unfortunately the order Hemiptera is not taxonomically a well known group and taxonomic expertise is not readily available. Spatial and temporal distribution of the group is not predictable. Hemipteran species also consign to high genetic and functional variability. Many hemipteran species are targeted species in the testing of pesticides and are of economic importance as agricultural pests. A full range of body sizes and growth forms also makes identification a very difficult process with most hemipteran species.

1.4 Parameters of ecological status.

Species richness and diversity are good parameters of ecosystem sustainability and stability. Changes in species richness or diversity can be a good indication of ecological change in an ecosystem (Majer 1983). To determine if a species could be used as a bio-indicator of ecosystem change, long-term data sets are needed at a variety of environmental conditions for accurate quantitative analysis.

1.5 Objectives of the study.

Eskom (Electricity Supply Commission of South Africa) started a rehabilitation project in 1990 on fly ash dams at Hendrina, Mpumalanga, South Africa. This project was started to minimize dust pollution and erosion in the area. As stated before rehabilitation success depends on the success of maintaining a sustainable industrial ecosystem that includes all fauna and flora.

Diversity is an important criterion for rehabilitation success and it is therefore important to maximise fauna and flora species diversity and species richness in the rehabilitated area. First of all a stable plant community needs to be established so that vertebrates and invertebrates can colonize the area.

The hypothesis is that hemipteran species diversity and species richness, which approaches and compares well with the adjoining grassland, is indicative of successful and sustainable rehabilitation. Hemipterans are a small part of a larger study that includes other invertebrates, vertebrates, soil-fauna and plant communities. The final objective is a model for the rehabilitated sites for future more accurate decision making on other rehabilitated areas. A predictive model on these rehabilitation methods should enable Eskom to reach the demands of rehabilitation stability in the least amount of time at minimum cost.

The objectives of this study were to determine if hemipteran assemblages could be used as insect bioindicators of ecological change on rehabilitated ash dams and rehabilitation success.

CHAPTER 2

MATERIAL AND METHODS

2.1 STUDY AREA

2.1.1 Location & Construction

The study was conducted at Hendrina Power station (26°03′S; 29°35′E), Mpumalanga, South Africa during the period March 1997 to May 1999. This part of Mpumalanga is rich in sub-surface coal and is therefore suitable for opencast mining. Coal fired power stations are common in this area.

The study site consists of a series of four ash dams or lagoons (Figure 2.1). Ash dam A is the lagoon situated nearest to the power station. Ash dams B and ash dam C were consecutively built to the south of ash dam A. The construction of Ash dam B was never finished because the stockpiles collapsed. Ash dam D is situated separately from the others and was still in production when the study was conducted. Construction of a fifth ash dam (ash dam E) was started late 1997.

The disposal areas are adjoined by land with a number of uses. The power station forms the northern boundary of the site. The northwestern boundary consists of a railway line and a coal loading station (siding). Maize field adjoins the southwestern, southern, and parts of the eastern side of the ash disposal areas. The northeastern border of the ash disposal areas consists of rehabilitated open cast coal mines and is severed natural grassland and by disturbed and reclaimed areas due to these mining activities.

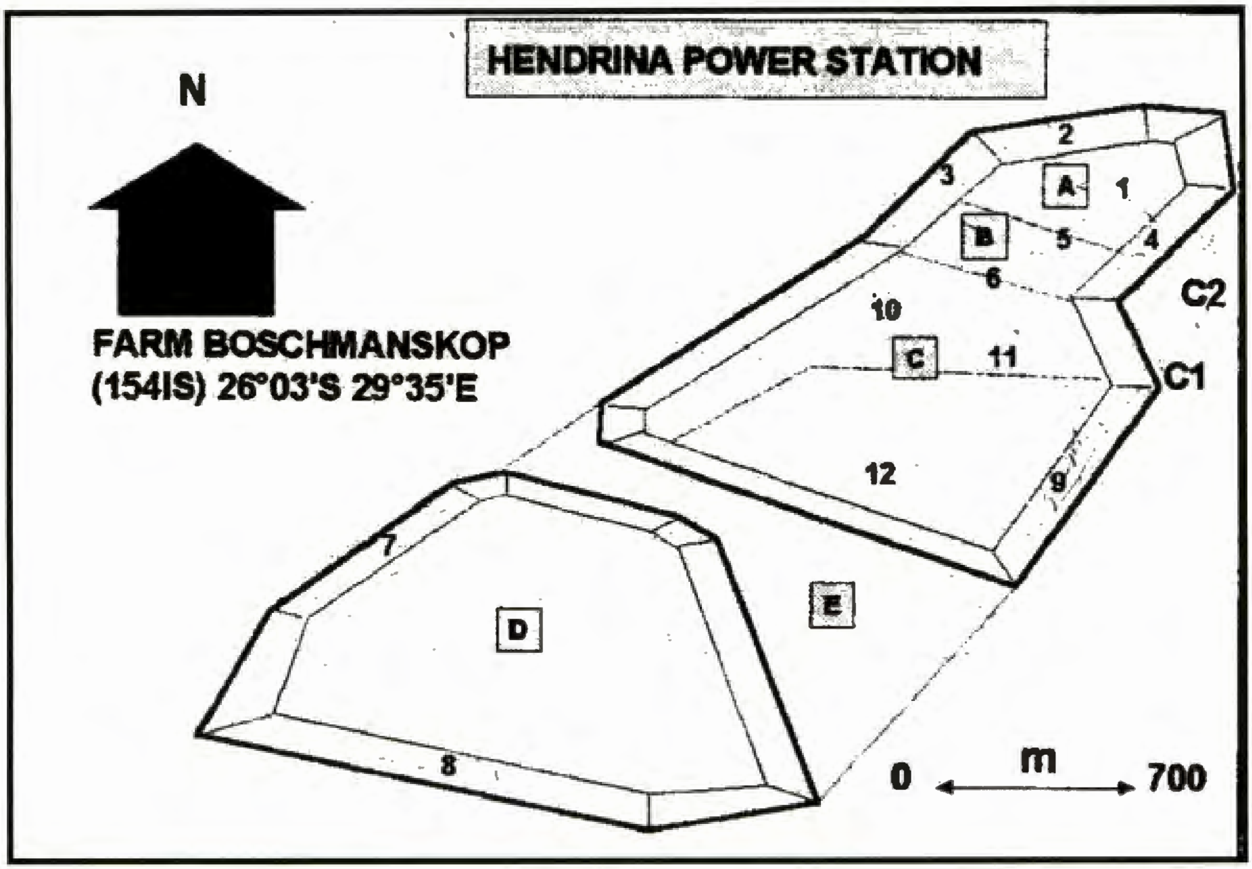

Figure 2.1: Map of the ash dams at Hendrina Power Station showing the location of the survey grids (1 – 12) and the control grids (C1 & C2).

2.1.2 Natural Vegetation

The Mpumalanga region belongs to the Grassland biome (Rutherford & Westfall 1986). Acocks (1988) describe the area vegetation as part of the eastern variation of the Bankenveld (veld type #61). Species of general occurrence include among others *Tristachya leucothrix, Eragrostis racemosa, Heteropogon contortus, Trachypogon spicatus, Digitaria tricholaenoides, Themeda triandra, Brachiaria serrata, Elionurus muticus* and more.

The recent vegetation map of Southern Africa classifies the vegetation of the region as part of the Moist Sandy Highveld Grassland (Bredenkamp & van Rooyen 1996).

2.1.3 Climate

According to the Köppen classification the Mpumalanga region has a warm temperate climate. The coldest month is in June with a maximum and minimum temperature of 18°C and -3°C respectively). The Mpumalanga region has a dry winter season and the warmest months are below 22 °C, but for at least 4 months of the year above 10°C. Data obtained from meteorological measurements at Carolina (45 km east of Hendrina Power Station; 1690 m a.s.l.), for the period 1994-1998, indicated average minimum and maximum temperatures of 7.7°C and 21.8°C respectively for the station. The weather station at Hendrina (18 km south-east of Hendrina Power Station, 1700 m a.s.l.) had an average precipitation of 767 mm for the period 1990-1998. The total precipitation for 1996, 1997 and 1998 were 958.7 mm, 883 mm and 804 mm respectively.

2.1.4 Rehabilitation History

The surface of the ash disposal areas A, B, C and D covers an area of approximately 215 ha. Ash disposal areas A and C have been rehabilitated to grasslands. Small areas of *Acacia mearnsii* woodland have also developed over the years. Ash disposal area B is partly a semi-wetland of dense stands of *Arundo donax* and *Pennisetum clandestinum*.

The first known revegetation work was undertaken in November 1986 as small experimental strips on top of ash dam A (Michael 1991). The seeds were scattered by hand in rows running north to south and then lightly rotavated with a tractor-mounted rotavator. Different species were planted along each strip. Lists of species used are given in Table 2.1. Half of the Crown vegetation *(Viscia dasycaipa)* was inoculated with bacteria. No results from these experiments are known. Very little of this species *(Viscia dasycaipa)* was found on top of ash dam A during this study.

The top of ash dam A was revegetated in the early 1980's with *Cortaderia sp.* and *Pennisetum clandestinum* (Treatment A; Table 2.3). During 1995 the *Cortaderia sp.* was removed and a 50 mm layer of topsoil was added. The company that did the rehabilitation used a mixture of topsoil and sub-soil originating from different soil depths. The soil that was used was probably from a soil form with a plinthic horizon, because the soil layer consists of numerous iron and manganese oxide concretions. The total aboveground biomass was determined as 956 kg/ha (Michael 1991).

The rehabilitation on the plateau of ash disposal C was conducted during 1991 and 1992 with similar seed mixtures and amelioration practices. The slopes of ash dam A and C were rehabilitated during 1992 and 1994. Ash dam slopes were contoured and ameliorated with an 8-10 cm soil layer. A seed mixture of 13 species was used (Treatment C; Table 2.3). This seed mixture was similar to the seed mixture used during the 1990 rehabilitation initiative. *Pennisetum clandestinum* and *Cynodon dactylon* were also planted at regular intervals (4m) along strips 450 mm wide for inhibition of erosion.

The second series of revegetation actions were done at the beginning of 1990 growing season on parts of the plateau of ash dam C. The ash was ameliorated with a 50 cm layer of topsoil and fertilized at 250 kg/ha of super phosphate and 200 kg/ha of 4:3:4 (30) with zinc fertilizer. An area of 15 ha was planted with a seed mixture of 16 species of grasses (Treatment B; Table 2.3). An evaluation of the rehabilitated area was undertaken in July 1991 (Michael 1991). The middle slope of ash dam D was

rehabilitated during the 1996/1997 growing season (Treatment D; Table 2.3).
Ash dam D slopes were similarly rehabilitated as the rehabilitation treatment of 1992. The topsoil originally used was from a previous maize field.

Table 2.1: Species used during a rehabilitation experiment on the plateau of ash dam A in November 1986.

Lotus corniculatus
Agrostis sp.
Atriplex
Cenchrus ciliaris
Chloris gayana
Cynodon dactylon
Digitaria eriantha
Eragrostis tef
Festuca arundinaceae
Italian Rye grass, Titania (Lolium?)
Medicago sativa
Pennisetum americanum
Secale cereale
Sorghum sp.
Trifolium sp.
Viscia dasycarpa

Table 2.2: Species basal cover values from a survey conducted on the plateau of ash dam C (rehabilitated in October 1990) during November 1991.

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

2.2 Survey site selection and establishment

Intensive research was undertaken to measure ecological parameters associated with the Hendrina rehabilitation efforts. Twelve survey grids; each with a standardized configuration (Figure 2.2) were established on the ash dams.

Table 2.3: Rehabilitation dates & seed mixtures applied on the ash dams at Hendrina PowerStation.

	TREATMENT A: Mixture used in 1986 (Plateau area of ash dam A – Grid1) revegetated 1995	TREATMENT B: Mixture used in 1990 (Plateau area of ash dam C – Grid12)	TREATMENT C: Mixture used in 1992 & 1994 (Slopes of ash dam A, C, D & – Grids 7, 8, 9, 10 & 11)	TREATMENT D: Mixture used in 1996-1997 (Middle parts of the slopes of ash dam D – Grids 7 & 8)
	1986?	**1990-1991**	**1992-1994**	**1996-1997**
SPECIES	*Pennisetum clandestinum sods*	*Cenchrus cilliaris*	*Chloris gayana*	*Chloris gayana*
	Cortaderia sp. Young plants	*Chloris gayana*	*Chloris virgata*	*Eragrostis tef*
		Chloris virgata	*Cynodon dactylon*	*Eragrostis curvula*
		Cynodon dactylon	*Digitaria eriantha*	*Eragrostis lehmanniana*
		Digitaria eriantha	*Enneapogon cenchroides*	*Enneapogon cenchroides*
		Enneapogon cenchroides	*Eragrostis chloromelas*	*Eragrostis echinocloidea*
		Eragrostis chloromelas	*Eragrostis curvula*	*Themeda triandra*
		Eragrostis curvula	*Eragrostis echinocloidea*	*Digitaria eriantha*
		Eragrostis echinocloidea	*Eragrostis lehmanniana*	*Cynodon dactylon*
		Eragrostis lehmanniana	*Eragrostis tef*	*Pogonarthria squarrosa*
		Eragrostis tef	*Hyparrhenia hirta*	*Panicum maximum*
		Fingerhutia africana	*Themeda triandra*	*Pennisetum clandestinum sods*
		Heteropogon contortus	*Pennisetum clandestinum sods*	
		Hyparrhennia hirta	*Cynodon dactylon sods*	
		Panicum maximum		
		Themeda triandra		
TOPSOIL	50mm Topsoil (1995)	10 cm	10 cm	10 cm
FERTILIZATION		Super phosphate (10.5 % P)	Super phosphate (10.5 % P)	Super phosphate (10.5 % P)
		4:3:4:(30) Zn	4:3:4:(30) Zn	4:3:4:(30) Zn
OTHER	Cortaderia sp. Removed 1995	KAN	KAN	KAN

The grids were sited in relatively homogeneous areas (to reduce background noise), specifically to assess the influence of macro-environmental features and cultivation factors on rehabilitation success. These factors included age/status of rehabilitation, vegetation communities and soil factors.

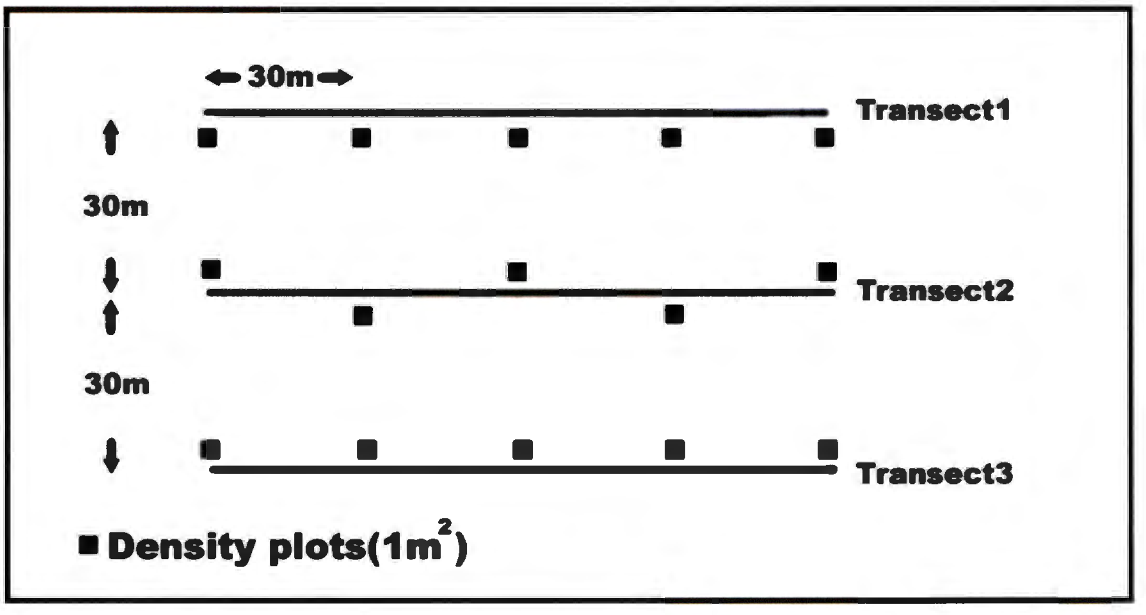

Figure 2.2: Diagram showing the grid layouts used on ash disposal sites at hendrina study area. Each density plot contains a single pitfall trap.

The twelve grids differ in terms of topography (slopes or plateau) and ecological status of neighboring areas (Table 2.4). Two control grids (Co1 and Co2) were also set out in adjoining natural grasslands. Although it is impossible to ever rehabilitate communities on the ash dam sites to the levels of diversity and complexity in natural grassland, baseline knowledge of community structure and temporal variability of neighboring grassland is vital to the interpretation of patterns observed on the ash dams. The twelve ash dam grids, with the controls, were surveyed either bi-monthly or quarterly for this study.

Table 2.4: Description of grids at Hendrina Power Station, showing the differences in terms of the year of rehabilitation, aspect, topography, status of adjoining areas, as well as vegetation classification.

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

* The codes for the adjoining areas and areas that were not rehabilitated:

1 – Disturbed areas; 2 - Natural grassland

2.2.1 Bi-monthly Surveys

Bi-monthly surveys were undertaken during the following periods:

1997: 10-14 March; 6-10 May; 15-20 July; 29 September-5 October;
1-6 December.

1998: 26 January-2 February; 16-22 March; 4-8 May; 28 July-2 August;
21-26 September; 1-4 December.

1999: 28-29 January; 24-27 March; 27-29 May

These bi-monthly surveys included the following:

a) Collection of substrate samples for extraction and analysis of nematode diversity and community structure was performed by other members of the Hendrina project team;
b) Collection of substrate samples for extraction and analysis of soil meso-fauna diversity and community structure was performed by other members of the Hendrina project team;
c) Sampling of other epiphytic and epigeal invertebrates to determine species diversity and community structure was performed by members of the Hendrina project team; including the sampling of hemipteran assemblages;
d) Phenological floral surveys was performed by other members of the Hendrina project team.

2.2.2 Quarterly Surveys

Quarterly surveys were undertaken on a seasonal basis, during the following periods:

1997: 6-10 May; 15-20 July; 29 September-5 October; 1-6 December.
1998: 26-31 January; 4-8 May; 28 July-2 August; 21-26 September; 1-4 December.
1999: 28-29 January.

During these quarterly surveys, project team members undertook the following tasks:

a) Extensive analyses of plant species, frequencies, diversity, basal cover and biomass;
b) CMR (Capture-Mark-Recapture) studies of small mammals to determine densities, diversity and community structure(s).

Comprehensive sampling and analyses were carried out annually during July 1997 and 1998 to determine impacts of the above parameters on substrate quality and structure.

2.3 Soil analysis

Soil quality is an important factor in the evaluation of rehabilitation success. Consequently, background variability in substrate characteristics was assessed. Three substrate samples at 0-10 cm and three at 10-20 cm were taken from each grid with the aid of a soil sampler on 30 July 1997 and again in May 1998.

Ecorehab[1] analyzed these samples for structure (particle size distributions) and macro & microelements.

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

The ash dam grids were classified into three plant communities, two sub-communities and six variants (Morgenthal 2001; Table 2.2).

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

The adjoining natural grassland (Co1 & Co2; Table 2.4) is characterized by this plant community. Diagnostic species of grass, which form part of this community, include the following: *Brachiaria serrata, Setaria sphacelata var. torta, Tristachya leucothrix, Elionurus muticus* and *Heteropogon contortus*. The community also includes a rich variety of forbs e.g. *Vernonia oligocephala, Hermannia transvaalensis, Acrotome hispida* and *Pentanisia angustifolia*. This particular area is known for its occasional veld fires and no grazing activities in this area could be detected.

Community 2: *Eragrostis curvula-Cynodon dactylon*

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

[1] Ecorehab, Private Bag X6001, Potchefstroom, South Africa, 2520

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

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

Variant 2.1.1: *Chamaecrista biensis*

Grass species associated with this variant include, *Pennisetum clandestinum*, *Eragrostis curvula*, *Hyparrhenia hirta*, *Cynodon dactylon* and the forb *Chamaecrista biensis*. This variant was found on top of ash dam C (Grids 10, 11 & 12) (Table 2.4).

