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RECOLONISATION BY ANTS AND OTHER INVERTEBRATES IN REHABILITATED COAL MINE SITES NEAR COLLIE, WESTERN AUSTRALIA

John van Schagen*

Abstract

This paper describes a study performed in a coal mine at Collie, Western Australia. Ten rehabilitated mine sites and 2 forest controls were investigated. The age of the rehabilitated plots ranged from 0.5 to 9.5 years. Soil from the rehabilitated areas had a higher inpenetrability and higher bulk density value than the controls. Plant species richness and ant species richness were lower in the rehabilitated areas than in the unmined forest.

Twenty nine ant species were found during the course of the study, of which 18 had colonised the rehabilitated plots. Ant species richness was positively correlated with plant species richness, but negatively correlated with soil inpenetrability. The time-associated trend indicated that ant species richness increased with age of rehabilitation. The recolonisation rate of ants reflected that of certain other invertebrates.

Data obtained in this study provide a comparison with similar studies performed in bauxite, manganese and mineral sand mines, which relate recolonisation rates of ants to annual rainfall.

Introduction

Invertebrates, especially ants, are important in assessing the success of rehabilitation of mined areas. Ants are particularly useful as bio-indicators because of their extremely high abundance, relatively high species richness, and the existence of many specialist species (Majer 1983). Ants and other invertebrates are also important because they play a role in soil aeration and drainage, pollination of flowers, seed distribution, plant predation, plant survival, and provision of food for other animals. Majer et al. (1984) found that ant species richness was positively correlated with plant species richness in bauxite mines in Western Australia, and also that ant return was encouraged by increased plant species richness and plant species diversity.

The mining company Western Collieries Ltd is mining coal 15km south-east of Collie, Western Australia. Rehabilitation of mined areas at mine site no. 5 commenced in 1975. One problem the company is faced with is erosion, as overburden is temporarily placed on large dumps. These dumps have very steep slopes that are heavily eroded by rain. Many gullies are formed and these are colonised by plants with great difficulty (Turner 1984). Current rehabilitation techniques allow the mined areas to be filled with overburden and covered with topsoil. In this way

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more contoured areas are created which are relatively easy to rehabilitate. The rehabilitation procedures at this minesite have been extensively investigated by Koch (1980, 1983) and Koch and Bell (1983, 1986).

The study reported here is an investigation of the soil, litter, vegetation, and invertebrates in 10 rehabilitated areas of differing age and 2 unmined forest control plots. The aim of the project was to determine a possible correlation between any of these factors in order to see which ones might enhance or reduce the recolonisation of flora and fauna. From this information the rate of recolonisation by ants and other invertebrates in the rehabilitated mine sites may be determined. The success of rehabilitation may further be determined by comparing some of the physical, vegetation, and invertebrate data from the rehabilitated plots with that of the forest controls.

Ant recolonisation data can further be compared with ant return data from Majer (1984a). Majer's previous studies investigated the relationship between ant recolonisation and climatic conditions, such as rainfall. Various areas throughout Australia have been studied in his report.

Experimental Plot Descriptions

Ten rehabilitated plots and 2 forest controls were selected for investigation. The age of rehabilitation of the 10 plots ranged from 0.5 to 9.5 years. These areas were located within the Western Collieries No. 5 mine site and all were located within a strip measuring 100-800m of the Collie River. The top-soil of most rehabilitated plots consisted of sandy-clay or sandy-loam and was placed over an acidic overburden. The 2 control plots, located in forest areas adjacent to the mine site, were a riparian forest adjacent to the Collie River and an upland forest control. These were selected to ensure that the full range of vegetation cleared for mining was covered by the control plots.

In each plot a 100m mid-line transect was marked out and meter-square quadrats were pegged at 10m intervals along each transect.

Field work was performed during February 1985, although most of the vegetation survey was undertaken in October-November 1984.

Materials and Methods

Physical Parameters

Various soil measurements were taken and samples were collected from 4 to 15 February, 1985. The following data were obtained:

Soil Inpenetrability - this was measured in every quadrat using a Proctor® penetrometer which indicates the force required to press a 12mm diameter tip into the soil to a depth of 5cm. The force was then read off a scale and converted to kiloPascals (kPa).

Soil Bulk Density - this was calculated by dividing the dry weight of each soil sample, by the calculated volume of the soil. To obtain the dry weight the soil was dried in an oven at 105°C for 48 hours. One sample was taken from each quadrat and was obtained using a soil corer of 5.5cm diameter and 9.9cm depth.

Soil Moisture - this is the percentage moisture in each soil sample. The soil was weighed before and after drying at 105°C in order to obtain the moisture weight, and the percentage moisture was then calculated.

Litter and Vegetation Survey

A vegetation survey of the 10 rehabilitated plots was performed in October-November, 1984, whereas litter measurements in the rehabilitated plots and control plots and the vegetation survey of the control plots were performed in February 1985. The data were obtained from meter square quadrats and from Levy-rod readings. The Levy-rod is a 2m long rod with alternating black and white bands each of 25cm length. The rod was placed every 2m along the 100m transect lines and the vegetation touching each of the 25cm bands was counted. The litter and vegetation survey included the following parameters:

Bare Ground - this was measured in every quadrat and was expressed as a percentage of the total area.

Litter Cover - this was measured in every quadrat and was expressed as a percentage of the total area in the quadrat.

Litter Depth - this was measured in mm from the bare ground using a meter ruler.

Litter Index - this value was calculated by multiplying litter cover by litter depth.

Deadwood - this is the amount of small pieces of wood and large logs. These were counted in a 2m wide strip located along one side of the transect lines. This variable was divided into deadwood smaller than 15cm and deadwood larger than 15cm diameter.

Ground Cover - this is the area of the quadrat covered by low vegetation. It was expressed as a percentage of the quadrat. Ground cover was also measured by recording the percentage of Levy-rod placings which resulted in any contact with vegetation.

Tree Cover - this is a measure of the cover of tree foliage over each quadrat. It was also measured by recording the percentage of Levy-rod placings which had tree canopy vertically above the rod.

Plant Cover Density - this is a measure of the thickness of vegetation in places where it occurred. This value was obtained by dividing the total number of plant contacts by the number of Levy-rod placings which resulted in any vegetation contact. This calculation was performed for each 25cm zone in order to construct a vertical profile of plant cover density.

Plant Species Richness - this is a measure of the number of plant species in each transect. This variable is expressed as the total number of species found in the 10 quadrats in each transect. Plant species richness is divided into plant species richness for native plants and for weeds.

Plant Species Evenness (J') - this was calculated from the Shannon and Weaver (1949) index (H') using the following formula:

$$H' = \frac{(N \log N - \Sigma i \; ni \log ni)}{N}$$

where N is the total number of plants and ni is the number of each species. The evenness index was then calculated from: $J' = H'/\log s$, where s is the number of species present.

Invertebrate Survey

Various methods were employed to collect the invertebrates:

(a) Pitfall traps were installed on 29 November, 1984 and left in the ground for 7 days. These were 42mm diameter and were inserted into the ground at 10m intervals along the transect lines. The pitfall traps were filled with alcohol to which glycerol had been added in order to reduce evaporation.

