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The succession and diversity of biological assemblages on rehabilitated ash disposal sites associated with power stations in South Africa: working towards a dynamic model

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Abstract

The rehabilitation objectives of ash disposal sites associated with coal driven power stations must satisfy the demands of sustainable ecosystems. The rate and success of ash site rehabilitation depends on the sustainability of plant, animal and micro-organism communities in these areas and ecosystem stability is enhanced by habitat and bio- diversity. This paper reports on a study on rehabilitated ash disposal sites to determine the succession of a number of biotic factors along as rehabilitation gradient. These biological parameters include vegetation, soil mesofauna, ants, beetles, and small mammals. The trend in total biodiversity index values shows an initial increase until five years after rehabilitation followed by a gradual decrease. Diversity patterns of the various biotic variables differed greatly, with beetles showing a strong decrease in diversity with age of rehabilitation and ants a significant increase. Succession of assemblages of the biological variables will be discussed. This paper will also report on a modelling attempt using neural network techniques, to determine indicators of rehabilitation success.

1 Introduction

South Africa is highly dependent on ten coal burning power stations, which are concentrated in the coal rich Highveld areas of Mpumalanga and Gauteng provinces. The environmental impact of these power stations is considerable It is generally recognised that South Africa has comparatively high levels of air pollution, particularly in the Mpumalanga Province where 75% of coal burning power stations are located which produce high levels of emissions of SO_2. Another major environmental problem is created by the annual production of about 22.2 million tons of fly ash by these power stations. This fly ash is mainly being transported by pipes in a watery sludge and pumped onto large ash dams. This ash is largely inert with high concentration of silicon and aluminium with a relatively high pH. The ash dams cover large areas of high quality farmland. It is estimated that these ash dams cover a total of about 4500 ha of productive farmland.

South Africa has extensive legislation directly related to the rehabilitation of derelict land which includes legislation for the prevention of water pollution and sustainable water utilisation, environmental conservation, extensive requirements regarding the **rehabilitation** of the surface of land disturbed by mining and industry, employment of environmental management programmes and the prevention of dust pollution on mine dumps.

Rehabilitation of ash disposal sites is therefore an important issue for the electricity provider and the objectives of sustainable rehabilitation in as short as possible time in the most cost efficient way is high priority. The term "rehabilitation" needs to be defined because the absence of definition could impact negatively on research planning and structure (Mentis & Ellery [1]). According to the interpretation of Barnard [2] of applicable environmental legislation, sites disturbed as result of industrial activities have to be "properly" rehabilitated, and restored to a "proper" condition and must satisfy the demands of sustainable development. Rehabilitation, sustainability and a "proper condition", is achieved if the economic value of a rehabilitated area is at least equal to the value of the resource that will be destroyed during development. Sustainability of rehabilitated ash disposal sites is therefore the main objective in rehabilitation.

The sustainability of ecosystems depends to a large extent on the diversity and adaptability of animal and plant populations. Comprehensive data are needed on the species diversity and community structure(s) of ash dams at various stages of rehabilitation to generate reliable estimates of ecological change and succession status (Inouye [3]). Information on the role of animals in disturbed environments is relatively scarce (Bhatt & Soni [4]) but recent literature on this subject emphasizes their importance as possible indicators of environmental change. (Andersen [5], Andersen [6], Andersen [7], Andersen [8], Andersen, Hoffmann, Müller &Griffiths [9], Andersen & Sparling [10], Bhatt & Soni [4]; Korn [11]; Kremer, Colwell, Erwin, Murphy, Noss & Sanayan [12]; Majer [13], Majer [14], Majer [15], Majer [16], Majer [17], Majer [18], Majer & de Kock [19], Majer & Nichols [20], Majer, Day, Kabay & Perriman [21], Majer, Sartori, Stone & Perriman [22], McGeoch [23], Woinarski, Andersen, Churchill & Ash [24], Samways, Caldwell, & Osborn [25]. One of the challenges is to develop management practices, which accelerate and direct ecological succession toward desired outcomes (Bradshaw [26], Luken [27]).

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The approach towards rehabilitation in mine site rehabilitation in South Africa is still strongly focussed on revegetation in contrast with the latest shift away from simple revegetation, towards more comprehensive ecosystem restoration with the aim of creating sustainable ecosystems similar to those occurring prior to mining (Anderson [7]). However, comprehensive assessments of ecosystems are impractical in a management context (Andersen [7]), emphasizing the need for bio-indicators of ecosystem change.