Variant 2.1.2: *Lespedeza cuneata-Hyparrhenia hirta*

Diagnostic species occurring within this variant include species such as the forb *Lespedeza cuneata* and the grasses, *Chloris gayana* and *Eragrostis plana*, while the dominant species within this variant include *Hyparrhenia hirta*, *Eragrostis curvula* and *Pennisetum clandestinum*. Most of the slopes, rehabilitated between 1992-1994, were part of this variant, except the top and middle transect of grids 7 & 8 (Table 2.4).

Variant 2.1.3: *Lepidium bonariense-Eragrostis trichophora*

The *Lepidium bonariense-Eragrostis trichophora* variant is characterized by a high dominance of *Pennisetum clandestinum* with low abundance of *Hyparrhenia hirta*, while *Digitaria eriantha* is absent from this variant. Dominant species include the forbs, *Conyza bonariensis* and *Tagetes minuta*. The habitat associated with this variant is very similar to the *Chamaecrista biensis* variant. This plant variant was never revegetated with a seed mixture, but instead planted with *Pennisetum clandestinum* and *Cortaderia sp.*, where after the *Cortaderia sp.* was removed in 1995 due to health risks. During this period a layer of topsoil was added with a large amount of gravel. This variant is found on the plateau of ash dam A (Grid 1; Figure 2.1; Table 2.4).

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

The forbs, *Amaranthus hybridus* and *Chenopodium album*, are indicative of this sub-community, with a dominant occurrence of forbs, such as *Cyperus esculentus* and *Tagetes minuta*. This sub-community is found on the middle parts of grids 7 & 8, which were rehabilitated in 1996 (Table 2.4), and could be subdivided into three variants.

Variant 2.2.1: *Portulaca oleracea-Bidens formosa*

The *Portulaca oleracea-Bidens formosa* variant is characterized by dominant species such as, *Tagetes minuta* and *Bidens formosa* and some garden plants such as *Gladiolus sp., Iris sp., Canna sp.* and *Mirabilis jalapa,* possibly due to the dumping of domestic refuge on already rehabilitated areas on ash dam C. Ruderal plant species such as *Portulaca oleracea, Bidens formosa, Cyperus esculentus* and *Tagetes minuta*, garden plants and perennial grasses like *Eragrostis curvula, Cynodon dactylon, Eragrostis chloromelas* and *Hyparrhenia hirta* can all be found in this variant (Table 2.4).

Variant 2.2.2: *Panicum maximum-Digitaria eriantha*

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

Variant 2.2.3: *Eragrostis tef-Enneapogon cenchroides*

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

Community 3: *Spergularia media*

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

2.5 Data collection: Hemipteran survey.

2.5.1 Pitfalls

Sweepnetting alone gives an underestimation of the total faunal diversity in any particular area, and it is therefore necessary to perform some additional survey techniques, such as hand collections and pittfalltrapping, if a more complete community census is required. Each grid consisted of three transects of 120 m with a total of five pitfall traps per transect, spaced at 30 m intervals (Figure 2.2). Pitfall traps were placed in holes dug into the ground, with the openings flush with the surrounding soil, without disturbing the surrounding soil and vegetation too much. Pitfall traps were marked with wooden stakes to facilitate finding them. Plastic specimen jars, 120 mm deep and 50 mm in diameter, were used for the trapping. Uys & Urban (1996) considers the ideal trap diameter to be about 40mm. As preservative, 70% ethanol was added to the pitfall traps on removal from the soil. Hemipterans were sampled by operating the traps for 48-hours, bi-monthly, from March 1997 to January 1999. After each collection of pitfall samples, a fresh set of jars was immediately returned to the holes in the soil for the next survey. This enabled pitfall traps to settle within the soil and also to avoid the disturbing, digging-in effect of traps (Greenslade 1973).

2.5.2 Sweep nets

Hemipteran species were collected using a 300 mm diameter sweep net. Vegetation sweeping was done between l0h00 and 14h00, bimonthly, from March 1997 to January 1999. Five vigorous 180 degrees sweeps were taken between each pitfall traps (30 m) (Figure 2.2). Sweep net contents were emptied in tight-sealing glass jars and filled with 70% ethanol as preservative.

2.5.3 Preservation and identification of Hemiptera

The collected hemipterans were stored in 70% ethanol until April 2000 when the samples were sorted into morphospecies with the use of a dissection microscope and the aid of identification keys. Hemiptera was identified to family level and species level where possible with the help of M. Stiller[2]. Various checklists and keys to the families and subfamilies of Hemiptera were used but mainly the classification of (China & Miller

1959.) All morphospecies were given a morphospecies number (e.g. ihe39m) and identified as detailed as possible. A reference collection of voucher specimens is held at the Potchefstroom University for CHE. One or more specimens of each morphospecies were mounted either directly on pins or card points (fig 2.3) depending on the size of the specimen the latter method was only used for species to small to be pinned. Each specimen was labeled with important information such as:

- The reference number which corresponds with data tables
- The date of collection
- The information of the collector
- The GPS co-ordinates as well as locality of collection.

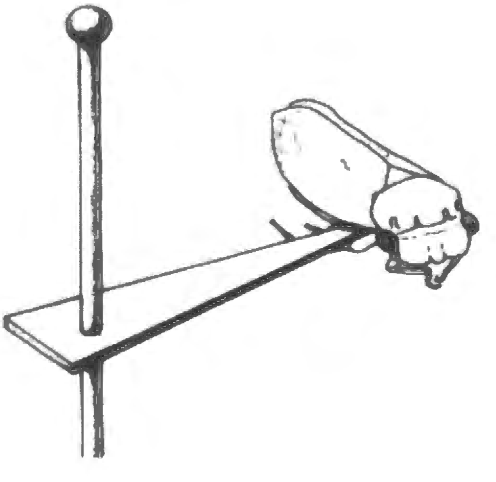

Figure 2.3: Leafhopper glued to a card point (Uys & Urban 1996).

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[2] Biosystematics Division, Plant Protection Research Institute, ARC, Private Bag X180, Pretoria, 0001

2.5.4 Vegetation surveys

Vegetation surveys were done by Dr. T. Morgenthal from Botany, School of Environmental sciences and development, Potchefstroom University for Christian Higher Education. These measurements include percentage bare ground, percentage plant cover, plant frequency of each species, vegetation structure and density, plant species richness and plant species composition, which were also taken along each, transect.

2.5.5 Physical surveys

Other physical surveys, such as sampling, were taken. Ten centimeters deep-soil cores were taken with a soil-auger in the middle of each transect, put into plastic bags, marked, sealed and sent to Ekorehab in Potchefstroom for analyses of minerals, pH, conductivity, organic matter and percentage sand, silt, gravel and clay content. These soil samples were taken during a winter survey of 1997. Litter in rehabilitated areas consisted largely of dead grass and forbs. Temperature and rainfall data were collected at the Hendrina weather station (18 km south-east of Hendrina Power Station, 1700 m a.s.l.) and the Carolina weather station (45 km east of Hendrina Power Station; 1690 m a.s.l.).

2.6 Data analysis

Relative abundance (percentage frequency) were calculated by dividing the number of individual hemipteran species at each transect (*Ni*) by the total number of hemipteran individuals caught per transect (*N*), and then multiplied by hundred.

Shannon-Wiener diversity index, species richness and species equitability are three important components of determining diversity in a community.

Statistical software MVSP (Multivariate Statistical Package) was used to determine these values.

Shannon-Wiener diversity index (*H'*)

Shannon-Wiener diversity index was used because it gives more value/weight to scarce hemipteran species compared to other diversity indexes like the Simpson diversity index, which gives more value/weight to abundant hemipteran species (Hellawell 1986).

Shannon-Wiener diversity index formula:

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

S = total number of species in a sample,
Ni = total number of individuals in the ith species in a sample and
N = total number of individuals in a sample.

Species equitability (*J'*)

Species equitability is a measure of the even distribution of individuals between species. Species equitability formula:

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

H' = Shannon-Wiener diversity index

S = natural log of the number of species within a sample

Species richness (S)

There are several species richness indexes but they are not suitable for all instances of sampling. The Margalef's index for example overestimates diversity in small samples and underestimates diversity in large samples. According to Georges 1994 species richness indexes are not suitable to compare localities and the number of species should be used instead. In this study species richness refers to number of species and not to a specific species richness index.

Other Statistical analysis

Further statistical analysis was performed with STATISTICA 6. Normality of samples was determined using Shapiro Wilk's test. Samples with a p-value greater than 0.05 were considered normally distributed. Parametric tests such as analysis of variance and Pearson's correlation coefficient were used when data was normally distributed. Analysis of variance was applied to determine statistically significant differences. Pearson's product moment correlation coefficient is used to determine the degree of proportion between values of two variables. It was used to determine if correlations between components of hemipteran species diversity and plant species diversity existed.

Non-parametric tests included Kruskal-Wallis ANOVA and Spearman-R correlation coefficient, which was used to determine if correlations between components of hemipteran species diversity, plant species diversity and different soil characteristics existed. A test described by Miller (1981) was used to test statistically significant differences between means of non-parametric variables such as mean Shannon diversity index, species equitability and number of species at different stages of rehabilitation.

The equation for Miller's test of significance is:

$$|\overline{R}i - \overline{R}j| \leq \sqrt{C(n-1;0,05) \cdot \frac{N(N+1)}{12}\left(\frac{1}{ni}+\frac{1}{nj}\right)}$$

$\overline{Ri}$ = sum of ranks of the *i*th sample

$\overline{Rj}$ = 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 one-way ANOVA was 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 was also used to indicate differences between species diversity, species equitability and number of species at different stages of rehabilitation in comparison to the natural grassland. The lognormal model was used during the analysis (Preston 1962; Williams 1964).

Linear regression analysis was used to determine correlation between hemipteran species and plant parameters as well as between hemipteran species and different soil parameters. Where data was normally distributed the Pearson correlation coefficient was used to examine the extent to which values of two variables are related to each other (Pearson 1896). Where data was not normally distributed the Spearman-R correlation method was used.

The use of multivariate ordination techniques makes it possible to examine the distribution of many species simultaneously as well as their relationship to environmental parameters (Ter Braak 1989). Less detailed knowledge of species biology is needed when using these techniques (Kremen 1992). Detrend Correspondence Analysis (DCA; detrend by polynomials, CANOCO program, Ter Braak 1988) was used to determine the patterns of co-variation 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 such as 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) is a direct gradient analysis that was used to analyze hemipteran 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 a test statistic (Ter Braak 1988).

Forward selection was used to determine which of the environmental variables had significant influence on the distribution of hemipteran species. Only the environmental variables, which contributed significantly to the distribution of the hemipteran 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 hemipteran species. These were the times when both hemipteran and plant species were abundant. Only soil data for 1997 was available. Because soil data was unlikely to change much in one year's time, hemipteran data for the whole of 1997 were compared to the soil parameters of 1997. Both plant and hemipteran data with a relative abundance of less than 0.5 were omitted from the analysis.

CHAPTER 3

RESULTS

3.1 Hemipteran assemblage structure

3.1.1 Hemipteran species composition at the Hendrina power Station ash dams and natural grassland.

All morphospecies could not be identified to genus or species level (Species list supplied in Appendix II). The samples collected during the surveys on the rehabilitated and unrehabilitated ash dams consisted of 61 morphospecies in 13 families (Figure 3.1, Appendix II), compared to 47 morphospecies in 16 families in the natural grassland (Figure 3.2, Appendix II). Morphospecies were sorted in categories of dominance, (5% - 100%) dominant, (0.5% - 5%) sub dominant and (0.05% - 0.5%) sub-ordinate (Table 3.1).

The assemblage structures of the morphospecies on the rehabilitated and unrehabilitated ash dams and natural grassland were studied and the total relative abundance of each morphospecies was determined. The dominant morphospecies collected on the ash dams were Aphididae sp.1 (iho11) (Relative abundance 15.46%), Heteroptera sp.1 (ihe39) (11.19%), *Paromius gracilis* (ihe5) (7.73%), *Balclutha auranticula* (iho3) (7.22%), *Euthestus leucosticus* (ihe1) (6.88%), *Tetartostylus brevistylus* (iho31) (6.64%), and *Cletus sp.1* (ihe49) (5.25%). The five families most abundant on the ash dams were

Aphididae, Heteroptera family 2, Lygaeidae, Cicadellidae and Alydidae (Figure 3.1, Figure 3.2, Table 3.1 and Table3.2).

The dominant morphospecies collected in the natural grassland were Heteroptera sp.2 (ihe39) (22.62%), Miridae sp.3 (ihe103) (14.05%), *Cletus sp.1* (ihe49) (abundance 11.95%), *Naudeus bivittatus* (iho15) (10.66%) and Issidae sp.1 (iho39) (7.75%). Of the dominant morphospecies on the ash dams and the natural grassland only two species occurred in both habitats Heteroptera sp.2 (ihe39) and *Cletus sp.1* (ihe49). In both instances these species were more abundant on the ash dams. The five families most abundant in the grassland were Heteroptera family 2, Miridae, Coreidae, Cicadellidae and Issidae (Figure 3.1, Figure 3.2, Table 3.1 and Table3.2).

3.1.2 Hemipterans as possible indicators of rehabilitation success.

Hemipteran species found at different stages of rehabilitation on the ash dams was determined. In this section the species of hemipterans that appear to be pioneer species as well as species, which are characteristic of later stages of succession, are identified. Species which only occur in the surrounding natural grassland are also important and future colonisation of these species could indicate further succession. The hemipteran species in the natural grassland, which colonise the rehabilitated areas, need to be identified.

The ash dams at the Hendrina power station were rehabilitated during different years. These different ages of rehabilitation create a possible gradient of succession. The mean abundance per transect of hemipteran species at different ages of succession is summarised in Table 3.2.

3.1.2.1 Primary succession hemipteran species.

Coreidae sp.2 (ihe35), *Sogatella capensis* (iho78) and HOMOPTERA sp.1 (iho1) appears to be early successional hemipterans, as they were found to be abundant in the unrehabilitated areas (Grid 7 & 8 top) and late rehabilitated areas (1994, Grid 2, 3 & 4). The species did not appear in the early-rehabilitated areas (1990, Grid 12) or in the natural grassland (Table 3.2; Figure 3.3, Figure 3.4 and Figure 3.5). There are also fourteen other hemipteran species that colonized the unrehabilitated areas, they are well represented on rehabilitated areas as well as in the natural grassland and could rather be considered as intermediate successional species.

3.1.2.2 Intermediate to late successional hemipteran species.

Intermediate to late successional species are species that were abundant in later stages of succession; a good example of such a species is HETEROPTERA sp.2 (ihe39). This species was present on the rehabilitated grids, unrehabilitated grids and the Natural grassland (Table 3.2; Figure 3.6). *Pratura graminea* (iho93), *Paromius gracilis* (ihe5), HETEROPTERA sp.1 (ihe8) and *Euthestus leucosticus* (ihe1) were also present on all grids but were dominant in the Natural grassland.

3.1.2.3 Late successional Hemiptera Species.

Late successional species are species that colonise a habitat at the later stage of rehabilitation (1994). There are some thirty species that were only recorded since 1994 in this late successional stage. Two of the most abundant of species were *Agonoscelis versicolor* (ihe93) (Figure 3.8; Table3.2) and *Spilostethus trilineatus* (ihe27) (Figure 3.7; Table3.2). HOMOPTERA sp.9 (iho21) is the only species that was sampled only on the oldest rehabilitated grid (1990). Unfortunately not enough of this species was sampled to make proper statements on the species presence.

3.1.2.4 Natural grassland species.

Species that were only found in the natural grassland and not on the ash dams are referred to as natural grassland species. Some of these species may not have been sampled on the ash dams due to the sampling size. These species are COREIDAE sp.1 (ihe63); REDUVIIDAE sp.3 (ihe65); PSEUDOCOCCIDAE sp.1 (ihe16) and *Pratura graminea* (iho22) (Figure 3.9; Table 3.2).

3.1.3 Quantitative analysis of hemipteran assemblages as possible indicators of ecological changes, due to rehabilitation success.

Species diversity, equitability (evenness) and species richness are all integrated parts of a quantitative analysis of species diversity, in a quantitative analysis on the hemipterans sampled at the Hendrina power station. The Shannon-Wiener diversity index was used. The Shannon-Wiener index emphasises rare species (Sheehan 1984). Equitability is the evenness of distribution of individuals between species while the number of species gives a good indication of species richness. Mean number of species was used rather than an index such as Margalef's index because of the variation in sample size. Parameters such as mean Shannon diversity, mean equitability and mean species richness was used throughout the study to compare the natural grassland with the ash dams.

An increase in the mean hemipteran diversity after the third year of rehabilitation was shown. From the third year to the ninth year after rehabilitation the mean Shannon diversity, mean equitability and mean number of species stayed fairly constant (Table 3.3 and Figure 3.10). According to Tukey's test for significance the unrehabilitated ash dams differed significantly in mean Shannon diversity and mean species richness only from the third to fourth year of rehabilitation.

There are significant differences in mean Shannon diversity, mean equitability and mean species between the third year of rehabilitation and the fourth to ninth year of rehabilitation. There are also significant differences between mean Shannon diversity, mean equitability and mean species richness of the fourth year of rehabilitation and the seventh and ninth year of rehabilitation as well as the natural grassland. Significant differences also occur between the fifth year of rehabilitation and the seventh year of rehabilitation (Table3.3).

Another way to represent the differences in species diversity is by way of rank abundance graphs (Curry 1994). The rank abundance graphs are drawn so that the ordinate represents the log of the percentage relative abundance (dominance), which is plotted against ranked species sequence. Hemipteran data from 1997-1999 were used to rank the species accordingly.

Table 3.1 Relative abundance values of the dominant, subdominant and sub-ordanate Hemiptera morphospecies on rehabilitated and unrehabilitated ash dams grids and in the natural grassland (Fig. 3.1 and Fig. 3.2) Species are ranked from abundant to scarce.

ASHDAMS				NATURAL VELDT			
		Relative abundance	Morpho species			Relative abundance	Morpho species
Dominant	1	15.46	iho11m	Dominant	1	22.62	ihe39m
	2	11.19	ihe39m		2	14.05	ihe103m
	3	7.73	ihe5m		3	11.95	ihe49m
	4	7.22	iho3m		4	10.66	iho15m
	5	6.88	ihe1m		5	7.75	iho39m
	6	6.64	iho31m	Sub-dominant	6	3.88	iho31m
	7	5.25	ihe49m		7	2.91	iho93m
Sub-dominant	8	4.24	iho15m		8	2.75	iho11m
	9	3.66	ihe103m		9	2.26	ihe5m
	10	3.32	ihe44m		10	1.78	iho88m
	11	3.02	ihe8m		11	1.62	iho3m
	12	2.81	iho93m		12	1.45	ihe24m
	13	2.68	ihe24m		13	1.45	ihe27m
	14	1.56	iho87m		14	1.45	ihe53m
	15	1.53	iho88m		15	1.29	ihe78m
	16	1.53	iho39m		16	1.13	ihe93m
	17	1.53	ihe33m		17	0.81	ihe1m
	18	1.25	iho12m		18	0.81	ihe44m
	19	1.05	iho91m		19	0.65	ihe7m
	20	1.05	ihe3m		20	0.65	ihe17m
	21	0.92	ihe32m		21	0.65	iho91m
	22	0.78	iho46m	Sub-ordinate	22	0.48	ihe71m
	23	0.71	ihe17m		23	0.48	iho30m
	24	0.54	iho37m		24	0.32	ihe3m
Sub-ordinate	25	0.37	ihe7m		25	0.32	ihe4m
	26	0.34	ihe42m		26	0.32	ihe16m
	27	0.31	ihe46m		27	0.32	ihe42m
	28	0.27	iho26m		28	0.32	ihe60m
	29	0.27	ihe53m		29	0.32	ihe72m
	30	0.27	ihe43m		30	0.32	ihe83m
	31	0.24	ihe52m		31	0.32	iho5m
	32	0.24	ihe36m		32	0.32	iho22m
	33	0.24	ihe35m		33	0.32	iho37m
	34	0.20	iho25m		34	0.32	iho45m
	35	0.20	iho1m		35	0.32	iho49m
	36	0.20	ihe73m		36	0.16	ihe6m
	37	0.20	ihe22m		37	0.16	ihe8m
	38	0.17	iho92m		38	0.16	ihe33m
	39	0.17	iho34m		39	0.16	ihe43m
	40	0.17	ihe58m		40	0.16	ihe46m
	41	0.17	ihe4m		41	0.16	ihe56m
	42	0.17	ihe27m		42	0.16	ihe58m
	43	0.17	ihe11m		43	0.16	ihe63m
	44	0.14	iho9m		44	0.16	ihe65m
	45	0.14	iho72m		45	0.16	ihe77m
	46	0.14	iho5m		46	0.16	iho13m
	47	0.14	iho19m		47	0.16	iho25m
	48	0.14	ihe97m		58	0.16	iho26m
	49	0.14	ihe6m		49	0.16	iho51m
	50	0.14	ihe13m		50	0.16	iho61m
	51	0.14	ihe102m		51	0.16	iho64m
	52	0.10	iho8m				
	53	0.10	iho64m				
	54	0.10	iho49m				
	55	0.10	iho17m				
	56	0.10	ihe72m				
	57	0.07	iho83m				
	58	0.07	iho7m				
	59	0.07	iho78m				
	60	0.07	iho55m				
	61	0.07	iho4m				
	62	0.07	iho30m				
	63	0.07	iho23m				
	64	0.07	iho16m				
	65	0.07	ihe94m				
	66	0.07	ihe93m				
	67	0.07	ihe77m				
	68	0.07	ihe71m				
	69	0.07	ihe37m				
	70	0.07	ihe15m				

Table 3.2 : Mean Number of Hemiptera caught per transect, during different stages of succesion. Hemiptera is aranged according to their succesion.

