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RECOLONIZATION BY ANTS IN BAUXITE MINES REHABILITATED BY A NUMBER OF DIFFERENT METHODS

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SUMMARY

(1) The ant fauna of thirty bauxite mines rehabilitated by a range of different methods and three forest controls was surveyed in the summer of 1978–79. Physical and botanical parameters were also measured.

(2) Forty-two species of ants were found in the rehabilitated areas although many of the original forest species were not yet present.

(3) Eight ant community parameters were initially screened by canonical analysis. Ant species diversity (H') and ant species richness were found to be the most useful measures for relating to mined area parameters.

(4) Multiple regression analysis using ant species richness and species diversity as dependent variables revealed that ant return was positively associated with plant species richness and diversity, time since rehabilitation, percentage plant cover and percentage litter cover. Presence of large logs was also an important factor.

(5) Principal components oridination analysis of the data suggests that plant species richness, and diversity, rehabilitation age and percentage litter cover also influence the species composition of the ant community in rehabilitated areas.

(6) The relevance of the findings to the improvement of rehabilitation practices is discussed.

INTRODUCTION

Knowledge of the return of invertebrates to rehabilitated mined areas is important in view of their role in soil aeration and drainage (Lee & Wood 1977), litter decomposition and nutrient cycling (Springett 1976), pollination (Faegri & van der Pijl 1971), seed distribution and survival (Berg 1975), plant predation (Whelan & Main 1979) and also in the provision of food for insectivorous vertebrates. It is probable that the developing ecosystem will not reach a sustainable state unless the appropriate invertebrate fauna recolonizes the mined areas.

Description of bauxite mine rehabilitation

Bauxite is currently being mined at two Jarrah (*Eucalyptus marginata*) forest localities in Western Australia. These are Jarrahdale and Del Park, approximately 45 and 90 km S.S.E. of Perth, respectively.

The present (1980) mining rehabilitation programme involves the following. Before mining commences, forest is cleared from the area to be mined following definition of ore bodies. The topsoil, the seed containing component of the soil profile, is first stripped off, followed then by the overburden above the caprock. The overburden is stockpiled while the topsoil is utilized as soon as possible. After soil removal the caprock is blasted and the ore

is removed down to the pallid zone of the original laterite profile which, on average, is 4–5 m beneath. The stockpiled overburden followed by the topsoil is then replaced. The area is then contour ripped to a depth of 1·75 m to loosen the compacted pallid zone, enhance root penetration and aid in soil erosion control (Tacey & Glossop 1980). Trees are then planted, the pit is seeded (1 kg ha^{-1}) and fertilizer is applied (200 g mono ammonium phosphate each tree, 425 kg ha^{-1} superphosphate broadcast).

Invertebrate monitoring in rehabilitated bauxite mines

Majer (1978a) has continuously monitored the epigaeic invertebrate fauna of three mined areas for a 3-year period following initial rehabilitation in mid-1976. One mined area had no vegetation returned, one was planted with Marri (*Eucalyptus calophylla*) and the other was seeded with mixed native plants. Ants were scored as species, while other invertebrates were recorded at the order or family level. The study revealed that there was a graduation in the order of unplanted, planted to seeded plot in terms of increased plant area cover, plant species richness, total invertebrate numbers, total ant individuals, and ant species richness. A calculated index of similarity of ant species composition showed that the seeded plot supported a fauna most similar to that of the original forest.

The study reported here is an extensive short-term study of thirty rehabilitated bauxite mines of different ages and treated by a range of revegetation methods. The aim is to elucidate the extent of ant return and the relative contribution of mined area environmental parameters to the degree of ant recolonization.

Ants contain species which derive nutrition from nectar (Way 1963), seeds (Berg 1975), carrion or invertebrates (Sudd 1967), and many have specialized feeding, nesting or foraging habits. It is possible that monitoring of this extremely prominent and diverse forest taxon (Wilson 1971) may provide a general index of the invertebrate fauna and several other aspects of the environment. For instance, the species richness of ants in the mined areas used in this study was correlated ($P < 0{\cdot}05$) with termite and springtail species richness (data from S. Bunn and P. Greenslade, pers. comm.) in the same areas.

Although all invertebrates present in the mined areas were sampled, only ants are discussed here. A long-term aim of the study is to identify other taxa to species level and to assess the relevance of the findings, based on the ant fauna, to these taxa.

METHODS

Plot descriptions

Twenty-three rehabilitated plots and two forest controls were selected at Jarrahdale, and seven mined plots and one control at Del Park. Previous surveys have shown no detectable difference in the forest ant fauna at the two localities (J. D. Majer, unpublished data). The mine plots had mostly been ripped, topsoiled with stored overburden, and planted at different times with either *Pinus pinaster* or a range of *Eucalyptus* spp. (Table 1).