The objective of this study is the identification of indicators, which reflect the general state of rehabilitated ash disposal sites associated with Hendrina power station in the Mpumalanga province, South Africa. Changes in species richness and species diversity as a measure of ecological change along a rehabilitation gradient, were investigated as a preliminary part of a broader rehabilitation management model.

Generally, species richness increases during the course of succession and increase in spatial heterogeneity, although important exceptions are found (Begon, Harper & Townsend [28]. For this study, the relationship between species diversity and species richness of possible indicator groups was determined as a first step in identifying suitable indicators, or assemblages of indicators of rehabilitation success on ash disposal sites.

The following possible indicator groups were investigated.

Vegetation

Rehabilitation of ash dams in South Africa is done by covering the ash with at least 10cm of top soil which is then sown with specially selected seed mixtures, best suited for that locality and medium characteristics. Several studies have indicated a gradual increase in species richness during succession (Bazzaz [29], Facelli & D'Angela [30]).

Terrestrial invertebrates

Terrestrial invertebrates are widely recognized as indicators of ecological change associated with human land use (Rosenberg, Danks & Lehmkuhl [34]). Invertebrates make good indicators of ecological change because they are highly diverse, functionally important, can integrate a variety of ecological processes, are sensitive to environmental change and are easily sampled (McGeoch [23]). Three groups of invertebrates are reported on:

a) Soil mesofauna

Several taxonomic groups are represented in this group such as the Acari (dominated by the Prostigmata), Collembola, subterranean ants and some of the other invertebrate groups. Soil mesofaunal organisms can be used as indicators of different soil factors such as organic matter content, pH value of soil, water content, nitrogen content and mechanical disturbance (Aoki, [35]; Van Straalen & Verhoef, [36]).

b) Beetles

This group of invertebrates has been researched as bio-indicators by Stork [38].

c) Ants

Ants are considered ideal candidates for use as bio-indicators because of their high abundance and diversity, their ecological importance at all trophic levels, the relative ease with which they can be sampled and sorted and their sensitivity to ecological change. Ants have been commonly adapted as bio-indicators in land management in recent literature (Majer [14], Majer [15], Andersen [7], Andersen *et al.* [9]).

Small mammals

Species replacements, changes in densities and competition effects typify succession of small mammal communities in areas recovering from disturbance, or under rehabilitation (Fox & McKay [39]; Kirkland [40]; Parker [41]; Ferreira & Van Aarde [42]. Successional tendencies appear to be habitat-specific.

2 Methods

2.1 Study area

2.1.1 Location

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

This region belongs to the Grassland biome of South Africa and is characterized by species such as *Tristachya leucothrix*, *Eragrostis racemosa*, *Heteropogon contortus*, *Trachypogon spicatus*, *Digitaria tricholaenoides*, *Themeda triandra*, *Brachiaria serrata* and *Elionurus muticus*.

The study area consists of four different ash dams (A-D) covering a surface area of approximately 215 ha (Figure 1). The construction of ash dam B was never finished, because the stockpiles collapsed. Ash dam D is the most recent rehabilitated area, and is separated from the other ash dams. Disposal of ash on ash dam D is still in progress. The construction of the fifth ash dam (ash dam E) commenced in late 1997. Rehabilitation techniques of the ash dams, used at Hendrina Power Station, have been documented in Michael & Bronner [43].

2.1.2 Survey site selections 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) was established on the ash dams. The grids were sited in relatively homogenous 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, aspect and topography (slopes or plateaus), and ecological status of neighboring areas. Two "control" grids (C1 and C2) were also established in bordering natural grasslands. Although it is impossible to ever rehabilitate communities on the ash dam sites to the levels of diversity and complexity on natural grasslands, baseline knowledge of

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community structure(s) and temporal variability therein is vital to the interpretation of patterns observed on the ash dams.

Of the 12 ash dam grids, two (Grid5 and Grid6) were assessed only once, during the initial survey of 1997. These grids were omitted from further surveys.