	UNREHABILITATED AREAS	1996	1996	1994	1992	1990	NATURALVELDT
Age of Rehabilitation	0	3	4	5	7	9	0
Grids	G 7 top & G 8 top	G 7 mid & G 8 mid	G 1	G2 & G3 & G4	G 7 bot & G 8 bot G9 & G10 & G11	G 12	Co1 & Co2
Number of transects	2	2	3	9	11	3	6
No. traps	10	10	15	45	55	15	30
ihe35m	2.500			0.222			
iho78m	0.500				0.091		
iho1m	0.500			0.222	0.273		
iho64m	0.500			0.222			0.167
ihe78m	0.500						1.333
iho26m	4.000						0.167
iho61m	0.500						0.167
ihe58m	1.000		0.667			0.333	0.167
ihe46m	0.500		0.667		0.455	0.333	0.167
ihe44m	0.500		2.000	9.222	0.727		0.833
ihe53m	1.000		0.667	0.222	0.182		1.500
iho88m	0.500		1.000	0.667	2.455	2.667	1.833
ihe39m	0.500	29.000	12.000	16.111	7.727	1.667	23.333
ihe1m	1.000	1.000	8.000	1.778	10.182	15.667	0.833
ihe5m	0.500	5.500	8.000	6.667	10.818	4.333	2.333
iho93m	1.000	2.000	2.333	2.222	3.455	4.000	3.000
ihe8m	0.500	2.000	4.000	5.889	1.182	2.000	0.167
ihe37m		1.000					
ihe94m		0.500			0.091		
iho30m		1.000					0.500
ihe36m		2.500	0.333		0.091		
iho8m		0.500		0.111		0.333	
ihe71m		0.500			0.091		0.500
ihe4m		0.500			0.091	1.000	0.333
iho87m		1.000	0.667		3.455	1.333	
ihe32m		1.500	0.333	0.333	1.545	1.000	
ihe103m		6.000	5.333	4.556	3.545		14.500
ihe7m		1.000	0.667	0.333	0.364		0.667
iho11m		204.000	2.333	2.000	2.000	0.333	2.833
ihe49m		7.500	20.667	5.000	2.818	0.667	12.333
iho31m		6.000	4.667	2.111	12.818	3.333	4.000
iho3m		2.500	4.667	4.556	11.818	7.667	1.667
iho15m		3.000	2.667	3.556	6.636	2.000	11.000
iho91m		1.000	1.000	0.889	1.545	0.333	0.667
ihe17m		0.500	1.000	0.444	0.909	1.000	0.667
ihe42m		0.500	0.333	0.333	0.273	0.667	0.333
iho23m			0.333				
ihe99m			0.333				
ihe15m			0.667				
ihe38m			0.333				
ihe22m			0.667	0.111	0.273		
iho49m			0.333		0.182		0.333
iho25m			0.333		0.455		0.167
ihe33m			2.333	1.778	2.000		0.167
ihe43m			0.667	0.444	0.182		0.167
ihe72m			0.333	0.111	0.091		0.333
ihe73m			0.333	0.111	0.182	0.667	
ihe3m			3.000	2.333		0.333	0.333
ihe6m			0.667	0.111		0.333	0.167
iho39m			0.667	2.222	1.091	3.667	8.000
ihe24m			2.333	4.889	1.182	5.000	1.500
iho12m			1.000	0.667	2.000	2.000	0.000
iho37m			0.333	0.333	0.273	3.000	0.333
ihe100m				0.111			
ihe104m				0.111			
ihe34m				0.111			
ihe52m				0.111	0.545		
iho34m				0.333	0.182		
iho9m				0.222	0.182		
iho83m				0.111	0.091		
iho7m				0.111		0.333	
ihe60m				0.111			0.333
ihe93m				0.222			1.167
ihe102m				0.111	0.182	0.333	
iho92m				0.000	0.182	1.000	
ihe11m				0.222	0.182	0.333	
iho5m				0.111	0.273		0.333
ihe27m				0.111	0.273	0.333	1.500
ihe13m					0.182	0.667	
iho46m					2.091		
iho55m					0.182		
iho71m					0.091		
iho72m					0.364		
iho16m					0.182		
iho17m					0.273		
iho19m					0.364		
ihe82m					0.091		
ihe97m					0.364		
ihe98m					0.091		
iho4m					0.182		
ihe56m					0.091		0.167
ihe83m					0.091		0.333
iho13m					0.091		0.167
iho45m					0.000		0.333
iho51m					0.091		0.167
ihe77m					0.091	0.333	0.167
iho21m						0.333	
iho22m							0.333
ihe16m							0.333
ihe63m							0.167
ihe65m							0.167
Total hemiptera caught	32	562	296	746	1106	208	619
Number of species	17	24	40	49	65	35	52

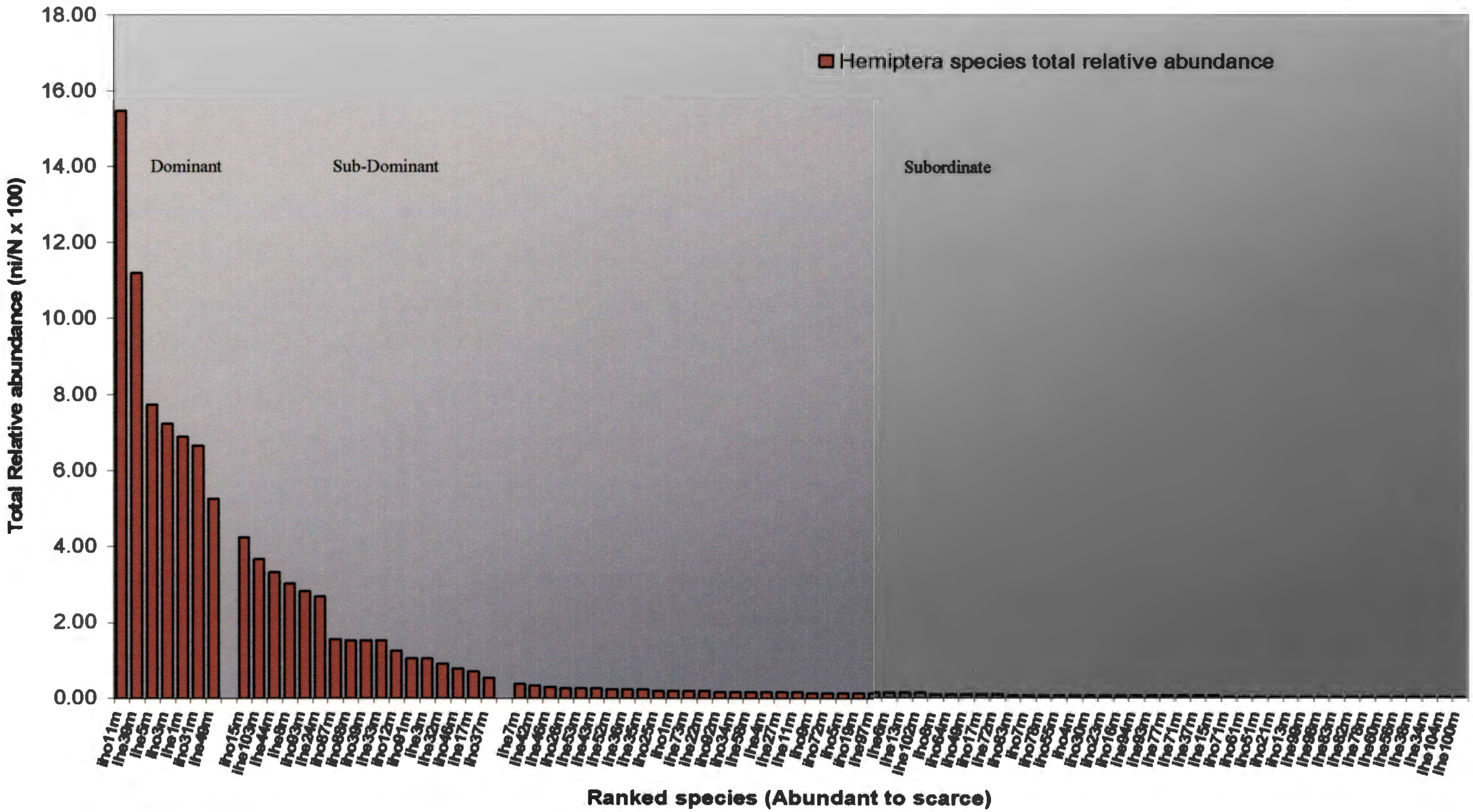

Figure 3.1: Total relative abundance of dominant, sub-dominant and subordinate hemipteran species collected on the ash dams at Hendrina power station.

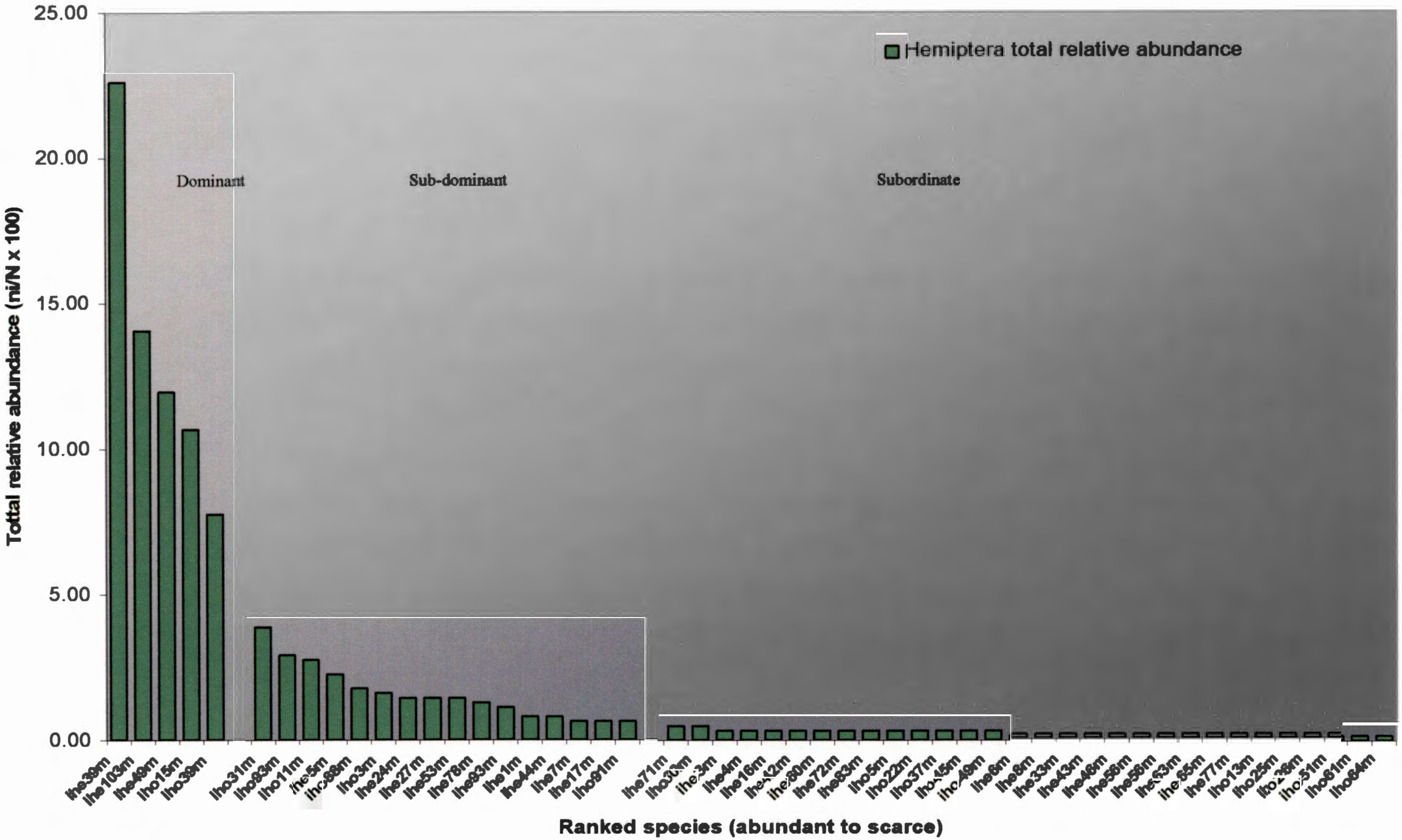

Figure 3.2: Total relative abundances of dominant, sub-dominant and subordinate hemipteran species collected in the natural grassland at Hendrina power station.

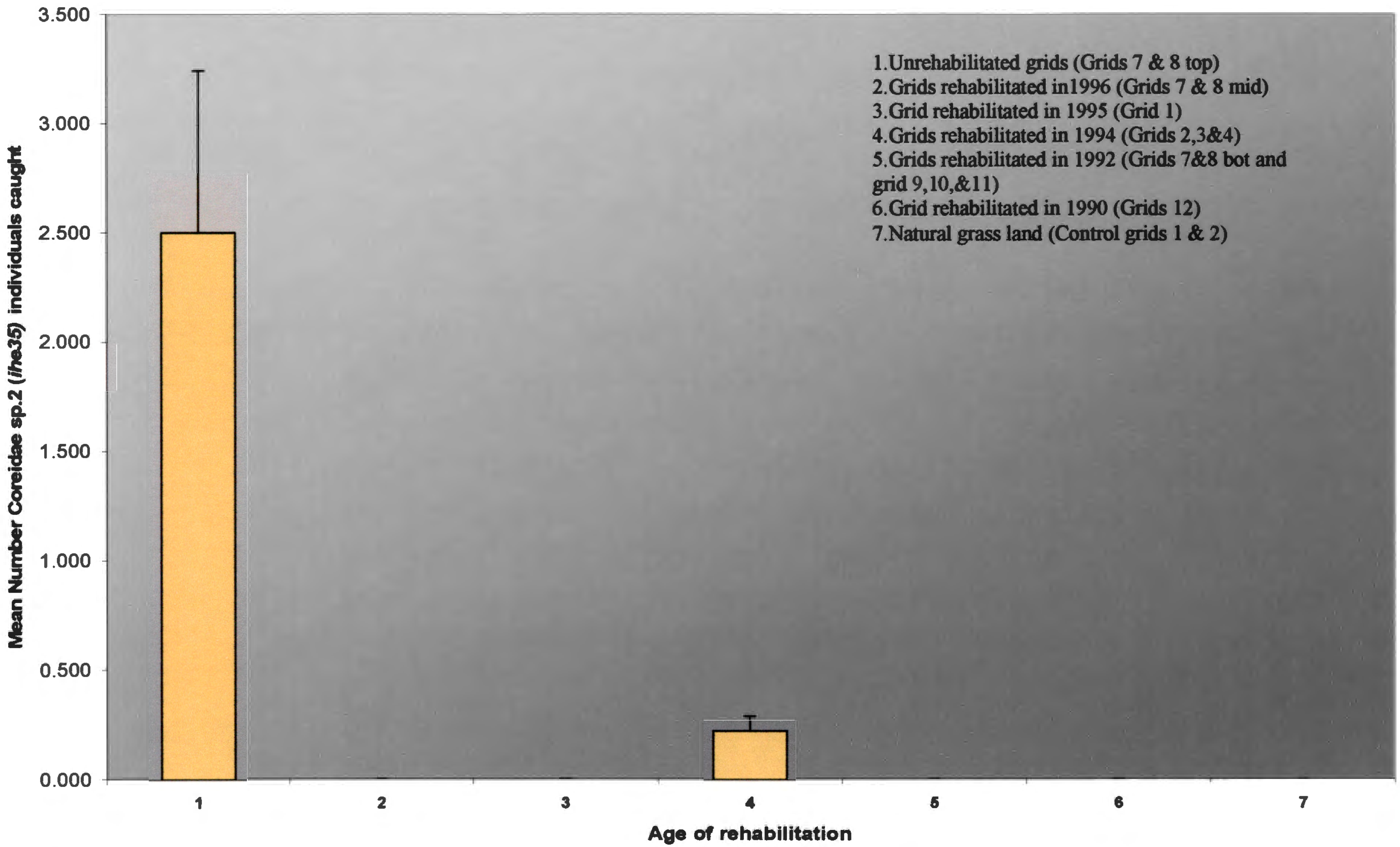

Figure 3.3: Mean number of COREIDAE sp. 2 (ihe35) individuals caught per transect during different stages of succession (Bars indicate ± 1sd).

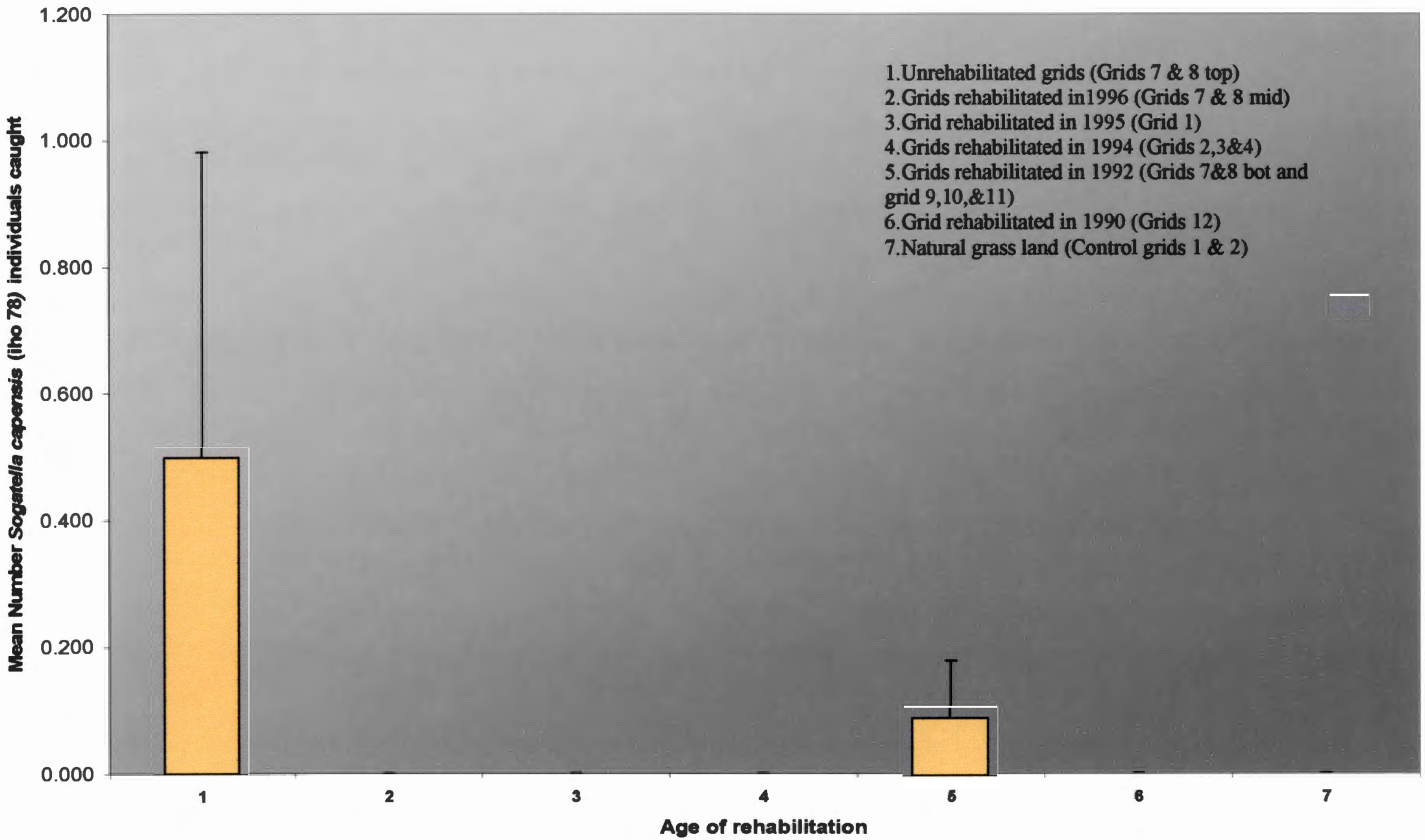

Figure 3.4: Mean number of *Sogatella capensis* (iho78) individuals caught per transect during different stages of succession (Bars indicate ± 1sd).