(b) Ants in each plot were hand collected during 1 hour of the day and 1 of the night. This, and the following two methods of collection were performed in February, 1985.

(c) Ten sweeps of vegetation were performed using a sweep net along lines of 20m length at right angles to the transects. The sweep lines were performed along alternating sides of the transect. The invertebrates were placed in jars of alcohol after each sweep.

(d) Tree beats were performed on 5 trees of height less than 1.3m located in each plot. The branches were beaten with a stick and the invertebrates that fell out were collected on a drop sheet.

The invertebrates were sorted and identified to 'order' level. The ants were identified into species. Representation of the collected specimens are housed at the School of Biology, Western Australian Institute of Technology, Western Australia.

Data Treatment

After all data were gathered the transect means for all physical, litter, vegetation, and invertebrate recordings were calculated. Plant species richness and ant species richness were calculated by respectively summing the plant species and ant species obtained by all methods. Plant species evenness and ant species evenness were calculated using the Shannon and Weaver index. Total invertebrates and total invertebrate taxa obtained by pitfall trapping, vegetation sweeping, and tree beating were also summed for each plot. Plant and ant species lists were obtained by combining all species found in the various plots.

A correlation matrix was produced for all variables in order to determine any relationships between physical, litter, vegetation, and invertebrate variables. The Pearson correlation coefficient with two-tailed probability levels was used to determine possible correlations. The variables which are significantly correlated are shown in the diagrams and arrows point in what is considered to be the most likely direction of causality. They point in both directions if the relationship is thought to be reciprocal.

Results

Physical Variables

Table 1 shows the summaries of physical and vegetation variables which were measured. Soil inpenetrability was higher in the rehabilitated areas than in the controls, in other words the rehabilitated area soil was more difficult to penetrate. The mean value obtained in the rehabilitated areas was 4062 kPa. This was 45% more than the mean of the controls. Soil bulk density also had a higher value in the rehabilitated areas. Here it varied from 1.04 g/cm3 to 1.69 g/cm3 while the control mean was 0.99 g/cm3. Soil moisture in the rehabilitated plots was on average 65% less than the control mean.

The only significant time-associated trend with physical parameters was soil inpenetrability. There was an increase in soil inpenetrability as the age of rehabilitation increased (Figure 1).

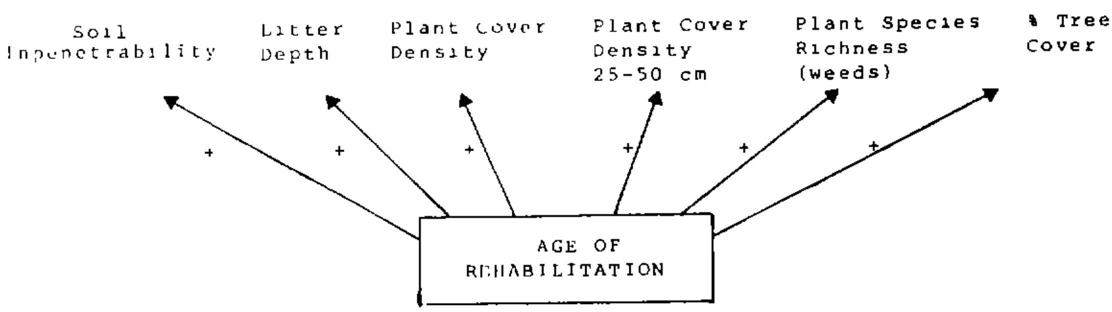

FIGURE 1. Diagram of the plot variables which were significantly correlated ($p < 0.05$) with the age of rehabilitation. The + marks indicate that the correlations were positive and the arrows point in the assumed direction of causality.

Vegetation Variables

Table 1 shows that the rehabilitated areas have more bare ground and less litter cover than the control plots. This resulted in a smaller value for the litter index in the rehabilitated areas. The litter index in the rehabilitated areas ranged from 2 to 420, whereas the control mean was 1372. The amount of deadwood was less in the rehabilitated areas than in the controls. The mean amount of deadwood < 15cm and > 15cm diameter was 13 and 2.5 respectively for the rehabilitated plots, whereas the control means were 32 and 22.5 respectively.

There are some differences in vegetation between the rehabilitated areas and the control plots. For instance ground cover, measured with the Levy-rod, was on average 58% less in the rehabilitated areas than in the control plots. Tree cover was also less in the rehabilitated areas. There was a lower plant cover density in the rehabilitated areas than in the control plots. The mean value here was 3.8 whereas the control mean was 6.7. Plant cover density mainly differed in the 150-175cm and 175-200cm strata.

The significant time-associated trends of litter and vegetation structure are shown in Figure 1. Litter depth, overall plant cover density, plant cover density (25-50cm), and percentage tree cover increased with the age of rehabilitation. The highest values for these variables were obtained in the rehabilitated plots ranging from 5.5 to 8.5 years.

Table 1 also shows plant species richness and evenness values. Species richness for all species in the control plots was 25% higher than the overall rehabilitated area mean. More native species and less weeds were present in the controls. A mean of 21 species was found in the rehabilitated plots, of which 17 were native species and 4 were weeds. In the control plots a mean of 28 species was obtained, of which 26 were native species and 2 were weeds. Plant species evenness for all species (weeds and native species) and for native species was generally higher in the controls than in the rehabilitated plots. The control mean evenness value was 0.65, whereas the mean of the rehabilitated areas was 0.31. The only significant time-associated trend was that of weed species richness. The number of weeds increased with the age of rehabilitation as shown by the gap between the lines for total plant species and native plant species versus time in Figure 2.

Table 2 shows the various stages of plant succession. A total of 90 species was collected in the study area. Thirty four of those were seen in the control plots of which 14 did not occur in the rehabilitated plots. **Hypochoeris radicata** (flat weed) was present in all the 12 plots. **Scirpus antarcticus** was present in all rehabilitated plots, but was not seen in the forest control plots. Seven species were found in the youngest plot, followed by 14 in the next plot, which was rehabilitated between 1 and 2 years previously. Five of these were **Acacia** species, 2 **Kennedia** species, 1 Asteraceae, **Eriostemon**, **Eucalyptus**, **Juncus**, **Stylidium**, **Trachymene**, and **Ursinia** species. In the 3 year old plot 14 more species appeared of which 3 were **Eucalyptus** (**patens**, **rudis**, and **wandoo**).

Figures 2 and 3 show the time-trends of plant species richness and plant species evenness respectively. Plant species richness fluctuated over the years and reached its peak after 6 years. Plant species evenness was very high in the first year but then dropped as more species colonised the area. It then increased again and reached its highest value after 8 years.