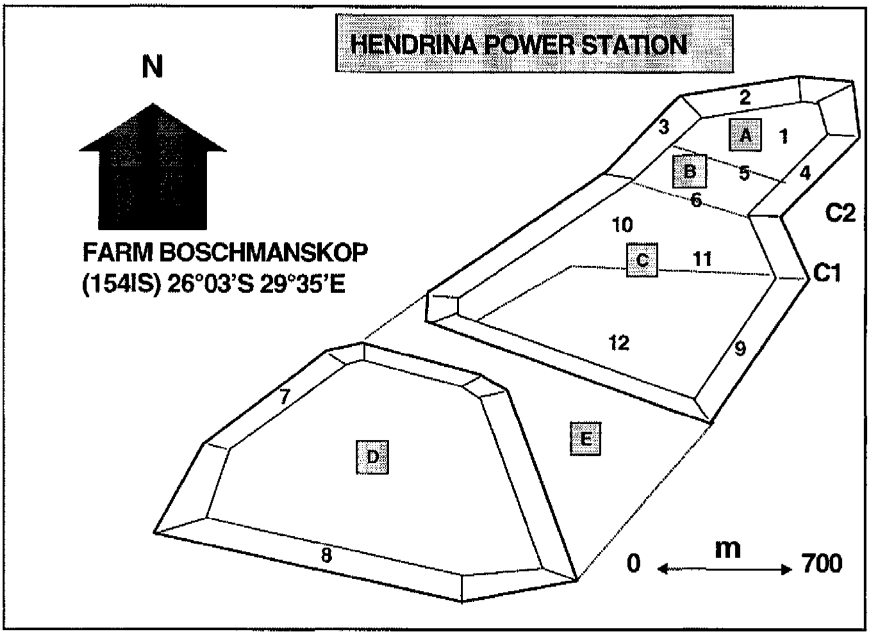

Figure 1: A map of the ash dams at Hendrina Power Station showing the location of survey grids 1 to 12, and of control grids (C1 and C2).

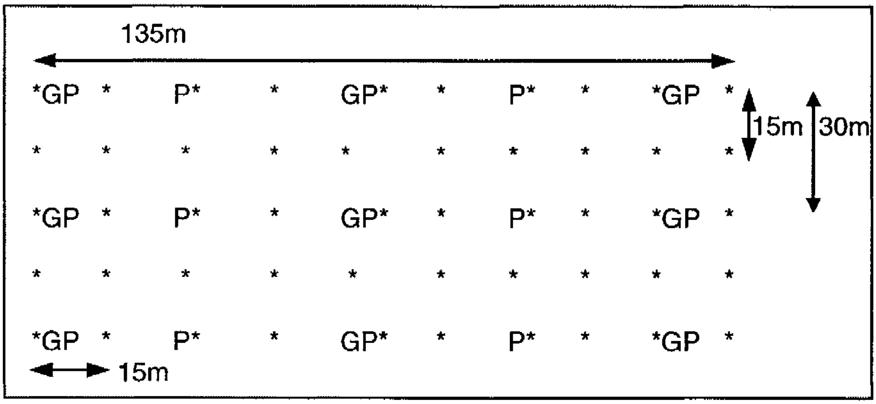

Figure 2: Grid layout at Hendrina study site. * = Small mammal traps; P = pitfall traps; G = general survey points for soil fauna.

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Each grid measures 135m x 60m and comprises of 50 mammal trap stations spaced 15m apart and 15 general survey sites spaced 30-45m apart.

The grids were renamed to facilitate their rehabilitation age identification from their grid reference number. A descriptive summary is given in Table 4.

2.2 Faunal and floral surveys

Quarterly surveys were undertaken from March 1997 until May 1999 with surveys in March, July, September and November during 1997, January, March, September and November during and January 1999.
These surveys included (See Figure 2):

- Pitfall trapping for 48 hours to collect epigeal invertebrates, mainly ants and beetles;
- Collection of substrate samples for extraction of soil mesofauna at the general sampling points;
- Five sweep net sweeps in the vicinity of each pitfall trap for catching epiphytic invertebrates;
- CMR (Capture-Mark-Recapture) studies of small mammals to determine densities and diversity according to the site plan in Figure 2.
- Floral frequency, diversity and community surveys.

All organisms were sorted, counted and identified as far as possible and given a morpho-species number.

Changes in species diversity (using the Shannon-Wiener index) and species richness (number of species) were determined for each transect in each grid.

Table 1: Summary of topography, slope details, number of transects and pitfall traps, and rehabilitation age for each survey grid.