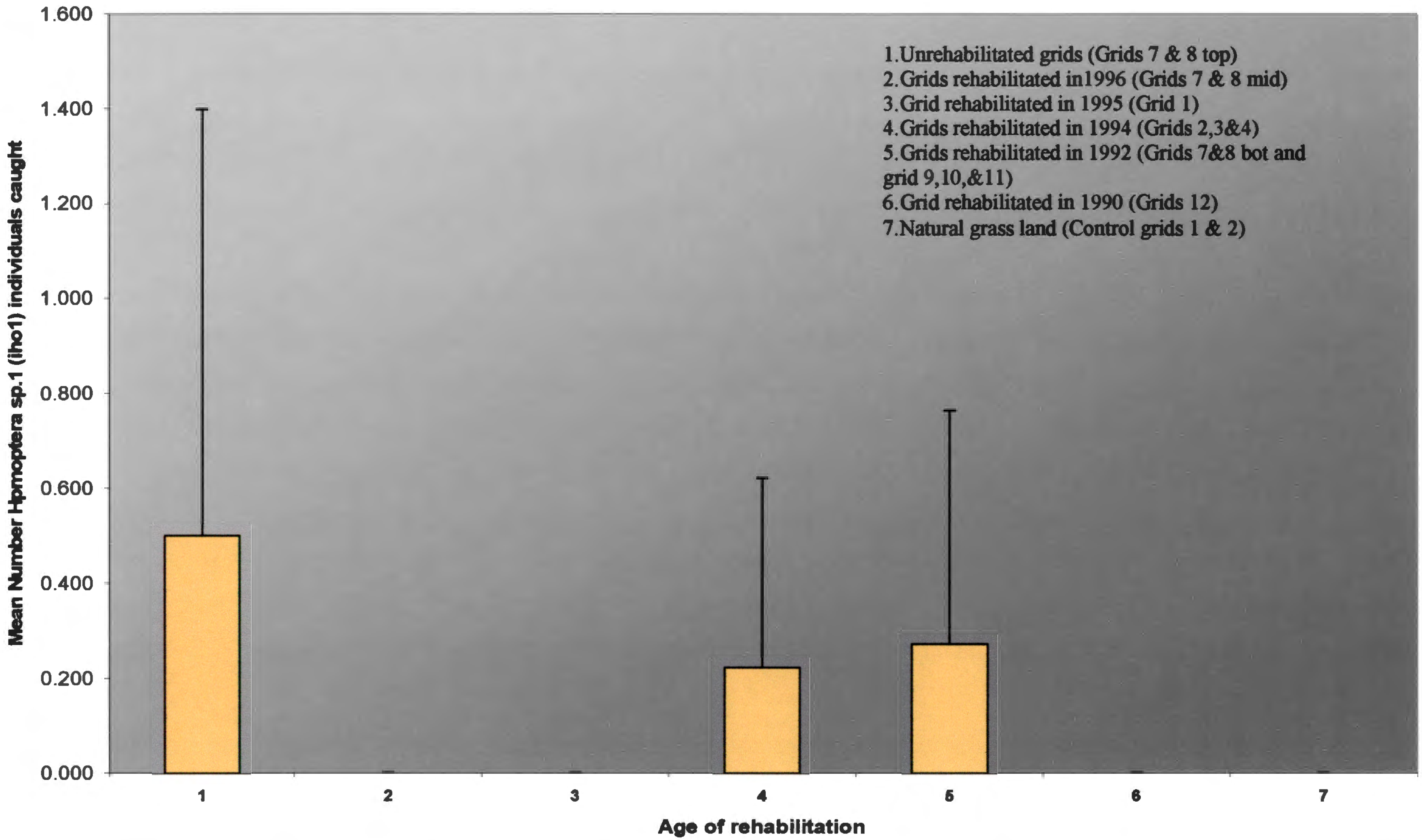

Figure 3.5: Mean number of HOMOPTERA sp.1 (iho1) individuals caught per transect during different stages of succession (Bars indicate ± 1sd).

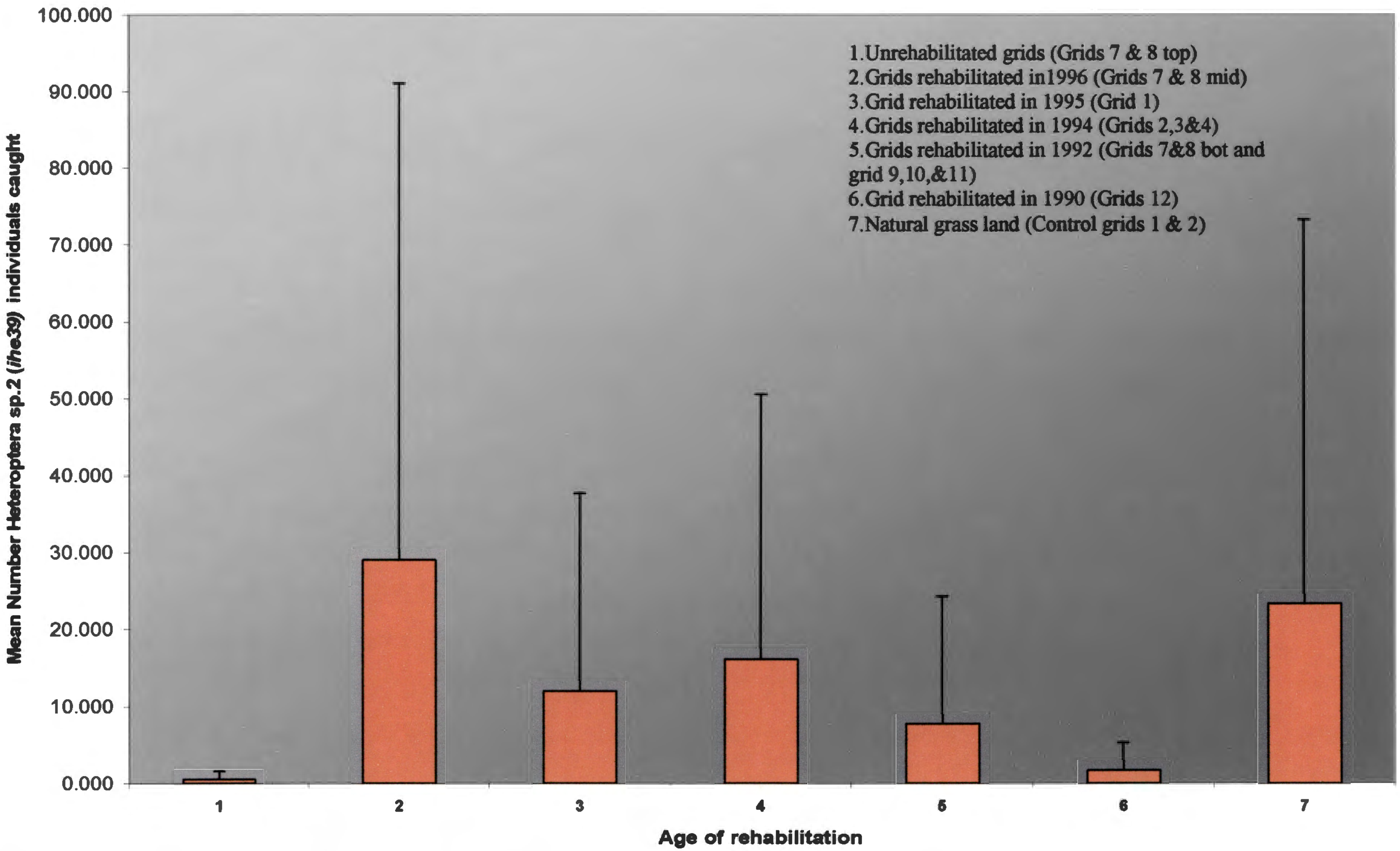

Figure 3.6: Mean number of HETEROPTERA sp.2 (ihe39) individuals caught per transect during different stages of succession (Bars indicate ± 1sd).

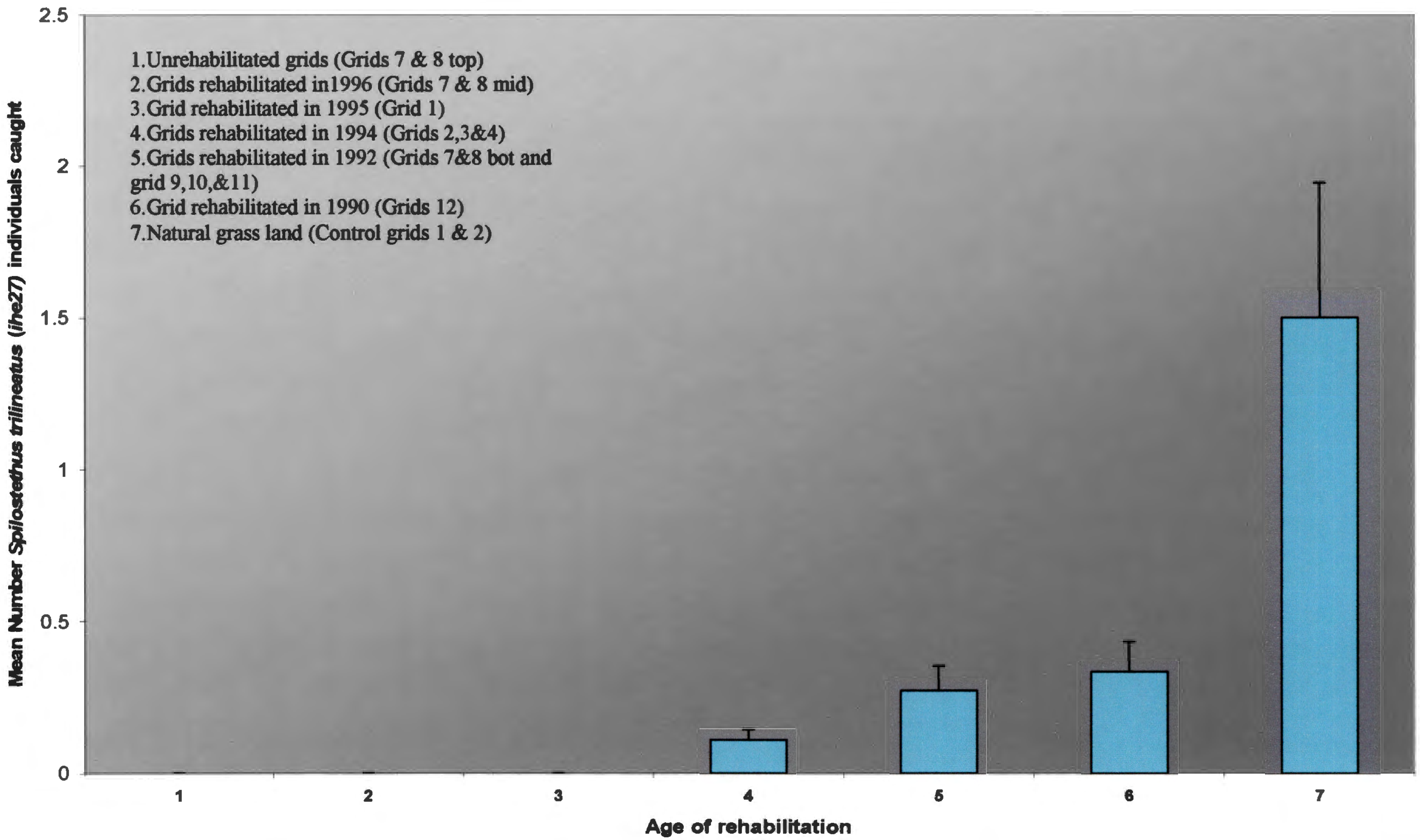

Figure 3.7: Mean number of *Spilostethus trilineatus* (ihe27) individuals caught per transect during different stages of succession (Bars indicate ± 1sd).

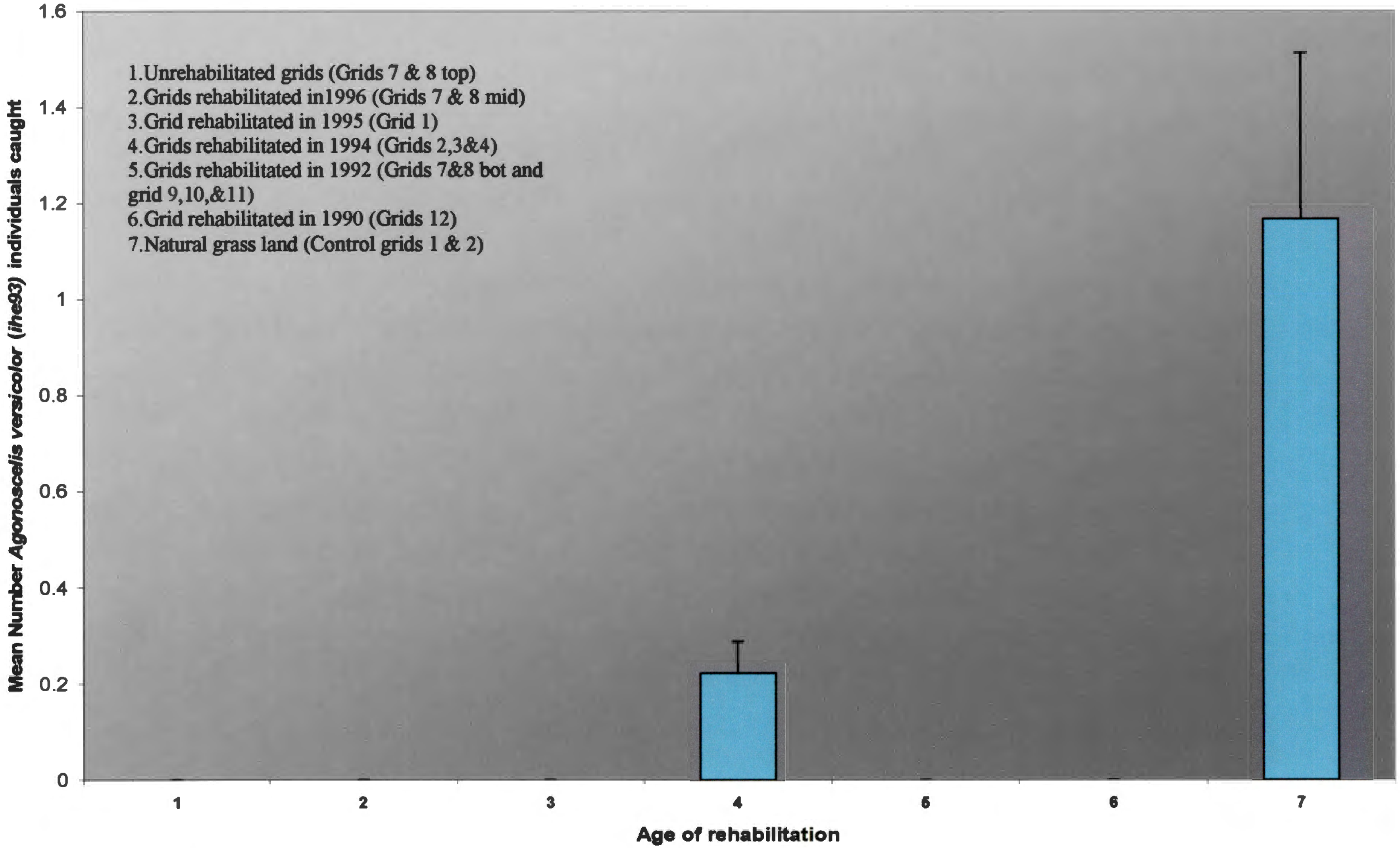

Figure 3.8: Mean number of *Agonoscelis versicolor* (ihe93) individuals caught per transect during different stages of succession (Bars indicate ± 1sd).

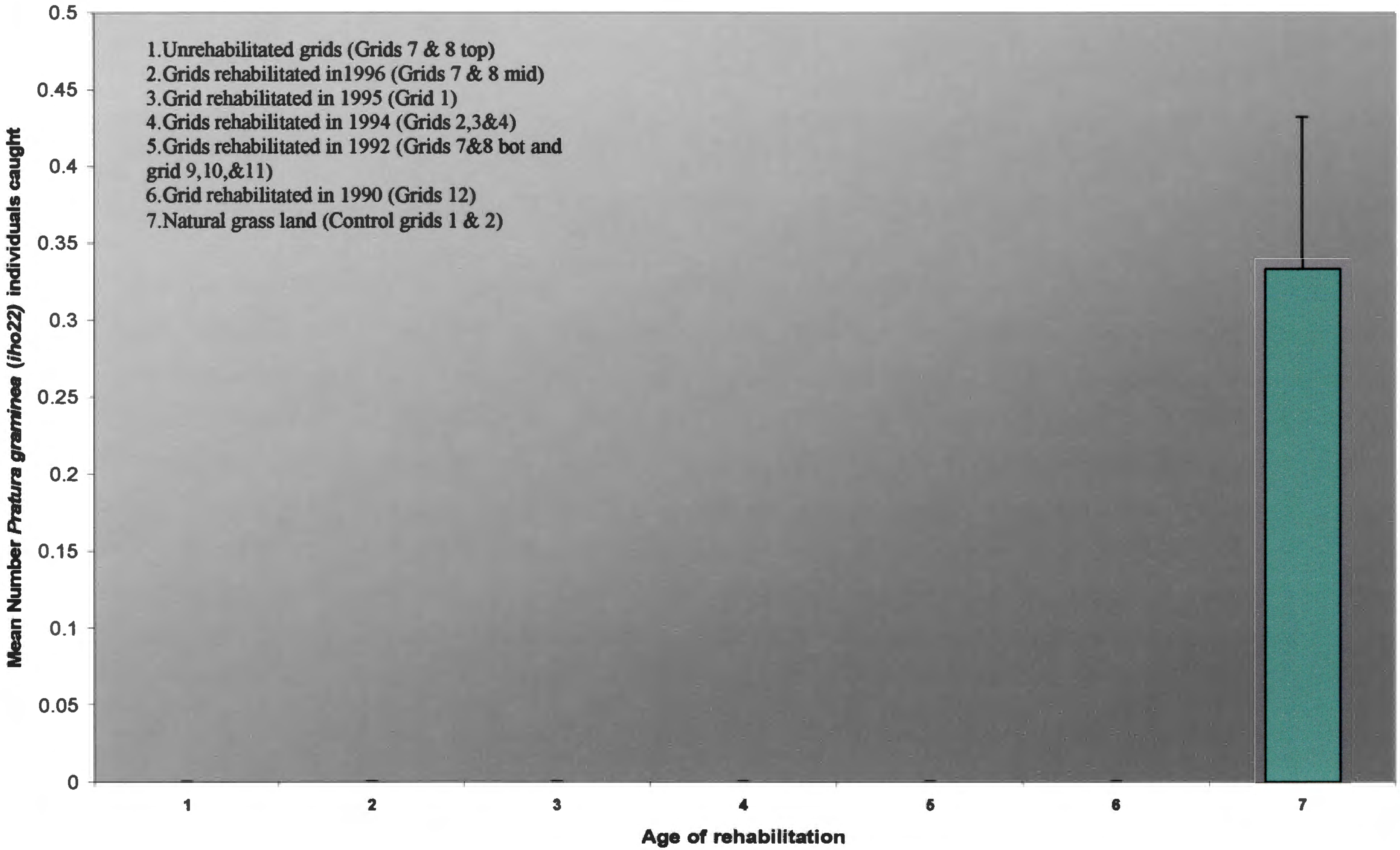

Figure 3.9: Mean number of *Pratura graminea* (iho22) individuals caught per transect during different stages of succession (Bars indicate ± 1sd).