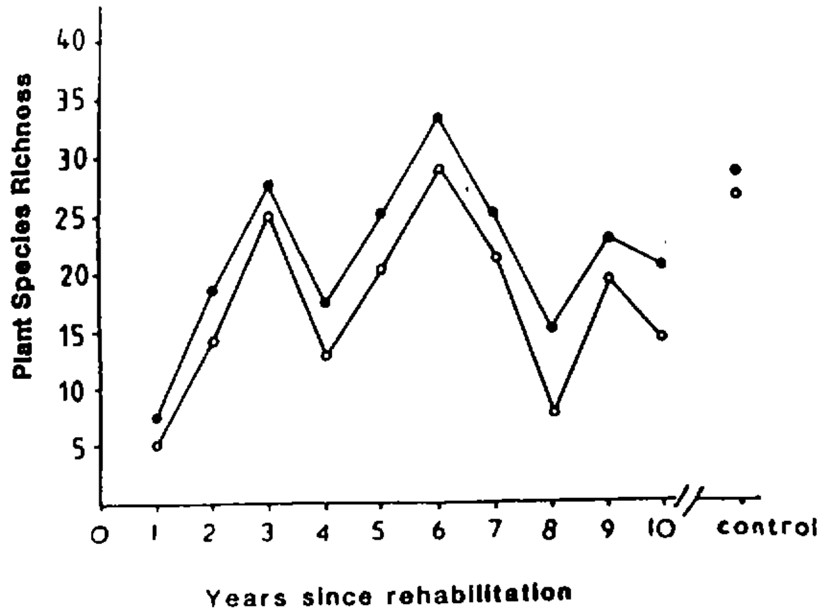

FIGURE 2. Diagram showing the relationship between plant species richness of all species (•) and native species (o) with age of rehabilitation.

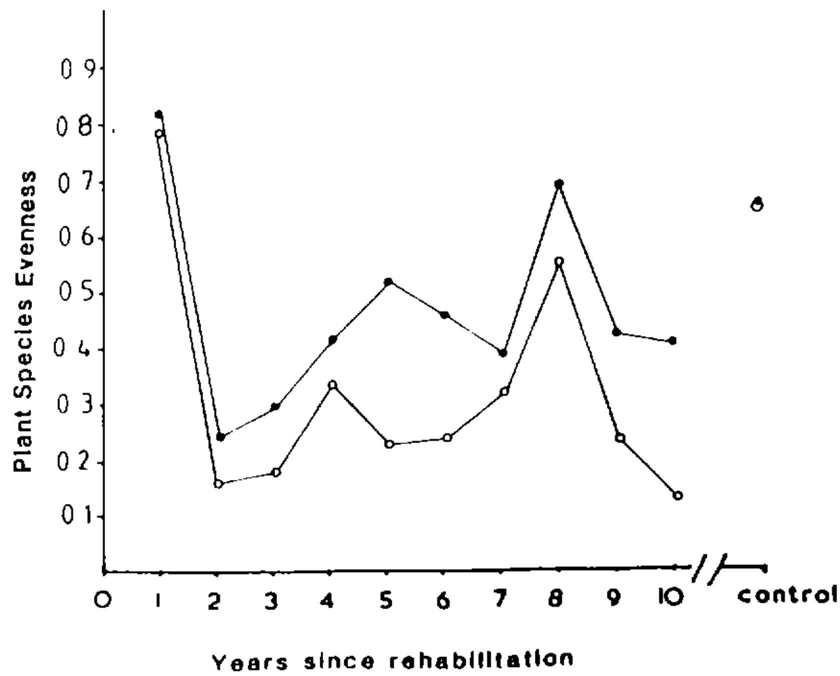

FIGURE 3. Diagram showing the relationship between plant species evenness of all species (•) and native species (o) with age of rehabilitation.

Invertebrate Parameters

Table 3 shows the invertebrates collected in the pitfall traps. Twenty nine 'orders' were obtained, of which 27 were found in rehabilitated areas. Isopoda and Caelifera were found only in the control plots. 'Orders' that were not found in the controls were Protura, Psocoptera, Thysanoptera, Neuroptera-larvae, and Coleoptera-others.

Acarina and Collembola were more abundant in the rehabilitated areas than in the controls. Mean values were 6.5 Acarina and 58.4 Collembola in the rehabilitated areas and 3.0 and 19.6 in the controls. The total taxa in the rehabilitated areas ranged from 11 to 16. The controls had between 17 and 20 taxa, indicating that less taxa were present in the rehabilitated plots.

Figure 4 shows that total invertebrate taxa in pitfall traps was associated with various physical and vegetation parameters. Soil bulk density and percentage bare ground were negatively correlated with total invertebrate taxa. Percentage litter cover, litter depth, litter index, amount of deadwood, percentage ground cover, percentage tree cover and plant species evenness were positively correlated with total taxa.

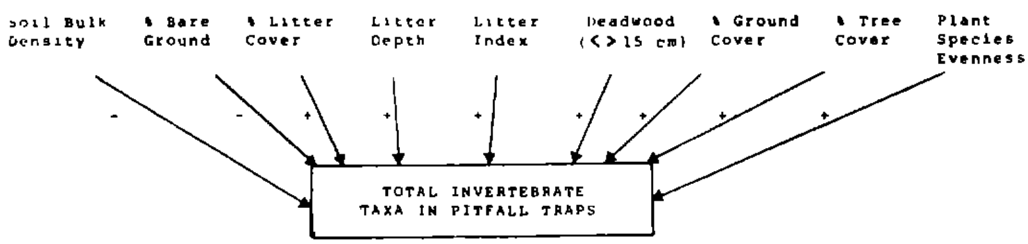

FIGURE 4. Diagram of the variables that correlated ($p < 0.05$) with the total taxa obtained in the pitfall traps. The +/- marks indicate the sign of the correlation and the arrows point in the assumed direction of causality.

Table 4 is a summary of all the invertebrates collected by sweeping the vegetation in the 12 study plots. Twenty one 'orders' were collected of which 17 were found in the rehabilitated areas. Acarina, Collembola, Psocoptera and Coleoptera-larvae were only obtained from the control plots. Mantodea, Gryllacridoidea, Neuroptera-larvae, and Scarabidoidea were not seen in the controls. The total number of invertebrates and total taxa in the controls were higher than those in the rehabilitated areas. Homoptera and Heteroptera were well represented in the first year since rehabilitation, but numbers decreased in the older plots. No significant time-related trends were found. Figure 5 shows that there is a positive correlation between total invertebrates and total taxa obtained in the sweeps.

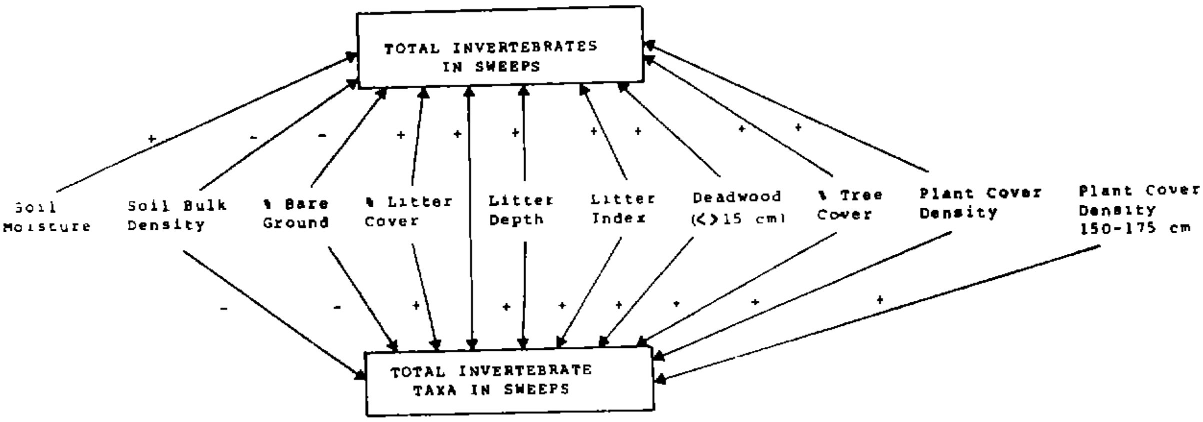

FIGURE 5. Diagram of physical and vegetation variables that correlated ($p < 0.05$) with the total invertebrates and total taxa in the sweeps. The +/- marks indicate the sign of the correlation and the arrows point in the assumed direction of causality.