Grids	Topography	Aspect	No transects	No. pitfall traps	Rehab. age	Grid no.
7&8 top	Slope	S&W	2	10	0	0
7&8 middle	Slope	S&W	2	10	3	3
1	Plateau		3	15	4	4
2	Slope	N	3	15	5	5a
3	Slope	W	3	15	5	5b
4	Slope	E	3	15	5	5c
7&8 bottom	Slope		2	10	7	7a
9	Slope	E	3	15	7	7b
10	Plateau		3	15	7	7c
11	Plateau		3	15	7	7d
12	Plateau		3	15	9	9
Control1	Plateau		3	15	nat.veld	C1
Control2	Plateau		3	15	nat.veld	C2

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3 Results and discussion

3.1 Species diversity and - richness on grids at different ages of rehabilitation

The species diversity and richness of a number of assemblages of organisms was determined with the objective to identify possible indicator assemblages of rehabilitation progression and –success. The species diversity and – richness in grids along a gradient of rehabilitation age is given in Figure 3.

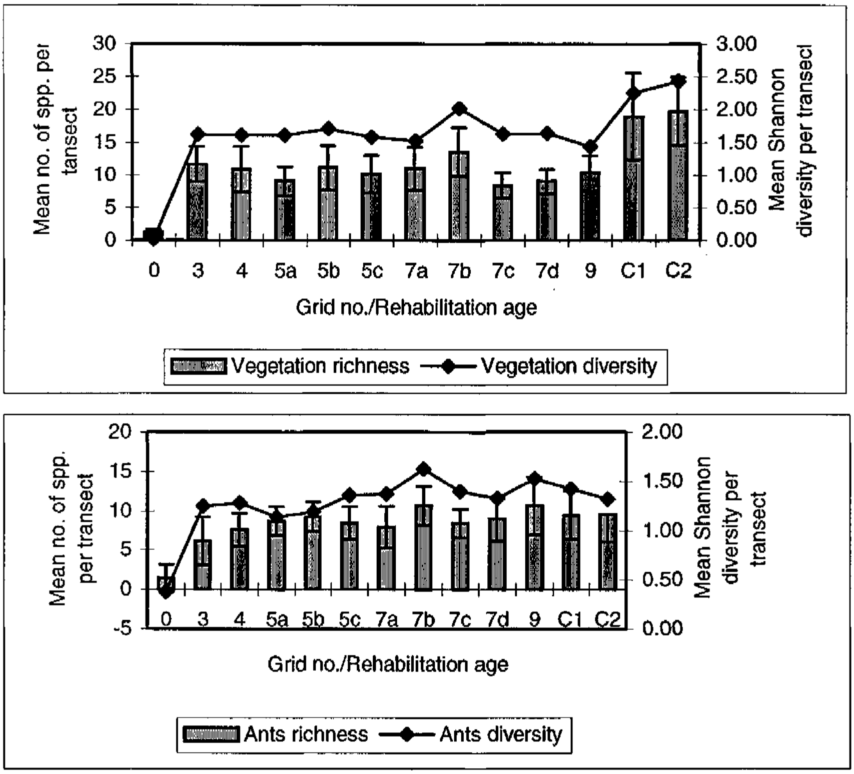

Figure 3: Mean species diversity and – richness of organism assemblages along a gradient of rehabilitation age. The numbers of grids indicate rehabilitation age; grid 0 represents unrehabilitated sites and C1&C2 are control grids (refer to Table 1) (continued on next page).