The total relative abundance values of hemipteran species in grids rehabilitated at the same time were used and pooled for all the surveys (Figure 3.11). Steep rank abundance curves indicate low equitability values, which is indicative of high dominance and low species diversity. A flatter rank abundance indicates higher equitability and higher species diversity.

A short rank abundance graph is indicative of low species richness. Grid 7 and Grid 8 middle and top both have low species diversity and a very high dominance. The other rehabilitated sites tend to have higher diversity and lower dominance compared to Grid 7 and grid 8. The natural veldt compared well to the trend of the rehabilitated sites with a slightly lower diversity and species richness (Figure 3.11).

3.2 Possible influences of edaphic variables on the hemipteran assemblage structure on rehabilitated ash dams.

It is important to know the habitat and other factors that could play a major role in the abundance of hemipteran species on the ash dams. Relationships between plant and hemipteran diversity should be determined as well as the relationship between hemipteran species and percentage vegetation cover. Other edaphic factors such as gravel, silt, sand and clay, conductivity, pH and organic matter must also be considered. Associations between hemipteran communities and specific plant communities on the ash dam grids must also be considered.

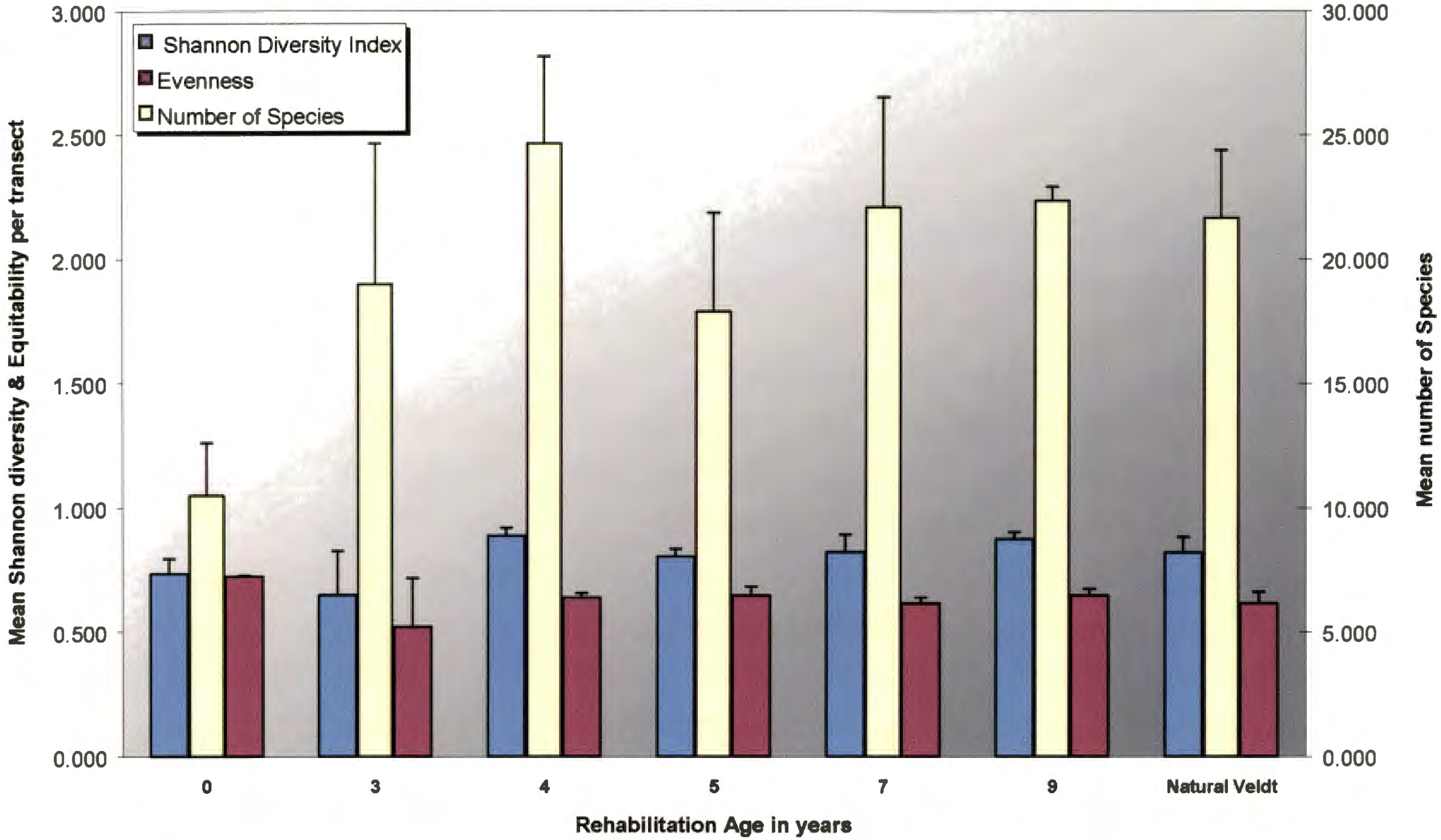

Figure 3.10: Mean Hemiptera Shannon diversity, mean Hemiptera species equitability and mean number of Hemiptera species, per transect during different stages of succession (Bars inicate ±1sd).

Table 3.3: Mean Shannon diversity index, mean equitability and mean species richness values per transect with standard deviations of the hemipteran assemblages, in relation to time since rehabilitation.

Rehabilitation age (Years)	**Shannon Diversity index (Mean ±sd)**	**Equitability (Mean ±sd)**	**Number of species (Mean ±sd)**
0 (Unrehabilitated)	0.736 ± 0.060	0.724 ± 0.004	10.500 ± 2.121
3	0.651 ± 0.177	0.523 ± 0.194	19.000 ± 5.657
4	0.888 ± 0.032	0.639 ± 0.018	24.667 ± 3.512
5	0.804 ± 0.030	0.648 ± 0.036	17.889 ± 3.983
7	0.824 ± 0.069	0.617 ± 0.024	22.091 ± 4.437
9	0.874 ± 0.027	0.648 ± 0.025	22.333 ± 0.577
Natural Grassland	0.820 ± 0.062	0.616 ± 0.048	21.667± 2.733
ANOVA	F_{29}=4.125649 $P<0.004$	F_{29} =2.949793 $P<0.023$	F_{29}=3.975438 $P<0.005$
	3 0 5 control 7 9 4	3 control 7 4 5 9 0	0 5 3 control 7 9 4

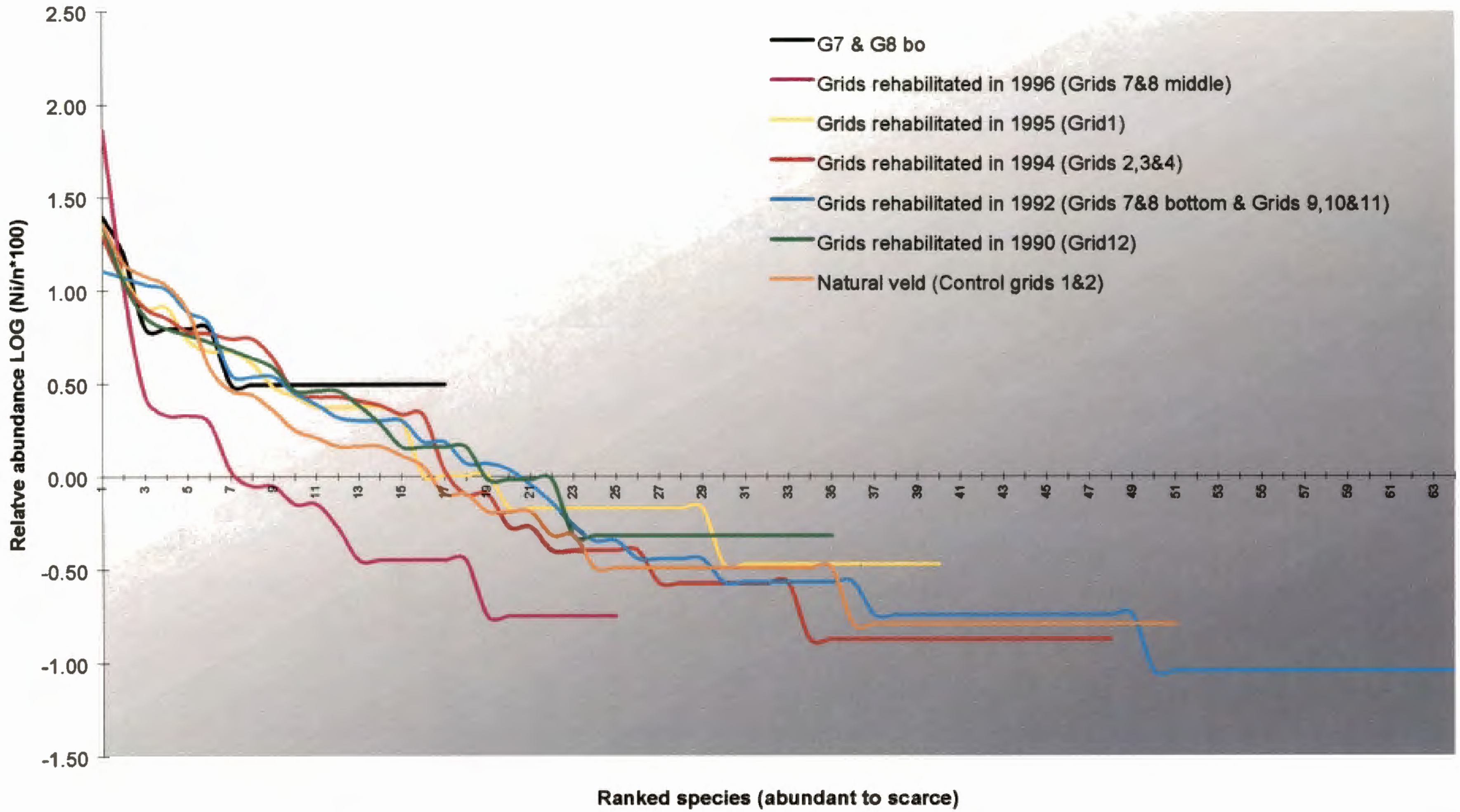

Figure 3.11: Rank abundance curves illustrating the diversity in the hemipteran assemblages on the ash dam grids and natural grassland, at specific stages of succession.

3.2.1 Plant species diversity and percentage vegetation cover in relation to diversity of hemipteran assemblages on rehabilitated ash dams.

Figure 3.12 shows the mean plant Shannon diversity, mean plant species richness and the equitability of the plant communities that were correlated with the hemipteran species richness, species equitability and Shannon diversity index. Only grids along a rehabilitation gradient (ash dam grids) were used in this section. Winter surveys and unrehabilitated areas were also excluded in order to limit variation in data.

Only hemipteran species equitability and percentage vegetation cover correlated significantly (Figure 3.13), whereas mean Shannon diversity and mean species richness did not correlate significantly with any of the four plant components (Table 3.4).

3.2.2 Possible indirect effects of soil characteristics of the ash dams on the hemipteran assemblages.

Soil characteristics could affect the vegetation on the ash dams and these soil characteristics could have a possible indirect effect on the hemipteran assemblages. The possible effects of the following soil characteristics will be investigated:

- pH.
- Organic matter determined as the percentage carbon.
- Electrical conductivity (EC).
- Particle size (%Clay, %Sand, % Gravel and % Silt).

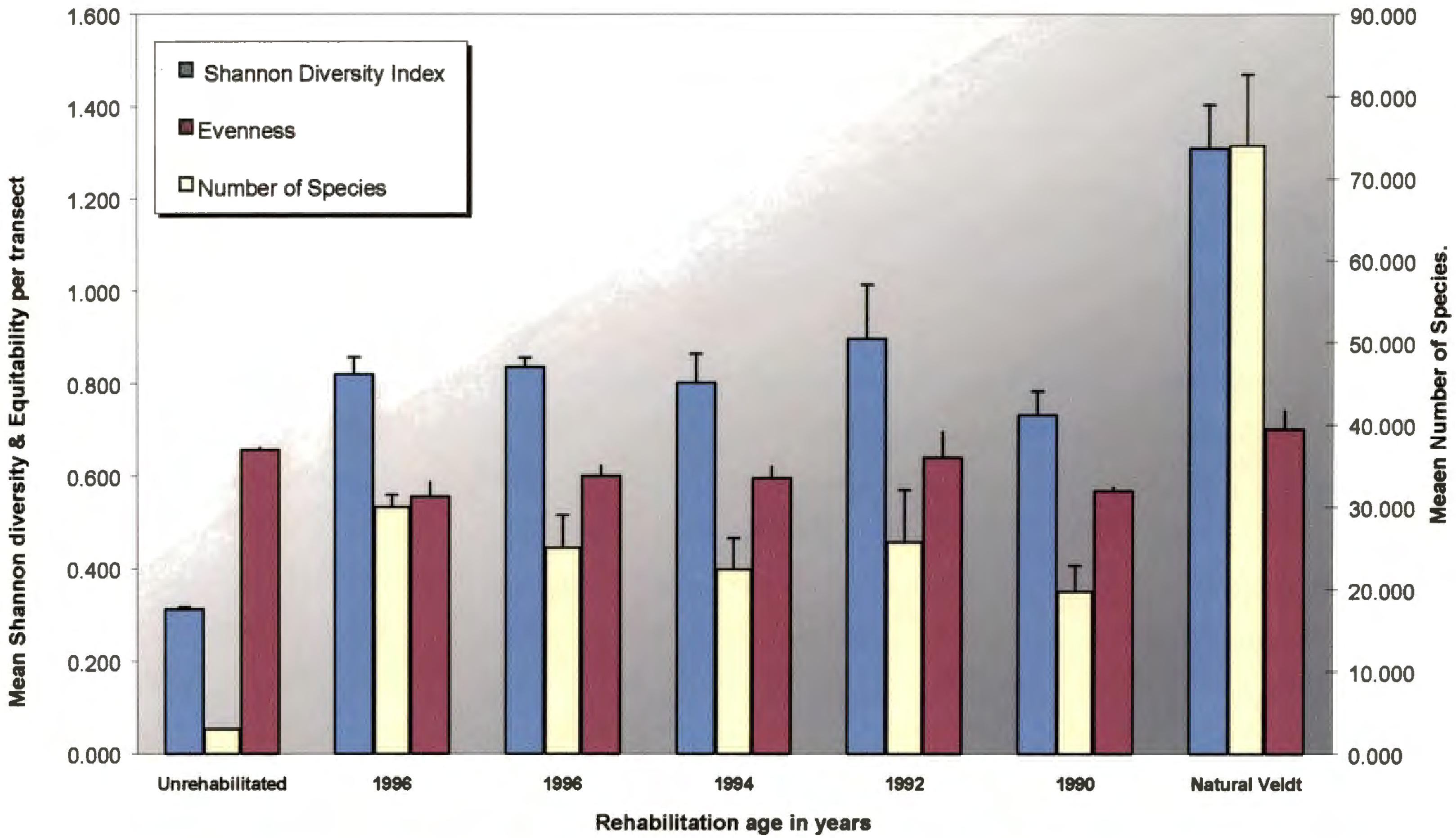

Figure 3.12: Mean plant Shannon diversity, mean species plant equitability and mean number of plant species, per transect, during different stages of succession from 1997-1999 (Bars indicate ±1sd).

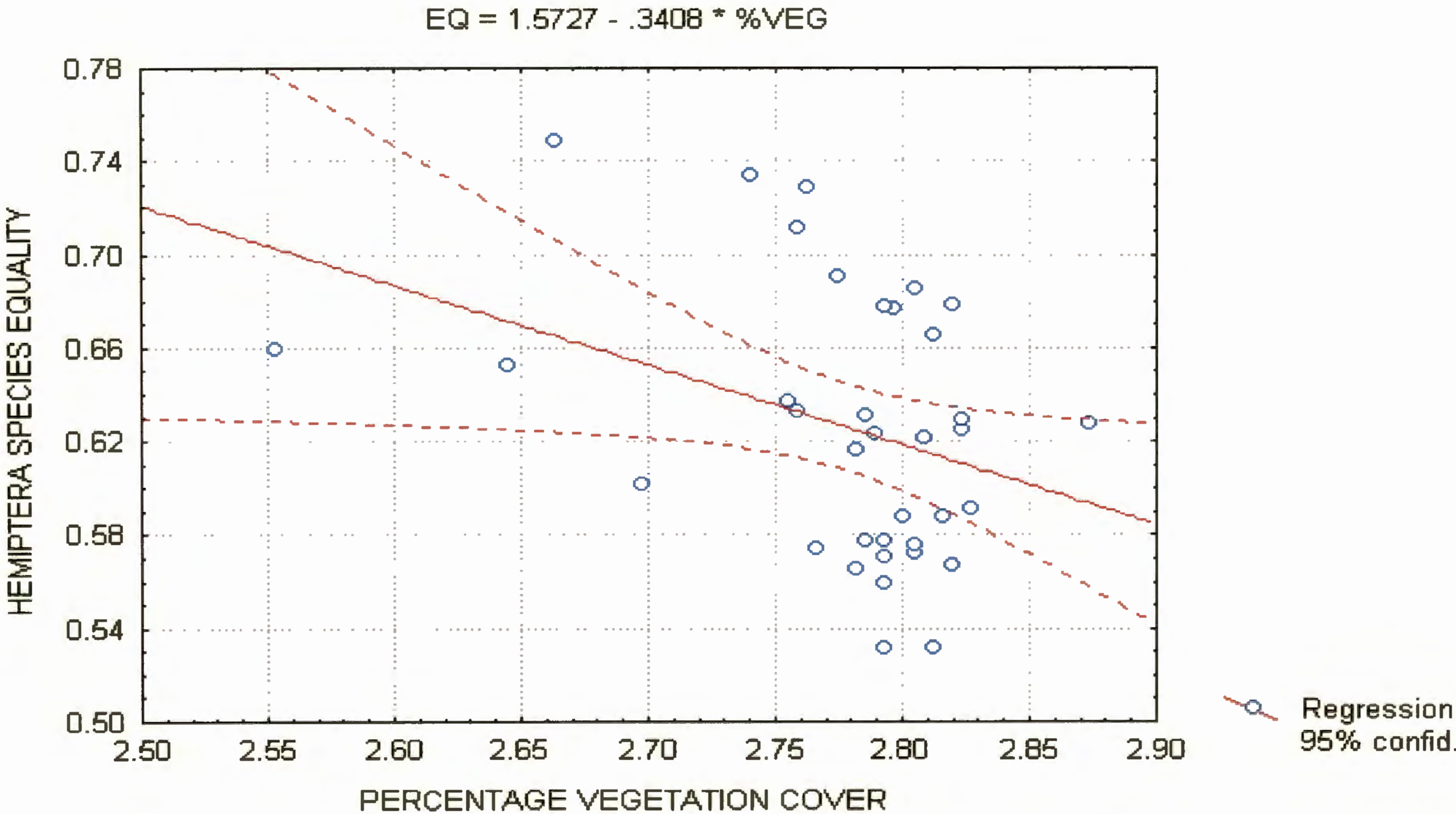

Figure 3.13: Linear regression between total hemipteran species equatability and percentage vegetation cover on rehabilitated ash dams at Hendrina power station during 1997.

Table 3.4: Linear regression analysis, showing the relationship between hemipteran Shannon diversity index, hemipteran species equitability, and hemipteran species richness and, four plant variables, Shannon diversity, equitability, species richness and percentage vegetation cover. The degree to which these variables are related is given by the correlation coefficient (r). Relationships are regarded significant at $p<0.05$. The fraction of the variability in each component of hemipteran species diversity that is accounted for by plant parameters is given by the coefficient of determination (r^2).