There are also a number of physical and vegetation parameters shown in Figure 5 which are related to total invertebrates and total taxa of the sweeps. Soil moisture was positively correlated with total invertebrates. Soil bulk density and percentage bare ground were negatively correlated with both total invertebrates and total taxa. Percentage litter cover, litter depth, litter index, deadwood, percentage tree cover, and plant cover density were positively correlated with total invertebrates and total taxa. Plant cover density (150-175cm) was positively correlated with total taxa.

Table 5 is a summary of all invertebrates collected by tree beating. A total of 13 species was collected, of which 12 were found in the rehabilitation plots. Hymenoptera was the only order not collected in the rehabilitated plots by this method. Scarabidoidea and Lepidoptera-adults were not found in the controls. No arboreal invertebrates were collected in the plots aged 0.5 and 1.5 years, because no trees were present. More taxa were obtained from the control plots than from the rehabilitated areas. There was a positive correlation between total individuals and total taxa from the beats (Figure 6). Total taxa was found to be negatively correlated with age of rehabilitation.

The significance of the relationships between the invertebrates obtained from pitfall traps and from sweeps is shown in Figure 7. None of the invertebrate parameters obtained by tree beating was correlated with those obtained by other methods. Total invertebrates from the sweeps was positively correlated with the total taxa obtained from the pitfall traps. Total individuals from the sweeps was positively correlated with the total individuals from the pitfall traps.

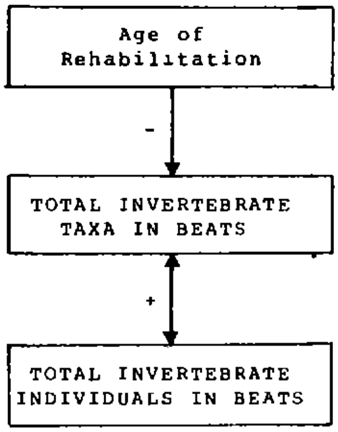

FIGURE 6. Diagram showing the correlation ($p < 0.05$) between age of rehabilitation and invertebrates obtained in tree beats. The +/- marks indicate the signs of the correlations and the arrows point in the assumed direction of causality.

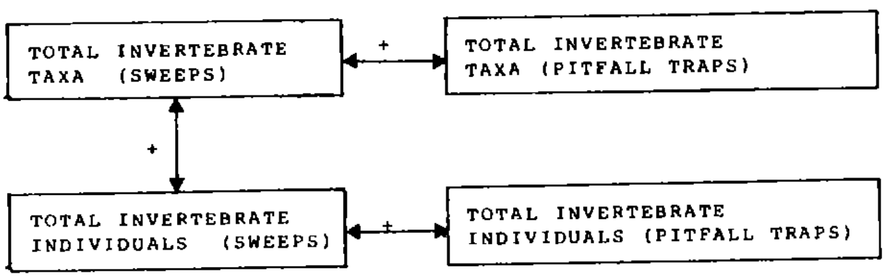

FIGURE 7. Diagram showing the correlation ($p < 0.05$) between invertebrates obtained from vegetation sweeps and pitfall traps. The + marks indicate that the correlations were positive and the arrows point in the assumed direction of causality.

Table 6 shows the species of ants which were collected in this study. Twenty nine species were collected, of which 22 were found in control areas and 18 were found in the rehabilitated plots. Species confined to the control plots were **Heteroponera imbellis, Chelaner** sp. JDM 626, **Monomorium** sp. 1 (ANIC), **Meranoplus** sp. 12 (ANIC), **Diceratoclinea** sp. JDM 211, **Iridomyrmex conifer, Iridomyrmex** sp. JDM 9, **Camponotus** sp. JDM 182, **Camponotus** sp. JDM 287, **Notoncus gilberti** and **Polyrhachis** sp. JDM 372. Species confined to the rehabilitated areas were **Cardiocondyla nuda, Iridomyrmex glaber, Iridomyrmex** sp. JDM 8, **Iridomyrmex** sp. JDM 433, **Camponotus** sp. JDM 26, **Camponotus** sp. JDM 106, and **Stigmacros** sp. JDM 375.

Iridomyrmex sp. 21 (ANIC) was an early coloniser of rehabilitated areas. This species was the first one to appear in the plot which was rehabilitated 0.5 years previously, and was found in all study plots. **Rhytidoponera inornata, Rhytidoponera violacea, Iridomyrmex purpureus, Iridomyrmex** sp. JDM 8, and **Camponotus** sp. JDM 199 followed in the 1.5 year old plot while **Cardiocondyla nuda** and **Pheidole** sp. JDM 44 first appeared in the 2.5 year old plot. **Iridomyrmex darwinianus** and **Camponotus** sp. JDM 26 first appeared in the 3.5 year old plot. These were followed by **Tetramorium** sp. 6 (ANIC), **Melophorus** sp. 1 (ANIC), and **Stigmacros** sp. JDM 375 which first appeared in the 4.5 year old plot. In the 5.5 year old plot **Tapinoma** sp. JDM 416 first appeared and **Monomorium** sp. 2 (ANIC) first appeared after 6.5 years of rehabilitation. After this period no new species colonised the rehabilitated areas.

The mean total number of ants in the rehabilitated plots was higher than in the controls. Ant richness in the control plots was higher than in the rehabilitated plots. The mean values were 14 and 10 respectively. Ant evenness was 20% higher in the control plots than in the rehabilitated areas. Figure 8 shows that ant richness and ant evenness were negatively correlated with soil inpenetrability and ant richness was positively correlated with percentage ground cover.

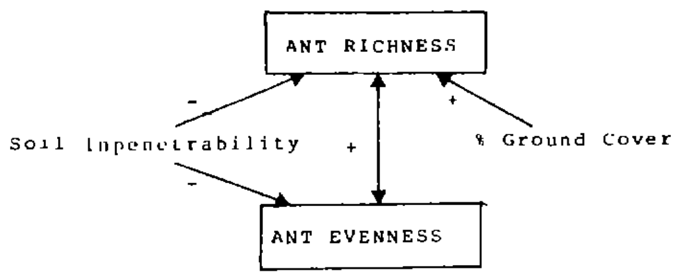

FIGURE 8. Diagram of the plot variables which were correlated ($p < 0.05$) with ant richness and ant evenness. The +/- marks indicate the signs of the correlations and the arrows point in the assumed direction of causality.