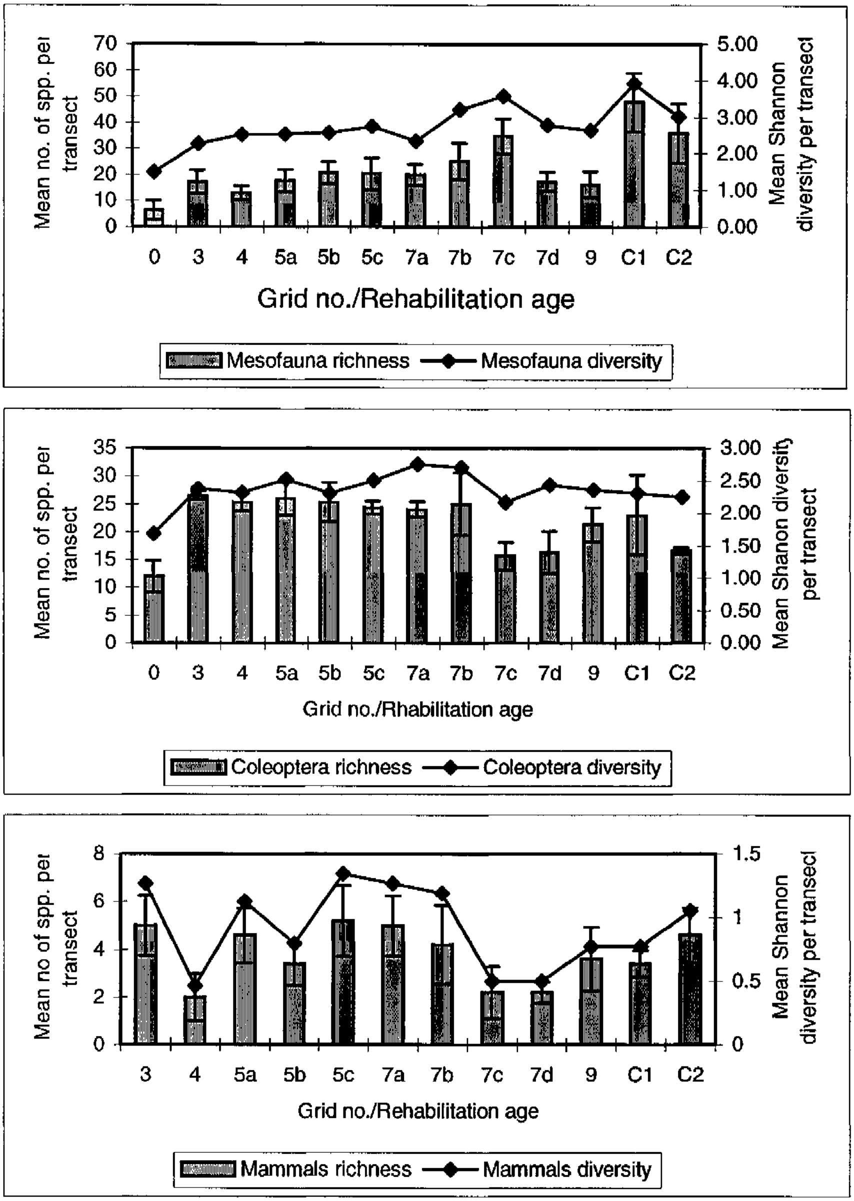

Figure 3: (Continued).

Figure 3 illustrates similar patterns in diversity and richness along a rehabilitation age gradient, although some smaller differences between these parameters were found probably as a result of spatial distributions affecting evenness. In general species richness and diversity increased rapidly from the

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initial rehabilitation but reached a plateau at 5 to 7 years after rehabilitation and tended to decrease from 7 to 9 nine years after rehabilitation. Changes in species diversity and – richness over time after rehabilitation, differed considerably between groups of assemblages. Vegetation diversity and richness tended to decrease over time after rehabilitation which is similar to the highest species richness at intermediate levels of ecosystem productivity found by Tilman [44] and Bond [45]. The main reason being the high emergence of pioneer species during the first stages of rehabilitation and the unfavorable conditions for plant species at later stages of rehabilitation due to the dominance of large tufted grasses from the seed mixture suppressing seed germination of other species. The beetle and small mammal assemblage diversity also tended to decrease with age of rehabilitation. However the diversity/richness of ants and soil mesofauna assemblages increased with increasing age of rehabilitation.

In order to identify assemblages sensitive for ecosystem change, the relationship between species diversity and – richness of these assemblages and age or progression of rehabilitation was determined. The regression analysis was carried out on rehabilitated sites; the unrehabilitated and natural grassland sites were not included to facilitate the analysis of the rehabilitation effect. The regression analysis of species diversity against age of rehabilitation is shown in Figure 4 and for species richness in Figure 5.

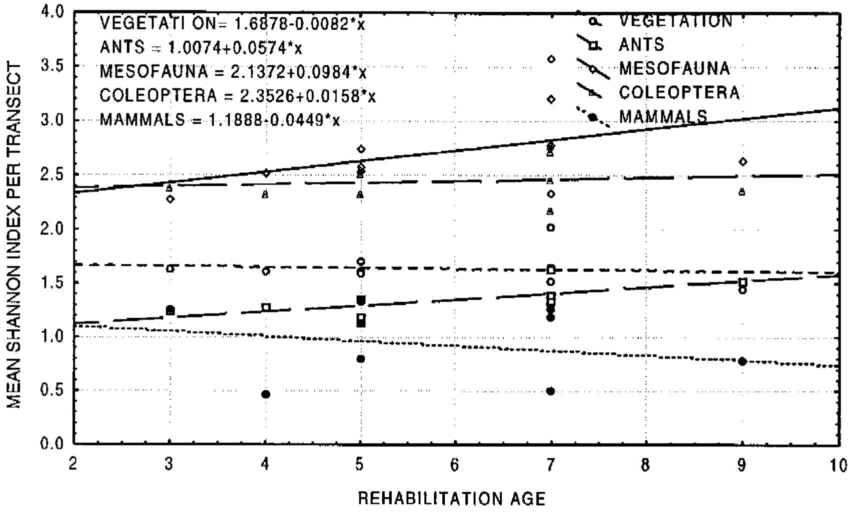

Figure 4: Regression analysis to show the relationship between rehabilitation age and species diversity of different assemblages of organisms.