Source of variance	Hemipteran Shannon diversity			Hemipteran species equitability			Hemipteran species richness		
	p	r	r^2	p	r	r^2	p	r	r^2
Plant Shannon diversity	0.349	0.161	0.026	0.487	0.119	0.142	0.796	0.447	0.199
Plant Species equitability	0.574	-0.097	0.009	0.781	0.048	0.002	0.404	-0.143	0.204
Plant species richness	0.162	0.238	0.057	0.434	0.135	0.002	0.310	0.174	0.030
Vegetation cover (%)	0.976	-0.005	0.000	0.052	-0.326	0.106	0.880	-0.026	0.000

Electrical conductivity (EC) is a measure of the water soluble salt content in soil (Grunwald, Iverson & Szafoni 1995). pH also plays an important role in nutrient availability for plant species in the soil (Grunwald, Iverson, Szafoni 1995). Soil structure affects the microclimate of the soil and could therefore affect the decomposing and mineralizing processes soil. Soil characteristics are unlikely to change very much in the period of one year. That is why only one analysis was conducted and applied to the 1997 data. Natural grassland and unrehabilitated areas were also excluded in the soil analysis.

Hemipteran species richness was correlated significantly with organic matter (%C), pH, and percentage clay. Hemipteran species richness was positively correlated with organic matter and negatively correlated with pH and percentage clay. The regression of the hemipteran assemblages and the organic matter, pH and percentage clay is illustrated in Figures 3.14, 3.15 and 3.16 respectively. Hemipteran species richness was not significantly correlated with any of the other remaining soil factors.

Neither the hemipteran Shannon diversity, nor hemipteran species equitability were significantly correlated with any of the soil characteristics (Table 3.5).

Table 3.5: Linear regression analysis, showing the relationship between hemipteran Shannon diversity index, hemipteran species equitability, and hemipteran species richness and soil characteristics on rehabilitated ash dam grids. The degree to which these variables are related is given by the correlation coefficient (r). Relationships are regarded significant at p<0.05. The fraction of the variability in each component of hemipteran species that is accounted for by soil parameters is given by the coefficient of determination (r^2).

Source of variance		Hemipteran Shannon diversity			Hemipteran Shannon equitability			Hemipteran species richness		
		p	r	r^2	p	r	r^2	p	r	r^2
Percentage gravel	Fraction of particle size	0.548	-0.119	0.039	0.202	0.249	0.062	0.569	0.112	0.013
Percentage sand	Fraction of particle size	0.077	0.340	0.116	0.601	0.103	0.011	0.232	0.233	0.542
Percentage silt	Fraction of particle size	0.412	-0.162	0.026	0.675	0.082	0.006	0.673	-0.083	0.007
Percentage clay	Fraction of particle size	0.053	-0.370	0.137	0.258	-0.221	0.049	0.046	-0.379	0.144
pH		0.095	-0.322	0.104	0.348	-0.184	0.034	0.022	-0.431	0.186
Electrical conductivity		0.134	0.290	0.084	0.880	-0.029	0.001	0.174	0.264	0.070
Organic matter (%C)		0.117	0.303	0.092	0.089	0.327	0.107	0.019	0.440	0.194

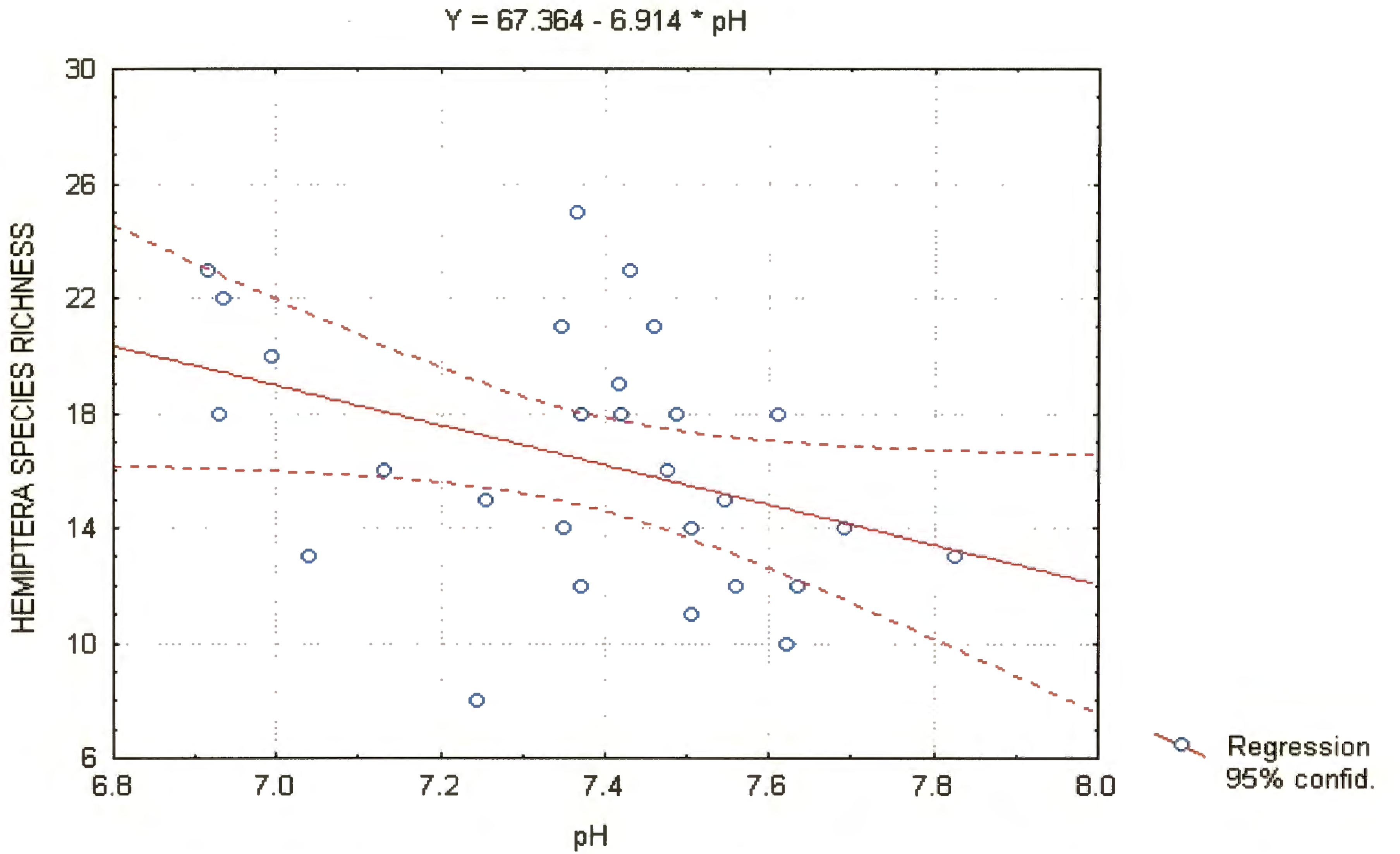

Figure 3.14: Linear regression between total Hemiptera species richness and soil pH on rehabilitated ash dams at Hendrina power station during 1997.

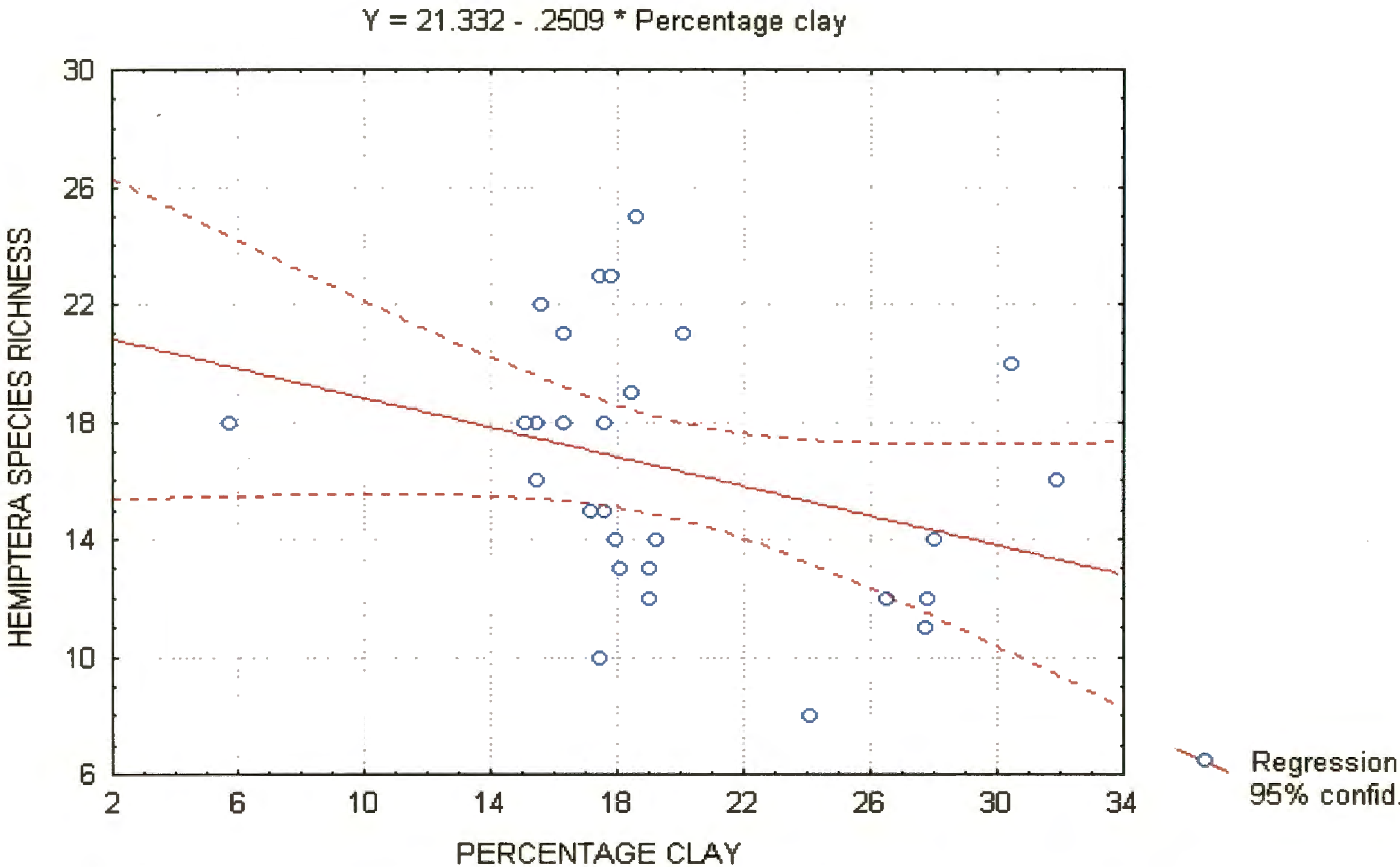

Figure 3.15: Linear regression between total hemipteran species richness and percentage clay on rehabilitated ash dams at Hendrina power station during 1997.

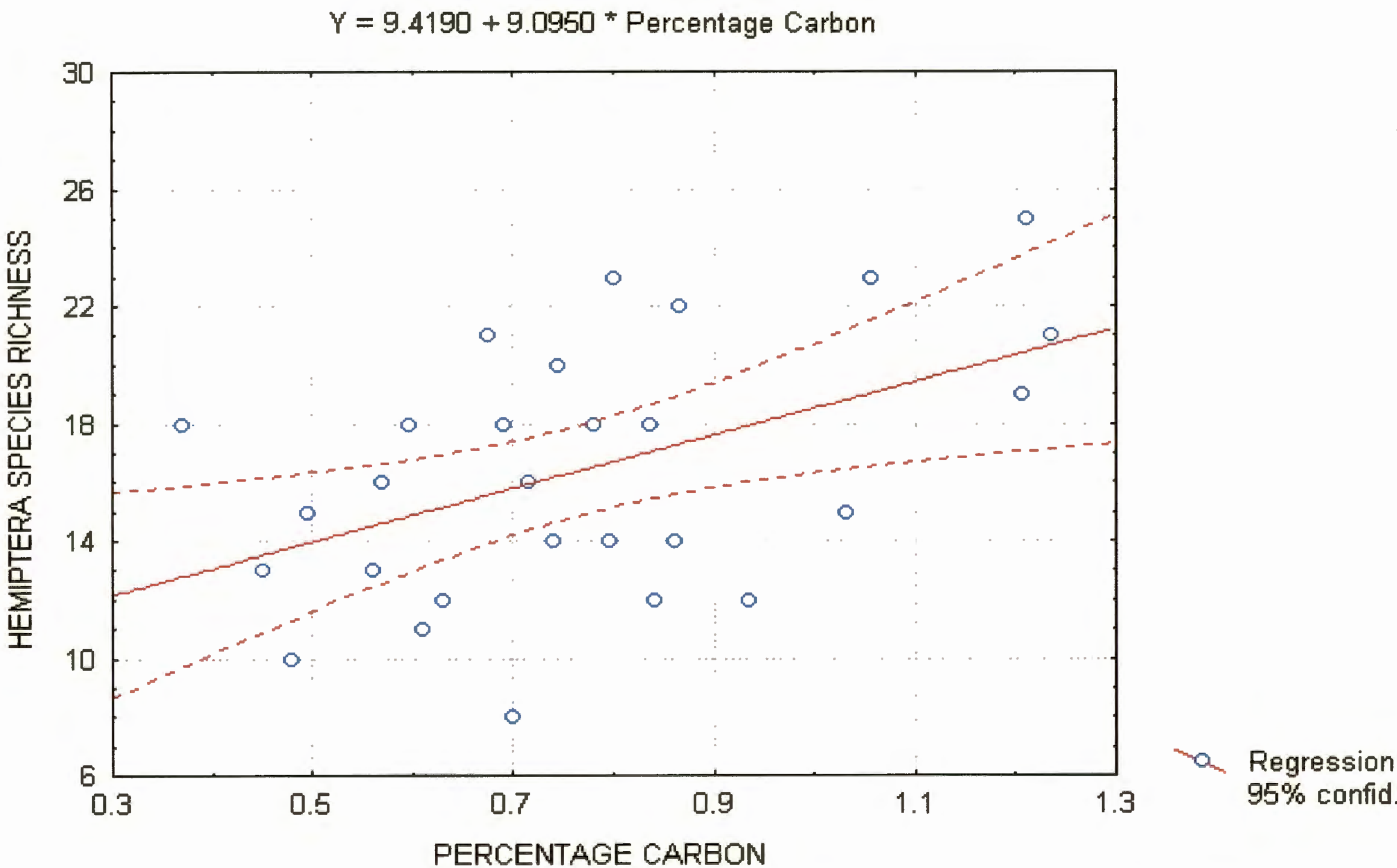

Figure 3.16: Linear regression between total hemipteran species richness and percentage organic matter in the soil on rehabilitated ash dams at Hendrina power station during 1997.

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

Ordination of plant species and the hemipteran assemblages on the ash dams were studied using the indirect gradient analysis of a Detrended Correspondence Analysis (DCA). Only summer and autumn data were used because plant and hemipteran species were then most abundant. The first ordination step ordinates the unrehabilitated ash dam grids, rehabilitated ash dam grids and the natural grassland along two principal ordination axes using a PCA ordination, according to the plant species, present in these different areas.

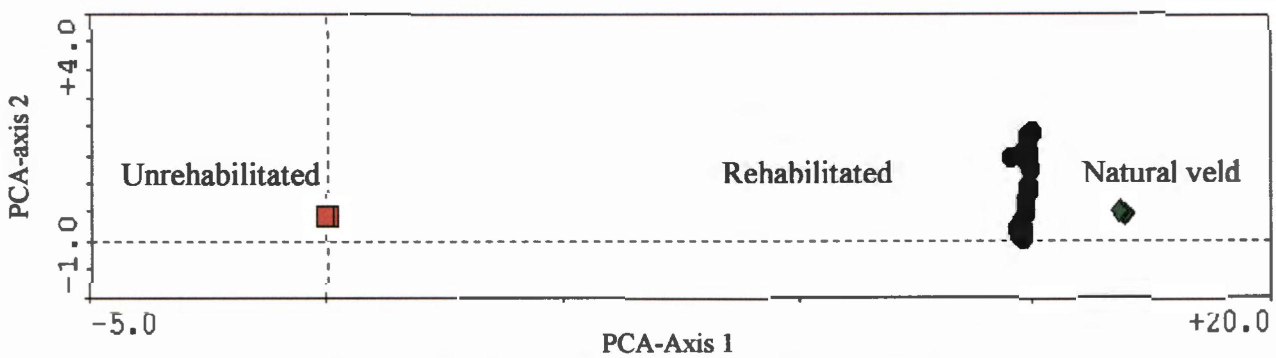

Figure 3.17: PCA ordination of grids according to vegetation composition, showing ordination of unrehabilitated ash dam grids, rehabilitated ash dam grids and grids in the natural grassland, along two principal ordination axes.

There were three outstanding groups on the first ordination axis that could clearly be identified and separated into unrehabilitated areas, rehabilitated areas and the natural grassland (Figure 3.17). Unrehabilitated areas are to the left hand side of the graph, the rehabilitated areas are set in the middle of the graph and the natural grassland grids are set to the right of the first ordination axis. The only plant species, which established on the unrehabilitated areas, were the forbs, *Spergularia media* and *Chenopodium album*. In between the forbs there is lots of bare ground. The hemipteran species associated best with these unrehabilitated conditions were HOMOPTERA sp.6 (iho26) and COREIDAE sp.2 (ihe35) (Table 3.2).

The natural grassland represented a *Brachiaria serrata-Setaria sphacelata* plant community (Chapter 2.4). Several hemipteran species were associated with the natural grassland (Table 3.2). Ash dam grids were rehabilitated at different stages. All the rehabilitated ash dam grids belong to the *Eragrostis curvula–Cynodon dactylon* plant community (Chapter 2.4). The ash dams are represented by other plant communities and variants as well.

3.2.3.1 Ordination of hemipteran assemblages on the ash dams, represented by different rehabilitation ages.

In the second ordination a Detrended Correspondence Analysis (DCA) was applied to the hemipteran species on the unrehabilitated and rehabilitated ash dam grids as well as the natural grassland (Figure 3.18). The Eigenvalues were 0.419 and 0.165 for the first and second ordination axes respectively. The species and the grids were scattered along the two axes. The Eigenvalues indicate that there were no significant gradients along any of the two axes. With no significant differences there is no use in doing Detrended Correspondence Analysis (DCA) on the rehabilitation ages separately.

3.2.3.2 Ordination of hemipteran species, plant species and percentage vegetation cover on the ash dam grids.

A Canonical Correspondence analysis (CCA) is a method to investigate associations between hemipteran species, plant species and % vegetation cover. In the CCA ordination (Figure 3.19) the arrows indicate the strength and direction of dominant plant species and percentage vegetation cover on the distribution of hemipteran species along different ordination axes. Plant species with long arrows are more closely correlated in the ordination than those with short arrows. Hemipteran species indicated by single points can be related to the different plant species or percentage vegetation cover by drawing a perpendicular line from the arrow line to the specific species. The order in which the point projects on to the arrow, from the tip downward through the origin indicates the position of the specific Hemipteran species in relation to the plant species or percentage vegetation cover. The closer the species are to the tip of an arrow the bigger the chance that the species is significantly correlated and influenced by the arrow. The species at the opposite end is less affected (Ter Braak 1987).

Three plant species had a significant influence on the distribution of the hemipteran species on the rehabilitated ash dam grids. These species are *Chamaecrista biensis, Cyperus esculentus, Eragrostis chloromelas* (Table3.6). The hemipteran species associated with the three plant species are listed in Table 3.6.