Figures 9 and 10 respectively show the relationship between ant richness and ant evenness with time. Ant richness increased with time up to 9 years since rehabilitation and then declined. Richness values indicate that the control plots had more species than the rehabilitated areas. No time-associated trend is seen in Figure 10. Figure 11 shows the positive correlations between ants and invertebrates collected by tree beats. These ant variables were not correlated with those for other invertebrates derived from the pitfall traps or vegetation sweep samples.

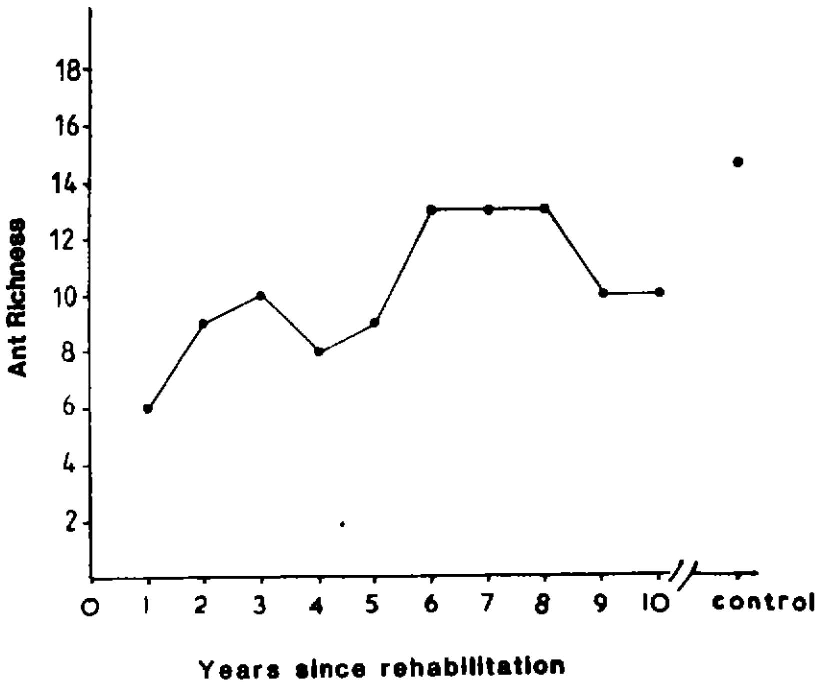

FIGURE 9. Diagram showing the relationship between ant richness and age of rehabilitation.

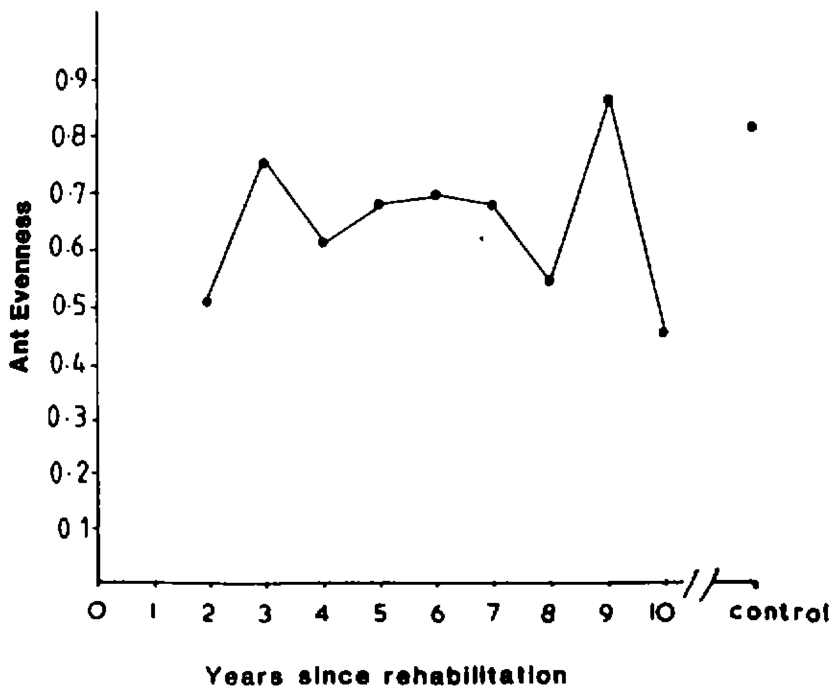

FIGURE 10. Diagram showing the relationship between ant evenness and age of rehabilitation.

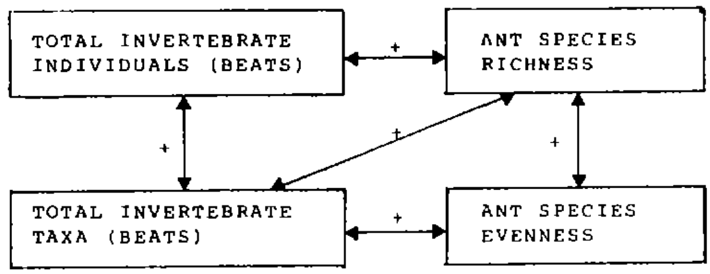

FIGURE 11. Diagram showing the correlation ($p < 0.05$) between ant species richness and evenness and invertebrates obtained with the tree beats. The + marks indicate that the signs of the correlation were positive and the arrows point in the assumed direction of causality.

Discussion

Rehabilitation technology at Collie has changed over the 10 years represented by the plots used in this study. The older plots were sown with cover crops and planted with trees and shrubs while the more recent plots were sown with mixtures of native plants. There have also been improvements in soil handling techniques and pit or dump contouring. For instance, deep ripping of the rehabilitated area substrate was introduced in 1977-1978. Consequently, some of the time-trends in physical or biological parameters which were observed in this study may be associated with the rehabilitation procedure rather than the age of the rehabilitation. Caution should therefore be exercised in interpreting the data although a number of general conclusions may be made.

This study has revealed that coal mining at Collie affects the soil, vegetation and invertebrate fauna. For instance, the values for soil inpenetrability and soil bulk density in the rehabilitated plots were higher than those observed in the control plots. This was probably caused by the way the soil was replaced, the heavy machinery driving over the plot when spreading the top-soil and by the lack of roots and soil animals which break up the soil. The relationship between soil inpenetrability and age of the rehabilitated areas may have been associated with the introduction of deep ripping in the younger plots or to some chemical bonding of the soil particles taking place over time. The rehabilitated plots also have appreciably more bare ground and less litter depth than the controls. This is because the vegetation has not had enough time to recolonise the rehabilitated areas although litter depth significantly increased with the age of rehabilitation (Figure 1).

Ground cover, tree cover, plant cover density and plant species richness were less in the rehabilitated plots than in the controls (Table 1). This is also associated with the lack of time for vegetation to recolonise the area. Figure 1 shows that plant cover density was positively correlated with the age of rehabilitation, so an increase in plant cover density is expected over the next few years.