Figures 4 and 5 illustrate the different relationships between the different groups of organisms and progression of rehabilitation. The diversity of the different assemblages has a definite influence on the significance of these relationships. The significance of the regressions of the different groups of organism assemblages to rehabilitation progression is summarized in Table 2.

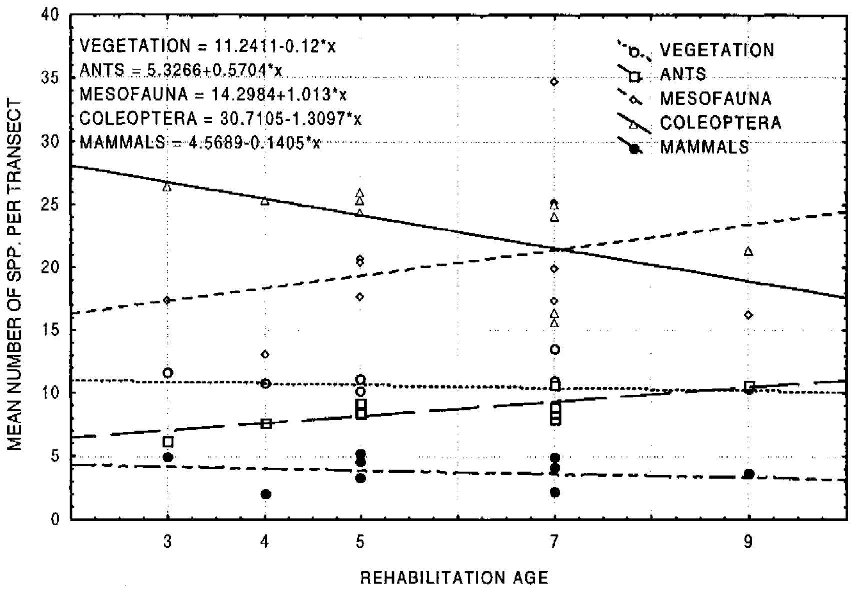

Figure 5: Regression analysis to shows the relationship between rehabilitation age and species richness of different assemblages of organisms.

Table 2: Summary of the regression analysis of the relationship between age of rehabilitation and species diversity and species richness of different assemblages of organisms. **r** = correlation coefficient, $\mathbf{r^2}$ = coefficient of determination and p reflects the probability and significance of the relationship. Statistical significant relationships are printed in bold.

	AGE OF REHABILITATION					
	Species diversity			Species richness		
	r	r^2	p	r	r^2	p
Vegetation	-0.0963	0.0093	0.7912	-0.1430	0.0204	0.6935
Ants	0.6997	0.4896	**0.0243**	0.7591	0.5762	**0.0109**
Mesofauna	0.4409	0.1944	0.2021	0.3018	0.0911	0.3068
Coleoptera	0.1571	0.0247	0.6647	-0.5952	0.3543	0.0695
Mammals	-0.2272	0.0516	0.5279	-0.2007	0.0403	0.5783

Table 2 confirms findings by various authors that ants can be regarded as sensitive to changes in ecosystems (Andersen [7], Andersen *et al.* [15], Majer [14], Majer [15] and can be regarded as good ecological indicators (McGeoch [23]). Mesofauna assemblages look promising but the large diversity within this group creates a lot of variation and the prostigmatic mites and Collembola as separate assemblages should be further researched. This study constitutes a preliminary selection of possible ecological indicators and needs to be followed up by the identification of functional groups of assemblages and research into responses of these indicator taxa to anthropogenic perturbations (Andersen [14]).

4 Conclusions

This study provided data for the preliminary selection of ecological indicators for use in sustainable ash dam rehabilitation. From the wide range of organisms surveyed, ants showed to be sensitive to rehabilitation progression. However, more specific biological and functional information is needed to be more predictive. This study presented an enormous amount of data from both biological and other environmental parameters and is in the process of being incorporated into a predictive model with the aid of neural network techniques. The identification of specific rehabilitation outcomes and objectives is a limiting factor but with the aid of present data and the continuous upgrading of datasets, a useful model for use in power station rehabilitation management will be available in near future.

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