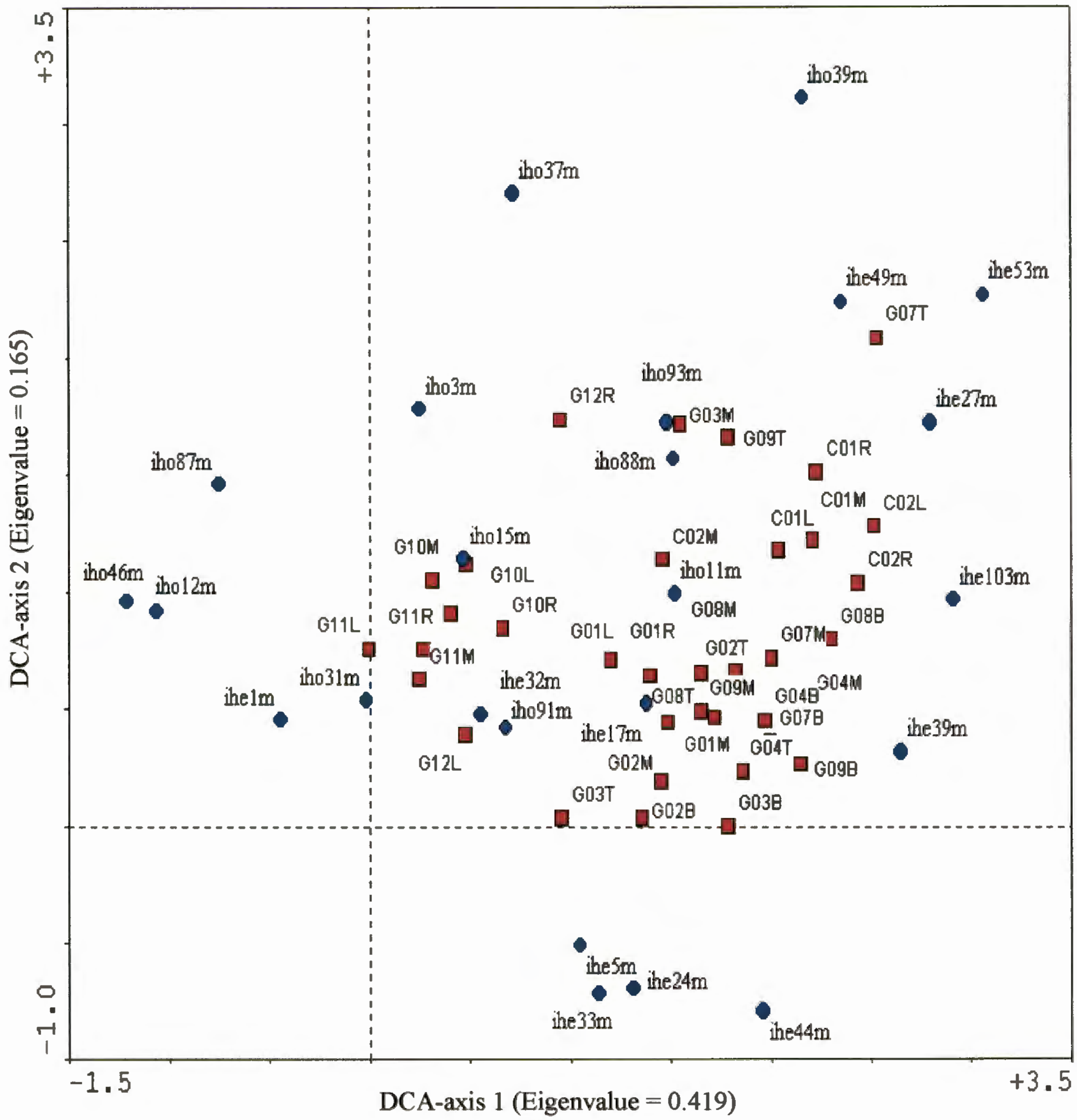

Figure 3.18: Detrended Correspondence Analysis (DCA), showing the ordination of hemipteran species in unrehabilitated grids, rehabilitated grids and natural grassland.

Table 3.6: List of hemipteran species of which its distribution is significantly influenced by plant species in left hand column as shown by Canonical Correspondence analysis (CCA).

Plant species	Hemipteran species
Eragrostis chloromelas	Ihe1m – *Euthestus leucosticus*
	Iho12m – *Scotoeurysa nigroacuminis*
	Iho15m - *Naudeus bivitatus*
	Iho31m – *Tetartostylus brevistylus*
	Iho37m – *Paradorydium aurantium*
Cyperus esculentus	Ihe5m – *Paromius gracilis*
	Iho3m – *Balclutha auranticula*
	Iho46m – Tingidae sp1.
	Iho87m – *Pravistylus exquadratus*
	Iho91m – *Toya propinqua*
Chamaecrista biensis	Ihe32m – *Mecidea prolixa*

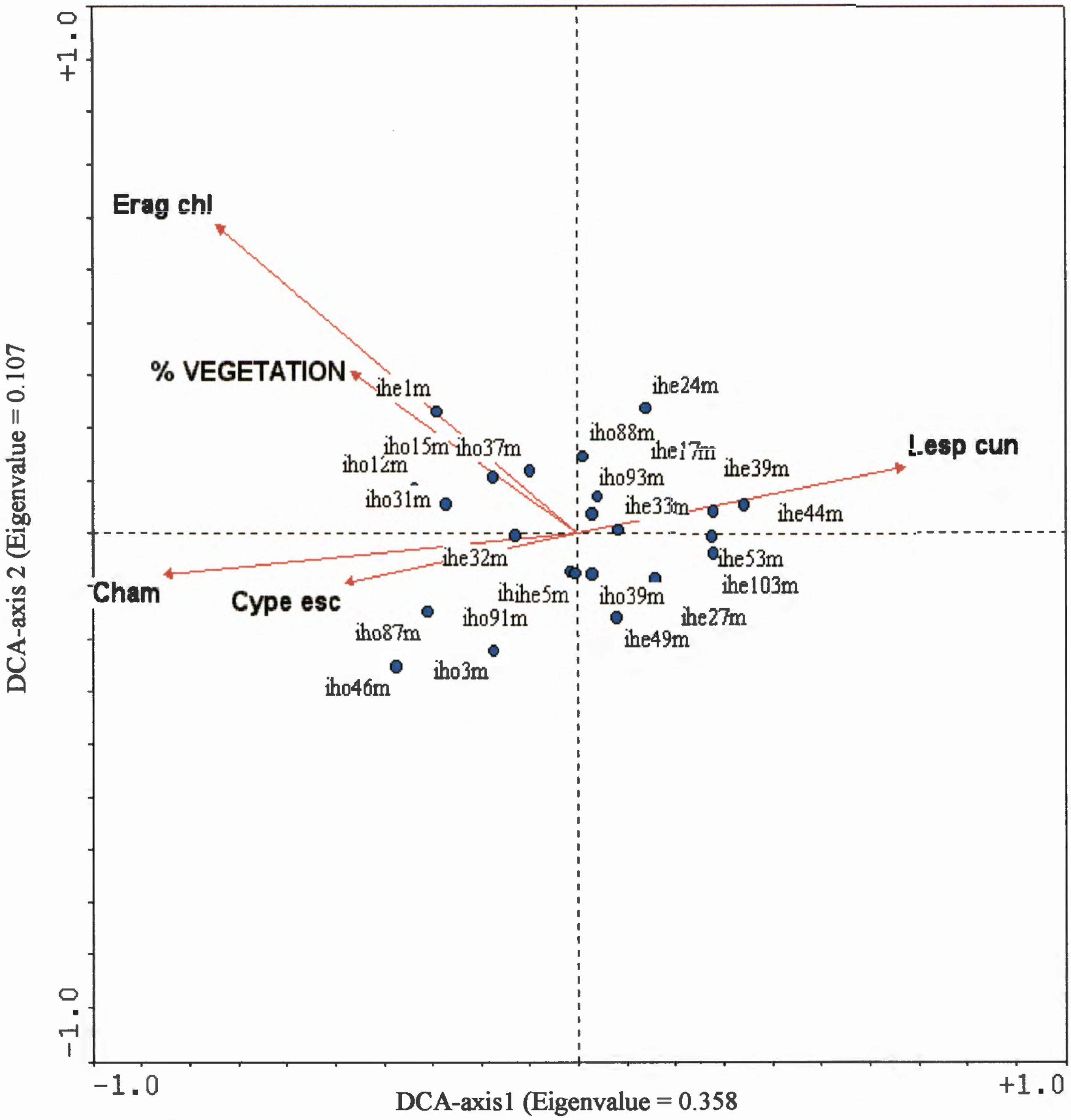

Figure 3.19: Canonical Correspondence Analysis (CCA) diagram showing the ordination of hemipteran species, plant species and percentage vegetation cover on rehabilitated ash dam grids.

3.2.3.3 Ordination of the relationship of hemipteran species, and various soil characteristics on the ash dam grids in 1997.

A Canonical Correspondence analysis (CCA) was used to investigate possible indirect associations between hemipteran species and various soil characteristics. The soil characteristics such as pH, electrical conductivity, percentage organic matter and substrate structure could affect plant species directly and therefore hemipteran species indirectly (Figure 3.20).

The arrows indicate the strength and direction of the specific soil characteristic along different ordination axes. Soil characteristics with long arrows are more closely correlated in the ordination than those with short arrows. Hemipteran species indicated by single points can be related to the characteristics. Soil analysis was only conducted during the winter survey of 1997. It was assumed that the soil characteristics will not change much over a one year period and were therefore applied to data collected during 1997. A forward selection of the edaphic variables that had the greatest possible indirect influence on the hemipteran species on the rehabilitated ash dam grids 1997 are summarised in Table 3.8.

The significance of a particular edaphic variable can be assessed through Monte Carlo testing of the axis associated with that variable, using the axis Eigenvalue as a test statistic (Ter Braak & Prentice 1988). Thus in a CCA, one can test the significance of edaphic variables. The variables with the highest Eigenvalue are the variables that have the greatest influence on the relative abundance of the various hemipteran species.

Percentage clay made the largest and only significant contribution to the observed abundance of hemipteran species on the rehabilitated ash dam grids during 1997. The other soil variables seem to have a very small effect on the ordination of the hemipteran species with none of the p-values <0.05 (Table 3.7). Eighteen species were correlated with the various soil characteristics during 1997 only three were significantly correlated with percentage clay (Table3.8, Figure 3.19).

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

Soil variables	Eigenvalue (λ)	ANOVA (F)	p-value
%CLAY	0.35	2.68	0.005
%GRAVEL	0.19	1.64	0.245
% SILT	0.17	1.73	0.305
CONDUCTIVITY	0.13	0.93	0.47
% CARBON	0.12	1.1	0.305
pH	0.1	0	1
% SAND	0.06	0.4	0.835

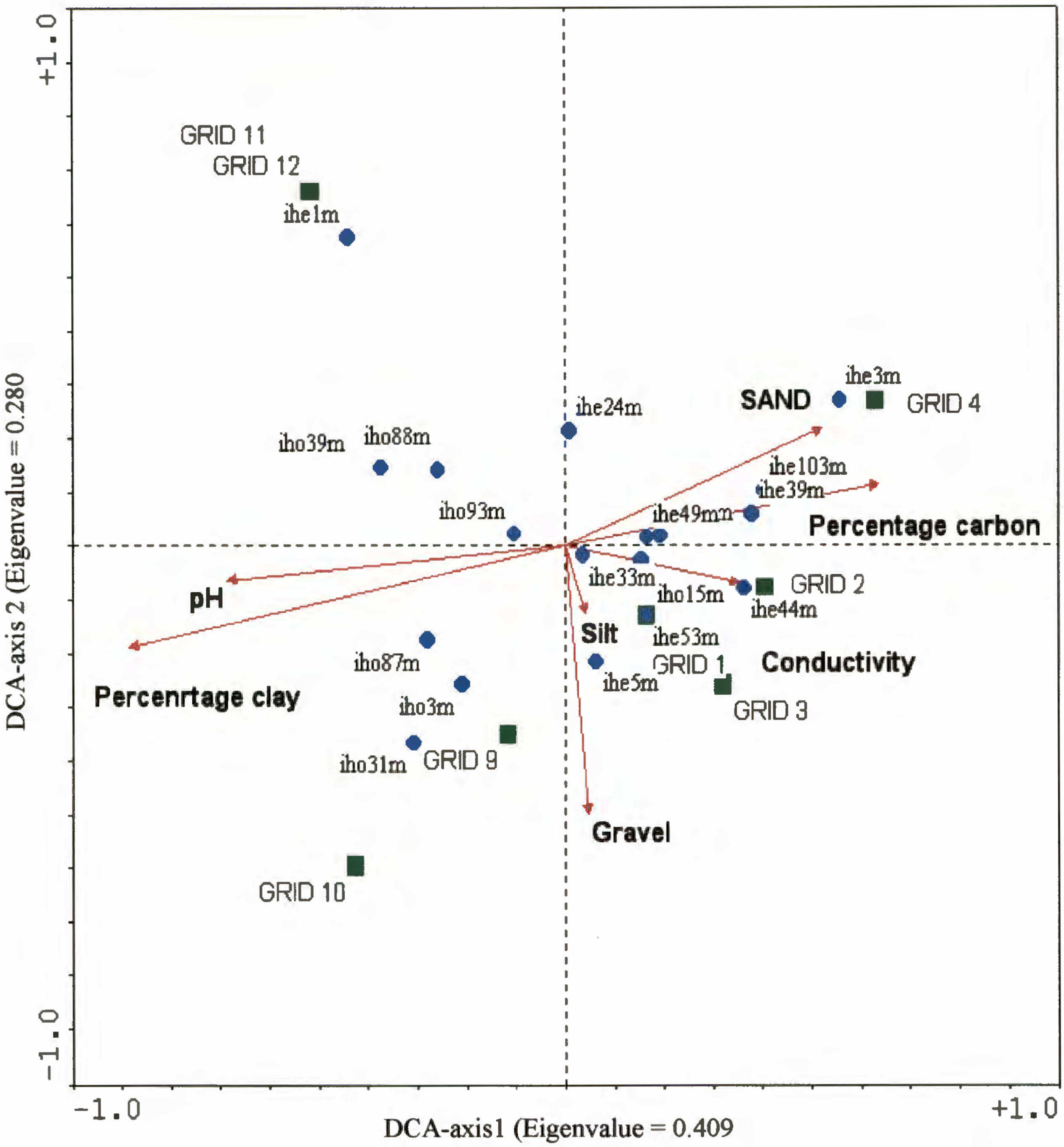

Figure 3.20: Canonical Correspondence Analysis (CCA) diagram showing the ordination between hemipteran species and significant soil characteristics on the rehabilitated ash dam grids during 1997.

Table 3.8: List of hemipteran species of which its distribution were significantly influenced by soil characteristics as shown by a Canonical Correspondence analysis (CCA). * Highly significant species associated with percentage clay content.**

Species
Ihe1m - *Euthestus leucosticus*
Ihe3m - *Aspilocoryphus fasciativentris*
Ihe5m - *Paromius gracilis*
Ihe24m - *Atrademus capeneri*
Ihe33m - *Acoloba lanceolata*
Ihe39m – *Heteroptera sp2.*
Ihe44m - *Nezara viridula*
Ihe49m - *Cletus sp.1*
Ihe53m - *Liorhyssus hyalinus*
Ihe103m – *Miridae sp.3*
***Iho3m - *Balclutha auranticula*
Iho11m – *Aphididae sp.1*
Iho15m - *Naudeus bivittatus*
***Iho31m - *Tetartostylus brevistylus*
Iho39m – *Issidae sp.1*
***Iho87m - *Pravistylus exquadratus*
Iho88m – Cicadellidae nymph 1
Iho93m - *Pratura graminea*

CHAPTER 4

DISCUSSION

4.1 Use of hemipteran assemblages to possibly determine rehabilitation success of ash dams.

4.1.1 Hemipteran species composition at the Hendrina power station ash dams and natural grassland.

In the results from the study at Hendrina Power Station it is clear that there are similarities between the ash dam grids and the natural grassland, but that there are also dissimilarities between the two ecosystems. These dissimilarities could determine the succession of species in these habitats. There were more hemipteran species collected on the ash dam grids (61 species) than in the natural grassland (47 species) this can be expected as a much larger area was sampled on the ash dam grids than in the natural veld. The mean number of species per grid was also lower in the natural grassland than on the ash dam grids. This result could possibly be due to sampling effects and sample size. Another possible reason could be that the hemipteran species in the natural veld are specialist species with lower abundance and lower catchability. The high incidence of pioneer plants in the earlier stages of rehabilitation could have led to an increase in pioneer phytophagous hemiptera.

Overall, there were 573 individuals caught in the natural grassland and 2763 individuals on the ash dams, this was expected because less grids were sampled in the natural veld than on the ash dams. Whitaker 1975 also found that the abundance and diversity of arthropods were lower in smaller and older habitat fragments.

4.1.2 Hemipteran species composition at Hendrina Power Station with progressive change in the assemblage along a rehabilitation gradient.

This part of the study was done to determine if the hemipterans could be used as indicators of rehabilitation success. A species has value as an indicator if it can indicate the absence or presence of a specific condition in the environment (Majer 1989). The hemipteran species were sorted into classes according to their absence, presence, and abundance during the different stages of succession (Table 3.1).

- **Primary succession Hemiptera species. (See 3.1.2.1)**

The early successional hemipteran species colonize the most recently rehabilitated areas first, or are the first species to be observed or collected in this disturbed area. These arthropods must be able to adapt to very harsh or barren conditions and are opportunists (Whitaker 1975).

The hemipteran species found in the primary succession phase were Coreidae sp.2 (ihe35), Homoptera sp.1 (iho1) and *Sogatella capensis* (iho78) (Figure 3.3, Figure 3.4, Figure 3.5 and Table 3.2). These species include the hemipteran families Coreidae and Delphacidae. Coreidae is a large family which comprises of many diverse forms. The Coreidae are all phytophagous and they attack young roots and shoot of plants or grass. It has been recorded that the family feeds on more than 100 species of plant in more than 38 families illustrating the wide feeding tolerances and adaptations to feed on the ash dams (Scholtz & Holm 1986). The Delphacidae is the one of the largest family of plant hoppers in southern Africa. The family is virtually confined to feeding on grass but are important vectors of diseases in cultivated plants (Scholtz & Holm 1986). It can only be assumed that these three species are primary successors as they virtually disappear in later stages of succession to very low numbers (Table 3.2).

- **Intermediate to late successional hemipteran species. (See 3.1.2.2)**

Intermediate to late successional species were found to be abundant in later stages of succession. Heteroptera sp.2 (ihe39) an unidentified species was present in the early stages of rehabilitation and continued to be present in later stages of succession as well (Table 3.2; Figure 3.6). Other species with the same occurrence are *Pratura graminea* (iho93), *Paromius gracilis* (ihe5), Heteroptera sp.1 (ihe8) and *Eustestus leucosticus* (ihe1).

As rehabilitation matures the habitat and vegetation changes and diversifies, and associated fauna are attracted which could serve as food or competition. Feeding patterns of arthropods must then adapt to utilize a less specialized diet. These species were found in the hemipteran families Cicadellidae, Lygaeidae and Alydidae. These are all families with a generalised diet that includes shoots of young plants, trees, grasses and seeds. These species probably indicate a habitat that is more mature.

- **Late successional Hemiptera species. (See 3.1.2.3)**

These species colonize a habitat at late stages of succession. The older rehabilitated ash dams have higher plant species diversity, more litter and more seed. There is also a greater diversity on the older ash dams. Some thirty species were found on ash dams rehabilitated in 1994. The ash dams were then rehabilitated for at least 4 years already and can be seen as a late successional stage in rehabilitation. Two of the most abundant of these species were *Agonoscelis versicolor* (ihe93) (Figure 3.8; Table3.2) and *Spilostethus trilineatus* (ihe27) (Figure 3.7; Table3.2). Homoptera sp.9 (iho21) is the only species that was sampled only on the oldest rehabilitated grid (9 years rehabilitated). Unfortunately, the abundance of this species was too low to make significant conclusions on the species presence.

There is a large group of families included in the late successional species. This could be explained due to the increase in food or niches in the more settled habitats. One of the families is Pentatomidae or better known as the stink bugs. This family also includes a number of pest species that are of economic importance (Schotlz and Holm 1986). There are also species from the families Alydidae, Delphacidae, Aphididae and Cicadellidae.

- **Grassland Hemiptera species. (See 3.1.2.4)**

The natural grassland represents a reference site. Although the ash disposal site will never rehabilitate to the same state as the reference site, it will give indications of hemipteran assemblages associated with the surrounding areas. There were some similarities in hemipteran assemblages on ash dams and in the natural grassland but there was also great dissimilarity. Species that were only found in the natural grassland and not on the ash dams are referred to as natural grassland species. These species are Coreidae sp.1 (ihe63), Reduviidae sp.3 (ihe65); Pseudococcidae sp1. (ihe16) and Pratura *graminea* (iho22) (Figure 3.9; Table 3.2).