The changes in invertebrate fauna are associated with changes in soil and vegetation factors. Soil bulk density was negatively correlated with the total taxa obtained by pitfall trapping. Animals nesting or burrowing in the soil might find it difficult to penetrate a heavier soil. Percentage bare ground was also negatively correlated with the total invertebrate taxa obtained in pitfall traps. By contrast, the increasing amount of litter provided conditions for the invertebrates to recolonise the mined areas by providing refuges, food, and a buffer to the microclimate.

Table 3 indicates that Acarina and Collembola are well represented in the rehabilitated plots. A number of species in these orders are colonisers of disturbed areas. These findings reflect those obtained by a similar study (Majer et al. 1982) in mineral sand mines near Eneabba, Western Australia. Majer et al. (1982) found that the control mean of small soil animals was 5268 animals per square meter but was approached or exceeded in a number of rehabilitated areas due to the abundance of Acarina or Collembola.

Figure 4 shows the correlation between the amount of deadwood and total invertebrate taxa obtained in pitfall traps. The presence of logs and small pieces of wood enhance the presence of invertebrates as they provide shelter for various groups.

Soil, litter and vegetation parameters also affected the number of invertebrates and number of taxa obtained in the sweeps (Figure 5). Soil bulk density and percentage bare ground both had a negative effect on the invertebrates obtained in the sweeps. These variables may have indirectly acted on the number of invertebrates by their association with vegetation parameters. There is a tendency for sweep-associated fauna to show similar trends to ground fauna. This may be because some of the same species of invertebrates may live on the ground and on vegetation or because both groups reflect the same changes in the rehabilitated areas.

Figure 6 shows the relationship between total invertebrates and total invertebrate taxa obtained in tree beats. Total invertebrate taxa was negatively correlated with the age of rehabilitation. This was probably due to the low number of trees present in the older plots, itself a result of changed rehabilitation technology.

The ant fauna of the rehabilitated plots differed from that of the controls. Some species were confined to the rehabilitated plots, whereas others were only found in the controls (Table 6). **Iridomyrmex** sp. 21 (ANIC) was the first species to recolonise the mined areas and is most numerous in the rehabilitated plots. Generally more ants were found in the rehabilitated areas than in the controls, but species richness was smaller. This may be associated with the rehabilitated areas having a high productivity and high seed and nectar output while exhibiting a lower habitat heterogeneity than the original forest. Figure 8 shows that ant richness was enhanced by percentage ground cover but was limited by high soil inpenetrability values. There was a time-associated trend with ant richness, as shown in Figure 9. A maximum of 13 species was obtained after 6 years of rehabilitation. Ant richness became less after 9 years of rehabilitation. This may be due to the different methods of rehabilitation employed in that year.

Ant richness data obtained in Collie may be compared with data from earlier studies performed by Majer et al. (1982), Majer et al. (1984), Fox and Fox (1982), Majer (1984b) and Majer (1984c). These studies compared the rate of ant colonisation with annual average rainfall in the area and are summarised in Majer (1984a).

The linear regression line fitted to recolonisation data shown in Figure 9 was not significant. The 2 oldest areas experienced vastly different rehabilitation procedures. For instance, deep ripping was not performed on their soils. If these were excluded from the analysis a statistically significant line could be fitted. This line gave an estimate of 8 ant species present after 3 years of rehabilitation.

In view of the fact that Collie has a mean annual rainfall of 973mm, but had dropped to 816mm during the 1975-85 period of rehabilitation, it appears that the rate of ant recolonisation at Collie is in line with that in other areas. For instance, Eneabba, Western Australia, has an average annual rainfall of 550mm and 6 species had returned after 3 years (Majer et al. 1982). Jarrahdale/Del Park, W.A., has an average annual rainfall of 1155-1287mm and 10 species had returned (Majer et al. 1984). Myall lakes, N.S.W. has an average annual rainfall of 1205-1362mm and 11 species had returned after 3 years (Fox and Fox, 1982). Nth Stradbroke Island, Qld., has a sub-tropical climate with 1645mm rainfall and 18 species had returned (Majer, 1984b). Gove, N.T., Groote Eylandt, N.T., and Weipa, Qld. had a tropical monsoon climate with 1277-2083mm and 22 species of ants had recolonised the mined areas (Majer 1984c).

Data from the present, and other, rehabilitation studies indicate that although rehabilitation technique influences the rate of return of ants, type of climate also plays an important regulatory role. In view of the fact that the development of the ant fauna tends to reflect the development of other components of the fauna (Figure 11) and vegetation (Majer 1983), these findings suggest that restoration of the ecosystem at Collie may take a longer time than Western Australian bauxite mines, but may be more rapid than in the Eneabba sand mines. The rainfall in Collie over the last 10 years has been below the average of 973mm. This provides harsher conditions for plants to recolonise the rehabilitated areas but fauna recolonisation might have been more rapid if the rainfall had been higher.

Because of the prevailing dry conditions it is predicted that it will take a long time for the mined areas to approach their original forest-like structure and function. The information in the present report should prove useful when designing future rehabilitation prescriptions for use at places such as Collie and elsewhere.

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TABLE 1: Mean values of physical and vegetation variables collected in 10 quadrats in the 10 rehabilitated plots and 2 forest controls.

Variable	AGE OF REHABILITATION (YEARS)										Controls	
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Riparian	Upland
Soil Penetrability (kPa)	2035	2143	3038	1536	4654	4647	5720	5033	4727	7095	2084	2424
Soil Bulk Density (g cm^{-3})	1.58	1.69	1.56	1.61	1.57	1.54	1.60	1.04	1.49	1.63	0.94	1.03
Soil Moisture (%)	3.0	3.4	1.1	2.5	1.5	2.2	3.6	7.0	1.0	3.9	12.2	4.4
Bare Ground (%)	96	95	95	92	95	69	69	54	54	97	0.2	0.9
Litter Cover (%)	1	2	3	8	3	20	23	42	31	3	98	98
Litter Depth (mm)	2	2	2	5	3	5	6	10	10	4	12	16
Litter Index (mm x %)	2	4	6	40	9	100	138	420	310	12	1176	1568
Deadwood (< 15 cm) (nos)	16	14	12	10	5	15	20	14	18	9	26	36
Deadwood (> 15 cm) (nos)	1	3	0	1	0	3	6	5	4	2	19	26
Ground Cover (Quadrats) (%)	0.1	7	13	8	9	8	12	65	40	3.9	24	10
Ground Cover (Levy rod) (%)	14	32	50	32	24	34	36	18	44	16	82	62
Tree Cover (Quadrat) (%)	0	0	0	0	0	0	4	7	0	4	38	26
Tree Cover (Levy rod) (%)	0	0	0	0	0	4	4	2	0	6	48	44
Plant Cover Density	1.3	3.7	1.7	3.6	3.5	5.3	5.2	4.6	5.8	3.6	8.2	5.3
Plant Cover Density (0-25cm)	1.3	1.3	1.8	2	3.3	3.3	5.2	1.8	4.1	2	2.7	3
Plant Cover Density (25-50cm)	0	2.6	1.4	1.3	2	3.3	2.1	2.8	4.8	3.5	2.2	3.4
Plant Cover Density (50-75cm)	0	4.7	2.1	1.8	1	3	1.1	1.5	3.8	2.0	2.3	2
Plant Cover Density (75-100cm)	0	3.1	1.9	2.8	4	3.4	4	3	0	1	2.2	0
Plant Cover Density (100-125cm)	0	1	1.4	3.8	3	2	3	4	2	1	1.8	0
Plant Cover Density (125-150cm)	0	0	1.3	1.3	1.5	3.5	2	1	3	1	3.8	1
Plant Cover Density (150-175cm)	0	2	2	1.5	2	2.5	0	3	0	2.5	5.4	3
Plant Cover Density (175-200cm)	0	0	1.5	0	0	2	3.5	1.5	0	2	10.4	2
Plant Species Richness (all spp.)	7	18	27	17	25	33	25	15	23	20	34	23
Plant Species Richness (native spp.)	5	14	25	13	20	29	21	7	19	14	30	23
Plant Species Richness (weeds)	2	4	2	4	5	4	4	8	4	6	4	0
Plant Species Evenness (all spp.)	0.81	0.22	0.30	0.41	0.51	0.46	0.39	0.69	0.42	0.40	0.67	0.62
Plant Species Evenness (native spp.)	0.79	0.16	0.18	0.32	0.23	0.24	0.32	0.55	0.23	0.12	0.67	0.62

TABLE 2. Listing of plant species found in the study, arranged according to age of rehabilitated area in which they first occurred.

SPECIES	CODE	AGE OF REHABILITATION (YEARS) 0	1	2	3	4	5	6	7	8	9	10	CONTROL
Acacia sp. seedling	A12	—	—	—	—	—	—	—	—	—	—	—	
Albizia lophantha	A16	—	—	—	—						—	—	
Gompholobium marginatum	A32	—	—				—	—	—	—	—		
Hypochoeris radicata	A10	—	—	—	—	—	—	—	—	—	—	—	—
Lepidosperma gracile	A17	—	—								—	—	—
Scirpus antarcticus	A8	—	—	—	—	—	—	—	—	—	—	—	
Synaphea petiolaris	B3	—	—		—	—	—	—	—				
Acacia lateriticola	A20		—	—			—	—			—	—	
Acacia celastrifolia	B35		—	—	—								
Acacia extensa	A5		—	—	—	—	—	—	—	—	—	—	—
Acacia pulchella	B1		—	—	—		—	—					
Acacia saligna	A25		—	—		—	—	—					
Asteraceae sp. 1	B30		—	—									
Eriostemon spicatus	B36		—	—	—	—	—	—					
Eucalyptus calophylla	B31		—	—									—
Juncus pallidus	A23		—	—	—	—	—	—	—		—	—	
Kennedia coccinea	B28		—	—	—	—	—						
Kennedia prostrata	A39		—	—	—	—	—	—	—	—	—		—
Stylidium sp. 1	B37		—	—									
Trachymene pilosa	A22		—	—	—			—	—	—	—	—	
Ursinia anthemoides	A6		—	—	—	—	—		—	—	—	—	—
Allocasuarina fraseriana	B45			—	—	—	—						—
Bossiaea eriocarpa	B18			—	—	—					—	—	
Cyperaceae sp. 1	A49			—	—		—	—		—	—		
Drosera sp. 1	B15			—	—	—	—	—	—	—	—		—
Eucalyptus patens	B9			—	—			—	—	—			
Eucalyptus rudis	B23			—	—		—	—	—	—			
Eucalyptus wandoo	C8			—	—								
Gompholobium shuttleworthii	C11			—	—								
Hakea undulata	B47			—	—	—	—						
Hibbertia glaberrima	C3			—	—								
Hibbertia rhadinipoda	C9			—	—	—	—			—	—	—	—
Liliaceae sp. 1	C6			—	—								
Lomandra sp. 1	A28			—	—	—	—	—	—	—	—		—
Loxyocarya sp. 1	A26			—	—		—	—	—	—	—		—
Asteraceae sp. 2	A9				—	—				—	—		
Daviesia decurrens	B38				—	—							—
Leptomeria preissiana	B10				—	—		—	—				
Leptocarpus tenax					—	—	—						
Acacia decurrens	A19					—	—				—	—	
Arctotheca calendula	B22					—	—		—	—			

SPECIES	CODE
Drosera erythrorrhiza	A36
Erodium sp. 1	C1
Hibbertia stellaris	B43
Liliaceae sp. 2	A42
Melilothus sp. 1	B20
Romulea rosea	A40
Asteraceae sp. 3	A31
Astartea sp. 1	A44
Poaceae sp. 1	A30
Conostylis sp. 1	B2
Cyathochaete avenaceae	A38
Hemiandra pungens	A45
Jacksonia furcellata	A47
Lepidosperma longitudinale	A27
Leucopogon sp. 1	A34
Liliaceae sp. 3	A48
Patersonia occidentalis	A33
Phlebocarya ciliata	A46
Poaceae sp. 2	A2
Poaceae sp. 3	A4
Lasmannia sp. 1	A35
Baeckea camphorosmae	B5
Dampiera linearis	B4
Dampiera sp. 1	B12
Eucalyptus cladocalyx	B27
Liliaceae sp. 4	B25
Scirpus sp. 1	B26
Oleraceus? sp. 1	B24
Ptilotus sp. 1	B14
Thysanotus sp. 1	B21
Acacia baileyana	A14
Acacia podalyriifolia	A21
Bossiaea aquifolium	A13
Xanthosia sp. 1	A1
Eucalyptus resinifera	A15
Acacia wildenowiana	D9
Podolepis gracilis	D12
Sonchus sp. 1	D13
Banksia grandis	
Boronia fastigiata	D8
Bossia ornata	
Brachysema praemorsum	D10
Eucalyptus marginata	
Stylidium sp. 2	D4
Orchidaceae sp. 1	D11
Persoonia longifolia	
Stylidium piliferum	D2
Thomasia angustifolia	D6
Xanthorrhoea preissii	

TABLE 3: Mean number of invertebrates collected by pitfall trapping (n = 10) in the 10 rehabilitated plots and 2 forest controls.