These species include the hemipteran families Reduviidae (which are predators); Coreidae; Peudococcidae and Cicadellidae. The reason these species could not colonize the ash dams could possibly be because their special food requirements or habitat needs, which are provided for in the natural grassland (Scholtz & Holm, 1986).

4.1.3 Hemipteran assemblages as possible indicators of ecological change, due to rehabilitation activities.

This study indicated that very diverse hemipteran assemblages occurred on the rehabilitated ash dams and the natural grassland despite the fact that the ash dams are disturbed habitats.

Mean Shannon diversity, mean equitability and mean species richness was used throughout the study to compare the natural grassland with ash dams. Figure 3.10 indicates that a diverse hemipteran assemblage could not establish on the unrehabilitated areas of the ash dams. Results also showed a steep rank abundance curve for the unrehabilitated areas of the ash dams in Figure 3.11. This is due to dominance of a few hemipteran species such as Coreidae sp.2 (ihe35) and Homoptera sp.6 (iho26). These species were able to benefit from the conditions on the unrehabilitated ash dams.

Colonization is an asymptomatic process, proceeding most rapidly initially (Strong, Lawton & Southwood 1984). On the ash dams the species diversity, which is an indication of recolonization of hemipteran species, remained fairly constant with very little fluctuations during the years of rehabilitation. It seems as if hemipteran species diversity reaches a maximum from which it stabilizes and then slowly decrease over time.

Mean number of hemipteran species caught per transect on the rehabilitated ash dams is higher than the mean number of species caught on the unrehabilitated ash dams. The mean number of species caught on the rehabilitated ash dams and mean number of species caught in the natural grassland were very similar. This could be an indication that the ash dam grids slowly began to show the characteristics of the natural grassland.

Looking at the results of the rank abundance curves for the grids, represented by different stages of succession it is evident that the steepness of the unrehabilitated survey area curve indicates low species richness and high dominance of hemipteran species. When the ash dam grids matured more plants established thus creating more niches and more food become available. The habitat and structural diversity of the ash dam grids are increased. The shallower rank-abundance curves in Figure 3.11 indicate a more diverse more abundant hemipteran assemblage.

The rank-abundance curve of the 4 year old rehabilitated ash dam grids indicates highest species diversity and species richness. It was expected that the natural grassland would have had the higher species diversity and species richness. This was not the case. The lower species richness and diversity could possibly be explained by the facts that the hemipteran species in the natural veld are specialist species with lower abundance and lower catchability.

The natural grassland mean Shannon diversity and equitability only differed significantly from a rehabilitation age of five years (Table3.3). This could possibly indicate that there may be hemipteran assemblage similarities in the rehabilitated ash dams and the natural grassland, probably due to colonisation of species from the natural grassland to the ash dams (Majer 1984; Villet Capitoa 1996). Another possible reason why the mean numbers of species per transect in the natural grassland was less than on the ash dams could be because the natural grassland reached its species complement (Parmenter & Macmahon, 1989).

There was a steady climb in mean number of species from unrehabilitated ash dams to 4 year old rehabilitated ash dams then there was a slight decline in mean number of species. From the fifth year till the ninth year the number of species remained relatively constant (Figure 3.10). The fact that species richness was virtually the same on the ash dam grids and the natural grassland, could be attributed to the fact that the natural veld could have more specialised species which are usually lower in abundance. This could reduce catchability of hemipteran species in the natural veld. Such instances could indicate a species composition artefact and point out a sampling problem. In such a case the sampling in the natural grassland leads to underestimation compared to ash dams.

4.2 Possible influence of habitat characteristics on succession of Hemiptera.

4.2.1 Vegetation characteristics as possible factors influencing hemipteran succession on rehabilitated ash dams.

There was no significant correlation between hemipteran species diversity, equitability, species richness and plant species diversity, richness and equitability (Table 3.5). A possible explanation could be the fact that hemipteran species are very mobile and could move between habitats effectively thus masking the effect of plant diversity on the hemipteran assemblages. Another explanation could be the fact that hemipteran species are generalist opportunistic feeders utilising a large variety of plants as food source (Scholtz & Holm 1986). There was a significant negative correlation between hemipteran species equality and percentage vegetation on the ash dam grids (Figure 3.13). A higher percentage vegetation cover correlated with lower hemipteran (equitability) and vica versa. This phenomenon is contradictory to what would be expected. It is possible that with the increase of vegetation cover more niches are created and it could be difficult to perform proper sampling.

4.2.2 Soil characteristics as possible indirect influence of hemipteran succession on rehabilitated ash dam grids.

Variation in the diversity of the hemipteran assemblages could possibly be explained by other factors as well. Characteristics such as pH, soil structure, conductivity and percentage organic matter could also play an indirect role in the succession of hemipteran assemblages on the rehabilitated ash dams. Although there were significant correlations between the soil parameters and hemipteran species the real effect could be due to the indirect influence on plant variables with a concomitant influence on the diversity of the hemipteran assemblages. These findings have to be investigated further.

It was found that the percentage clay significantly correlated (negative) with the hemipteran species richness (Table 3.5, Figure 3.15). This is due to the fact that the hemipteran species richness increase or remains relatively constant with age of rehabilitation and the percentage clay on the ash dams decrease with age of rehabilitation. Clay soils influence the absorbance of proteins by plants due to the fact that the clay keeps the protein between the clay particles (White 1997). Clay soils also causes water logging which makes conditions unsuitable for arthropods.

Hemipteran species showed a significant positive correlation with organic matter (%C) and pH (Figure 3.16). The positive correlation could be explained in that the higher the carbon or nitrogen sources in and above the soil the higher the feeding options and niche diversity for the hemipterans (Majer, 1984). The negative correlation to pH could possibly be explained in that the pH of the ash dam grid decreases with rehabilitation age and plant species increase, thus with ageing of the ash dams the niches' and food supply increase while the pH decreases (Figure 3.14).

4.3 An evaluation of the status of Hemiptera species in relation to rehabilitation age and conditions, by the use of multivariate techniques.

There were three outstanding groups areas along the first ordination axis namely unrehabilitated areas, rehabilitated areas and the natural grassland (Figure 3.17).

A gradient length of 4 SD is considered as a statistically significant gradient in a Detrend Correspondence Analysis (Ter Braak & Smilauer 1998). A gradient of 0.419 for the first ordination axis and a gradient of 0.165 for the second ordination axis indicates that no significant contribution to the distribution of hemipteran assemblages between the research sites (Figure 3.18) could be illustrated. This could possibly indicate that the hemipteran species are opportunistic feeders and can be found in various habitatsalong the rehabilitation gradient.

The Canonical Correspondence Analysis (CCA) of hemipteran species in relation to the plant species showed that only three plant species had a significant influence on the distribution of the hemipteran species (Figure 3.19). The significant plant species and the hemipteran species they influenced are listed in Table 3.7. Grass species were primarily used as indicators of success during rehabilitation processes (Morgenthal 2000). The grass species which significantly influenced the hemipteran species were not the dominant grass species on the ash dams or in the natural grassland. This indicates the possibility that hemipterans may not be successful bioindicators as they don't correlate positively with important plant indicator species on the rehabilitated ash dams.

The Canonical Correspondence Analysis (CCA) of the hemipteran species in relation to soil characteristics showed that only percentage clay had a significant influence on the distribution of the hemipteran species. This corresponds with the results of the linear regression between soil characteristics and the hemipteran species (Table 3.5 Figure 3.20).The three hemipteran species that were significantly influenced were *Balclutha auranticula* (iho3) *Tetartostylus brevistylus,* (iho31) and *Pravistylus exquadratus* (iho87). No literature references could be found on why percentage clay could possibly have such a significant effect on these three species. It can only be assumed that the percentage clay in the soil composition have an direct affect on the plant communities on the ash dam grids and in such a way influenced the hemipteran species, more work needs to be done in this regard.

CHAPTER 5

CONCLUSION

5.1 Indicative value of hemipteran species at Hendrina power Station

This study showed that not only flora is important when rehabilitation success is being investigated but that fauna could also serve as possible useful bio-indicators. The use of insects as possible terrestrial bioindicators was defined in Chapter 1.

Hemipteran assemblages/species portrays many of the important characteristics needed to be a possible successful insect bioindicators of environmental change, but the hemipteran assemblages and species also have many shortcomings.

The positive characteristics of hemipterans for being possible successful bioindicators on the Hendrina ash dams were:

- They are cost efficient and effective to use as a possible bioindicators species.
- They were abundant on the ash dams and in the natural grassland, making them an effiecient group to work with. They were caught in the pitfalls as well as the sweepnets.
- They were easily sampled and sorted. No expensive or specialized techniques were necessary.

- The hemipterans had adequate representation and abundance with over 2500 individuals and 90 different species collected.

- The hemipterans were easily sorted and stored.

- The sampled hemipteran individuals were expendable.

- Hemipterans are recognised in their importance to the agricultural environment as well as food resources or possible pests.

- Hemipterans tend to be distributed over a range of habitats and environments as was seen in this study.

- Hemipteran assemblages are represented in low-, medium- and high diversity groups.

- Lastly hemipterans feed on a wide range of vegetation as was seen in this study this indicates the high possibility of the hemipterans being opportunists.

The negative characteristics noted during this study, possibly preventing hemipterans being used as successful bioindicators on the Hendrina ash dams were:

- The hemipterans are not a taxonomically well known group even with help of a hemipteran taxonomist relatively few species could be identified to species level.

- Insufficient baseline data on non agricultural hemipteran biology as well as insufficient knowledge on hemipteran behavior and migratory patterns are available.

- The hemipteran species also tend to indicate a high genetic and functional variability to be able to serve as bioindicators.

- Hemipteran species are not easily cultured in laboratories.

- Hemipterans have various ranges of body sizes and growth form, which complicates the taxonomy and complicates various other aspects such as sampling techniques.

- The hemipteran group does not have species that are widely dispersed in similar habitats within their distributions.

Aspects from this study also indicated:

- Hemipterans are good colonizers exploiters of possible niches and food sources as shown by the increase in species richness and diversity from unrehabilitated ash dam grid to 9 year old rehabilitated grids.

- Hemipterans can be sampled throughout the year including all four seasons.

- Hemipterans could unfortunately not be identified as well as was hoped for. The reason being that for the identification of African Hemiptera up to species level, a specialized taxonomist is needed. Classification up to family level or functional groups is a possible solution or the use of morphospecies.

- It was made clear in this study that the use of hemipteran assemblages could also not be used to great success as possible indicators of rehabilitation success although they can be divided into indicative groups such as predators, phytophagous feeders or scavengers concerning feeding habits. The hemipterans could also be divided in to indicative groups such as primary, secondary or tertiary succession species if specific rehabilitation conditions and the rehabilitation age is known as was the case in this study. Unfortunately insufficient baseline data on hemipteran biology as well as insufficient knowledge on the hemipteran behavior and migratory patterns are known to make successful assumptions.

5.2 Further predictions and recommendations for the improvement of the study of Hemiptera as indicators of rehabilitation success at Hendrina power Station.

There is a huge lack of functional information and literature on the role of hemipterans in ecological succession in industrial ecosystems. This study was only performed on a very small part of South Africa's industrial environment and has to be expanded to other parts of the country as well. Future studies would give further insights in impacts of industrial disturbed areas and the possible role hemipterans could possibly play. If a similar project were considered for the future:

- More replications need to be done on more grids to ensure more reliable quantitative assumptions.

- More and different survey areas need to be established. This has to be done to sufficiently compare survey areas effectively with one another.

- Survey areas should include a better representation of the natural grassland, because colonizing arthropod species could possibly migrate from these adjacent grasslands into the rehabilitated grids.

- Previous quantitative studies would be very helpful to compare our results.

- The study period needs to be prolonged to gain sufficient temporal data on the change of the hemipteran assemblages.

- The taxonomy of hemipteran species is a specialized skill if identification needs to be done to species level. Information on the biology of hemipteran pest species is well known, but not the biology of African grassland species.

- The hemipteran species were sorted into morphospecies, families and species. This process is very time consuming and difficult. To make effective conclusions hemipterans need to be identified up to species level and not just functional groups.

- Pitfall trapping was not as effective as the sweepnet method due to the fact that most hemipteran species can fly. Sweepnetting was very effective and provided valuable data on the relative abundance of hemipteran assemblages with the vegetation.

- Additional ecological soil is needed if ecological disturbances has to be interpreted.

It is imperative for South Africa's considerable biological diversity to be properly assessed. It is an attractive concept that there may exist certain taxonomic groups that can act as predictors of biodiversity in general or even as specific terrestrial bioindicators. This is not always possible and there are few cases where ecologists can provide decision-makers with tried and tested terrestrial insect indicators as tools for conservation assessment and planning.

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APPENDIX I

The table below includes abbreviations used for the survey grids, Hemiptera species and plant species in Chapter 2, Chapter 3 and Chapter 4.

SURVEY GRIDS

Abbreviation	Survey grid
G1	Grid 1
G2	Grid 2
G3	Grid 3
G4	Grid 4
G5	Grid 5
G6	Grid 6
G7	Grid 7
G8	Grid 8
G9	Grid 9
G10	Grid 10
G11	Grid 11
G12	Grid 12
Co1	Control 1
Co2	Control 2

APPENDIX II

The table below includes abbreviations used for the survey grids, Hemiptera species and plant species in Chapter 2, Chapter 3 and Chapter 4.

HEMIPTERAN SPECIES LIST

Species number	Species
ihe1m	*Euthestus leucosticus* (Stal) ALYDIDAE
ihe3m	*Aspilocoryphus fasciativentris* (Stal) LYGAEIDAE
ihe4m	*Aethus sp.* CYDNIDAE
ihe5m	*Paromius gracilis* (Rambur) LYGAEIDAE
ihe6m	*Aconurella sp.* CICADELLIDAE
ihe7m	*Spilostethus pandurus elegans* (Wolff) LYGAEIDAE
ihe8m	HETEROPTERA 1
ihe11m	ALYDIDAE nymph
ihe13m	REDUVIIDAE 1
ihe15m	*Stictopleurus scutellaris* (Dallas) RHOPALIDAE
ihe16m	PSEUDOCOCCIDAE
ihe17m	MIRIDAE 1
ihe22m	*Aspilocoryphus fasciativentris* (Stal) LYGAEIDAE
ihe24m	*Atrademus capeneri* (Slater) LYGAEIDAE
ihe27m	*Spilostethus trilineatus* (Fabricius) LYGAEIDAE
ihe32m	*Mecidea prolixa* (Stal) PENTATOMIDAE
ihe33m	*Acoloba lanceolata* (Fabricius) PENTATOMIDAE
ihe34m	MIRIDAE 4
ihe35m	COREIDAE sp.2 nymph 2
ihe36m	*Bagrada hilaris* (Burmeister) PENTATOMIDAE
ihe37m	REDUVIIDAE 2
ihe38m	*Eupododus mundus* (Germar) PENTATOMIDAE
ihe39m	HETEROPTERA 2
ihe42m	*Aeliomorpha simulans* (Stal) PENTATOMIDAE
ihe43m	HETEROPTERA 3
ihe44m	*Nezara viridula* (Linnaens) PENTATOMIDAE

ihe46m	*Diploxys cornuta* (Distant) PENTATOMIDAE
ihe49m	*Cletus sp.1* COREIDAE
ihe52m	HETEROPTERA 4
ihe53m	*Liorhyssus hyalinus* (Fabricius) PENTATOMIDAE
ihe58m	*Metonymia affinis* (Am. & Serv.) PENTATOMIDAE
ihe60m	*Oncopeltus famelicus* (Fabricius) LYGAEIDAE
ihe63m	COREIDAE sp1. nymph
ihe65m	REDUVIIDAE 3
ihe71m	MIRIDAE nymph
ihe72m	*Spilostethus pandurus elegans* (Wolff) LYGAEIDAE
ihe73m	*Mirperus jaculus* (Thunberg) ALYDIDAE
ihe77m	PENTATOMIDAE nymph
ihe78m	SCUTELLERIDAE nymph
ihe82m	HETEROPTERA 5
ihe83m	HETEROPTERA 6
ihe93m	*Agonoscelis versicolor* (Fabricius) PENTATOMIDAE
ihe94m	HETEROPTERA 7
ihe97m	*Bolbocoris obscuricornis* (Stal) PENTATOMIDAE
ihe98m	*Durmia horisontalis* (Distant) PENTATOMIDAE
ihe99m	*Veterna sanguineirostris* (Thunberg) PENTATOMIDAE
ihe100m	*Carbula recurva* (Distant) PENTATOMIDAE
ihe102m	*Euthestus sordidus* (Stal) ALYDIDAE
ihe103m	MIRIDAE 3
ihe104m	HETEROPTERA 8
iho1m	HOMOPTERA 1
iho3m	*Balclutha auranticula* (Naude) CICADELLIDAE
iho4m	*Chiasmus hyalinus* (Evans) CICADELLIDAE
iho5m	*Goniagnathus agenor* (Linnavuori) CICADELLIDAE
iho7m	HOMOPTERA 2
iho8m	HOMOPTERA 3
iho9m	*Chiasmus undulatus* (Theron) CICADELLIDAE
iho11m	APHIDIDAE sp.1
iho12m	*Scotoeurysa nigrocacuminis* (Muir) DELPHACIDAE
iho13m	TROPIDUCHIDAE
iho15m	*Naudeus bivittatus* (Naude) CICADELLIDAE
iho16m	HOMOPTERA 4
iho17m	*Hodoedocus acuticeps* (Linnavuori) CICADELLIDAE
iho19m	*Opsius stactoglans* (Fieber) CICADELLIDAE
iho21m	HOMOPTERA 9
iho22m	*Pratura graminea* (Theron) CICADELLIDAE
iho23m	HOMOPTERA 5

iho25m	Coelidiinae nymph CICADELLIDAE
iho26m	HOMOPTERA 6
iho30m	*Ulopella termiticola* (Poisson) CICADELLIDAE
iho31m	*Tetartostylus brevistylus* (Theron) CICADELLIDAE
iho34m	DELPHACIDAE nymph
iho37m	*Paradorydium aurantium* (Naude) CICADELLIDAE
iho39m	ISSIDAE sp.1
iho45m	*Sphaerocoris testudogrisea* SCUTTELLERIDAE
iho46m	TINGIDAE sp.1 HEMIPTERA
iho49m	Stymphalus modestus (Linnavuori) CICADELLIDAE
iho51m	*Putala sp.* DICTYOPHARIDAE
iho55m	HOMOPTERA 7
iho61m	*Quintilia sp.* CICADIDAE
iho64m	*Basutoia brachyptera* (Linnavuori) CICADELLIDAE
iho71m	HOMOPTERA 8
iho72m	*Tetartostylus sp.* nymph CICADELLIDAE
iho78m	*Sogatella capensis* (Muir) DELPACIDAE
iho83m	*Hecalus virsescens* (Distant) CICADELLIDAE
iho87m	*Pravistylus exquadratus* (Naude) CICADELLIDAE
iho88m	CICADELLIDAE nymph
iho91m	*Toya propinqua* (Fiber) DELPHACIDAE
iho92m	*Exitianus capicola* (Stal) CICADELLIDAE
iho93m	*Pratura graminea* (Theron) CICADELLIDAE

APPENDIX III

The table below includes abbreviations used for the survey grids, Hemiptera species and plant species in Chapter 2, Chapter 3 and Chapter 4.

PLANT SPECIES LIST

Abbreviation	**Survey grid**
Agro lac	*Agrostis lachnantha*
Amar hyb	*Amaranthus hybridus*
Aris con	*Aristida congesta*
Bare grd	*bare ground*
Bide for	*Bidens formosa*
Bide bip	*Bidens bipinnata*
Cala spp	*Calamagrostis sp.*
Cham bie	*Chamaecrista biensis*
Chen alb	*Chenopodium album*
Chlo gay	*Chloris gayana*
Cirs vul	*Cirsium vulgare*
Comm ben	*Commelina benghalensis*
Cony bon	*Conyza bonariensis*
Cyno dac	*Cynodon dactylon*
Cype esc	*Cyperus esculentus*
Cype usi	*Cperus usitatus*
Digi eri	*Digitaria eriantha*
Enne cen	*Enneapogon cenchroides*

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