TAXON	AGE OF REHABILITATION (YEARS)										UNMINED FOREST	
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Riparian	Upland
Arachnida - Pseudoscorpionida								0.2			0.1	
- Acarina		16.1	5.7	11.4	14.2	15.1	0.6	1.3		0.5	3.2	2.7
- Araneae	1.5	1.3	1.8	1.0	1.3	1.7	2.5	2.4	3.0	1.3	5.2	2.0
Crustacea - Isopoda											0.8	0.1
Chilopoda			0.2									0.2
Collembola	54.1	46.3	36.9	117.5	8.4	78.2	58.9	80.1	64.4	38.7	22.6	16.5
Insecta - Protura	0.1											
- Diplura			0.2	0.2						0.1	0.1	
- Blattodea							0.1					0.4
- Dermaptera	3.8	4.5	0.4	0.3			0.6	0.3	0.1		3.7	1.0
- Tettigonioidea							0.1					0.1
- Grylloidea		1.1	0.1	0.2		0.1			0.2	0.1		0.3
- Caelifera												0.1
- Psocoptera										0.2		
- Homoptera	0.8	0.5	0.5	0.2	0.1	0.5	0.3	0.4	1.0	0.5	3.1	0.3
- Heteroptera	0.1		0.2			0.1	0.1				0.1	0.1
- Thysanoptera										0.1		
- Neuroptera-larvae	0.1			0.1								
- Staphylinidae	0.4	0.4		0.7			0.1	0.6	0.1	0.2	1.3	0.8
- Curculionoidea		0.4	2.1	0.8	0.8	0.3		0.2				0.8
- Carabidoidea	4.7	2.0	2.8	0.3	0.3	0.1	0.4	0.5	0.2	0.6	1.0	1.2
- Scarabaeoidea	2.0	0.5	0.4	0.5	0.3	0.3	1.0	0.3	0.3	0.2	0.5	0.8
- Coleoptera-larvae				0.2					0.3		0.6	0.1
- Coleoptera-others					0.1							
- Mecoptera					0.2						0.1	
- Lepidoptera-adults							0.1	0.2		0.1		0.1
- Diptera-adults	47.1	4.8	4.9	5.3	1.3	4.2	4.8	7.4	2.3	2.2	28.1	6.1
- Hymenoptera-ants	0.5	28.8	43.4	32.8	31.2	48.3	29.3	56.8	26.3	45.3	16.4	21.8
- Hymenoptera-others	0.1	0.2	0.3	0.2	0.1		0.1	0.1	0.2		3.2	
Total invertebrates	115.3	106.9	99.9	171.7	58.3	148.9	99.0	150.8	98.4	90.1	90.1	55.5
Total Taxa	13	13	15	16	12	11	15	14	12	14	17	20

TABLE 4: Total number of invertebrates collected by vegetation sweeping (n = 10) in the 10 rehabilitated plots and 2 forest controls.

TAXON		AGE OF REHABILITATION (YEARS)										UNMINED FOREST	
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Riparian	Upland
Arachnida	- Acarina											2	2
	- Araneae	6	14	40	12	29	7	8	16	36	14	26	29
Collembola												3	3
Insecta	- Blattodea									1			2
	- Mantodea			1				1					
	- Gryllacridoidea						2						
	- Tettigoniodea				1								1
	- Grylloidea	1	1										2
	- Caelifera		1				2					1	1
	- Psocoptera											6	2
	- Homoptera	5	2	4	1	1	1	1			1		14
	- Heteroptera	12		1			4	1	4	4	1	6	7
	- Neuroptera-larvae						1						
	- Curculionoidea				1	1			1	1			8
	- Scarabidoidea			1									
	- Coleoptera-larvae											3	1
	- Coleoptera-others	2	2	2	1	3	4			1	3	7	3
	- Lepidoptera-adults			2								1	
	- Lepidoptera-larvae		1		1		1	1		8	3	2	3
	- Diptera	1	1	4		1		1	1			4	3
	- Hymenoptera			4		1	1			3		1	
Total invertebrates		27	22	56	17	36	23	13	22	54	22	62	81
Total taxa		6	7	9	6	6	9	6	4	7	5	12	15

TABLE 5: Total number of invertebrates collected by tree beating (n = 5) in the 10 rehabilitated plots and 2 forest controls.

TAXON		AGE OF REHABILITATION (YEARS)										UNMINED FOREST	
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Riparian	Upland
Arachnida	- Acarina						1					1	3
	- Araneae			7	4	11	12	6	12	3	8	12	4
Collembola								1					1
Insecta	- Psocoptera						2	1		1			4
	- Strepsitera-larvae							7					1
	- Homoptera			1			1				12		2
	- Heteroptera					1	10					4	1
	- Curculionoidea							1					1
	- Scarabeadoidea				1								
	- Coleoptera-others			4	1	2	20	3	3	4	1	5	1
	- Lepidoptera-adults								1				
	- Lepidoptera-larvae					5			1		1		1
	- Hymenoptera												1
Total invertebrates		0	0	12	6	19	46	19	17	8	22	22	20
Total taxa		0	0	3	3	4	6	6	4	3	4	4	11

TABLE 6. Mean number of ants collected by pitfall trapping (n = 10) or collected by other methods (*) in the 10 rehabilitated plots and 2 forest controls.

GENERA		AGE OF REHABILITATION (YEARS)										UNMINED FOREST	
		0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	Riparian	Upland
Dolichoderinae	Iridomyrmex conifer												0.4
	Iridomyrmex darwinianus				0.4		0.1	0.1	1.4		2.2	2.6	
	Iridomyrmex glaber										*		
	Iridomyrmex purpureus	*	9.6	6.4	0.7	3.9	3.0	0.7	36.1	0.8		2.6	
	Iridomyrmex sp. 21 (ANIC)	0.5	17.5	14.0	19.7	14.1	16.1	12.1	4.3	8.0	35.0	0.3	6.1
	Iridomyrmex sp. JDM 8		0.2	0.6	5.9	0.1	7.8				*		
	Iridomyrmex sp. JDM 9											2.8	0.8
	Diceratoclinea sp. JDM 211												*
	Tapinoma sp. JDM 416						0.4	0.3	0.1	1.5		*	
	Iridomyrmex sp. JDM 433			*			*						
Formicinae	Notoncus gilberti												2.9
	Melophorus sp.1(ANIC)	*				3.3	3.7	1.9	5.0	5.2	0.9	0.1	
	Camponotus sp. JDM 26		*	*	0.4		0.1	2.8	*	*	*		
	Camponotus sp. JDM 106		*		*			*	0.2				
	Camponotus sp. JDM 182												1.4
	Camponotus sp. JDM 199	*	0.8	11.0	4.0	3.3	11.7	3.6	1.1	5.3	1.5	0.2	
	Camponotus sp. JDM 287											*	
	Polyrachis sp. JDM 372												*
	Stigmacros sp. JDM 375					0.2	0.5	0.3					
Myrmicinae	Cardiocondyla nuda	*	*	9.5		0.3	0.3	0.2					
	Pheidole sp. JDM 44			0.1			0.1	1.0	2.9	2.2	0.1	2.3	
	Monomorium sp. 1 (ANIC)											4.4	4.4
	Monomorium sp. 2 (ANIC)							0.3	0.3	1.2	2.0	0.9	3.0
	Tetramorium sp. 6 (ANIC)			*		0.2			0.9	1.4			*
	Meranoplus sp. 12 (ANIC)												*
	Chelaner sp. JDM 626											0.1	
Ponerinae	Heteroponera imbellis												0.5
	Rhytidoponera inornata	*	0.6	1.7	1.6	5.8	4.5	8.8	4.6	1.8	4.0	0.2	0.3
	Rhytidoponera violacea		0.1						0.9				2.3
Total ants		0.5	28.8	43.3	32.6	31.2	48.3	34.1	57.8	27.4	45.7	16.7	22.1
Richness		6	9	10	8	9	13	13	13	10	10	14	13
Evenness (J')		-	0.504	0.786	0.621	0.698	0.705	0.692	0.565	0.876	0.464	0.786	0.852