Certain plots were selected to show the effects of variations in the original rehabilitation pattern. For instance, plot 19 was cleared of vegetation although mining was never performed; thus, rehabilitation with *P. pinaster* was carried out on the original soil profile. Plot 27 was treated with fresh, unstored, topsoil before being planted with *E. globulus*. Plot 20 was seeded with mixed native plants at the same time that *E. calophylla* and *E. resinifera* were planted. The *E. calophylla* and *E. wandoo* seedlings were accompanied by a straw-bitumen mulch at the time of planting in plot 22, while the double stripped topsoil treatment, described in the introduction, was utilized in plot 23 which was then planted

TABLE 1. Location of, and brief description of revegetation method performed in, study plots listed by rehabilitation method

Plot no.	Principle species used for rehabilitation	Year of rehabilitation	Location of plot	Method of revegetation	Features of particular interest to this study
1.	*Pinus pinaster*	1966	Jarrahdale	planted	—
2.	*P. pinaster*	1970	Jarrahdale	planted	—
19.	*P. pinaster*	1969	Jarrahdale	planted	Area cleared but not mined so revegetation on original soil
17.	Mixed *Pinus* spp.	1969	Jarrahdale	planted	—
3.	*Eucalyptus maculata*	1966	Jarrahdale	planted	—
4.	*E. maculata*	1970	Jarrahdale	planted	—
5.	*E. maculata*	1971	Jarrahdale	planted	—
6.	*E. maculata*	1976	Del Park	planted	—
7.	*E. saligna*	1966	Jarrahdale	planted	—
8.	*E. saligna*	1969	Jarrahdale	planted	—
9.	*E. wandoo*	1969	Jarrahdale	planted	—
10.	*E. resinifera*	1970	Jarrahdale	planted	—
11.	*E. resinifera*	1973	Jarrahdale	planted	—
32.	*E. resinifera*	1973	Jarrahdale	planted	—
28.	*E. resinifera*	1973	Del Park	planted	—
12.	*E. resinifera*	1974	Jarrahdale	planted	—
13.	*E. resinifera*	1974	Del Park	planted	—
14.	*E. globulus*	1969	Jarrahdale	planted	—
27.	*E. globulus*	1974	Del Park	planted	Fresh topsoil was used here
15.	*E. calophylla*	1973	Del Park	planted	—
16.	*E. calophylla*	1975	Jarrahdale	planted	—
25.	*E. mullerana*	1968	Jarrahdale	planted	—
18.	Mixed *Eucalyptus* spp.	1970	Jarrahdale	planted	—
24.	Mixed *Eucalyptus* spp.	1976	Del Park	planted	—
33.	Mixed *Eucalyptus* spp.	1973	Jarrahdale	planted	—
20.	*E. calophylla* & *E. resinifera*	1976	Jarrahdale	seeded	Considerable understorey diversity induced by variety of seeds
22.	*E. calophylla* & *E. wandoo*	1977	Jarrahdale	planted	Area was mulched with bituminized straw
23.	*E. calophylla*	1975	Jarrahdale	planted	Double stripped topsoil used here
21.	Subterranean clover	1976	Jarrahdale	seeded	Area appears like a pasture
26.	No revegetation	1978	Del Park	—	—
F1	Forest control	—	Jarrahdale	—	—
F2	Forest control	—	Jarrahdale	—	—
F3	Forest control	—	Del Park	—	—

with *E. calophylla*. Plot 21 was an experimental treatment in which clover seed was applied to produce a pasture-like growth. No vegetation had appeared by December 1978 in plot 26 although it had been double stripped and seeded in late 1978. This plot was selected to represent the unvegetated condition.

The type and age of rehabilitation used in each plot is shown in Table 1. The mean, standard deviation and range of pit size, time since clearing and rehabilitation, ripping depth, type of fertilizer treatment and tree thinning treatment for the plots are shown in Table 2.

Generally speaking, only one plot representing a particular rehabilitation treatment was available for each revegetation date. To enable replication, each plot was halved. A 100-m transect was marked out in each half to provide the basis of most subsequent samples and recordings. Only one transect was established in plot 33.

All field work was performed between December 1978 and February 1979. This was the summer period which, with the exception of the first week of sampling, was devoid of appreciable rainfall. Seasonal trends resulting from different sampling times of plots were not considered to be large.

TABLE 2. Listing of rehabilitation treatment, physical and plant measurements used in the statistical analyses. The variable codes, mean, variance and range are given (forest controls excluded). The last column shows the variable range for the forest controls

Variable name	Variable code	Mean	S.D.	Range of variables in mined areas	Range of variables in forest controls
Pit size (ha)	SIZE 1	8·9	12·7	0·4–43·1	N.A.
Years since clearing	TIME 1	8·5	4·9	3–17	N.A.
Years since rehabilitation	TIME 2	7·0	3·5	0–13	N.A.
Ripping depth (m)	RIP	0·8	0·7	0–1·8	N.A.
Whether spot fertilized	RE 4	—	—	Yes/No	N.A.
Whether re-fertilized	RE 5	—	—	Yes/No	N.A.
Whether trees thinned	RE 6	—	—	Yes/No	N.A.
Reduction in soil temperature at 5 cm (°C)	AT 1	4·1	3·1	0–10·9	6·5–16·1
Reduction in air temperature at 5 cm (°C)	AT 2	0·5	0·8	0–3·7	0–0
Reduction in air temperature at 2 m (°C)	AT 3	0·4	0·7	0–2·9	0–0·1
Increase in % relative humidity at 2 m	AT 4	1·2	1·5	0–6·4	0–3·5
Reduction in light intensity (eV)	AT 5	0·7	0·9	0–5·0	0–1·8
Reduction in % soil moisture	S 2	3·7	1·2	1·6–6·3	5·4–8·4
Soil hardness (hits 15 cm^{-1})	S 1	3·8	1·8	1·2–8·9	1·2–2·3
Deadwood (1–9·9 cm diameter)	LOG 1	28·5	12·2	8–50	13–48
Deadwood (10–29·9 cm diameter)	LOG 2	6·4	3·8	0–16	9–14
Deadwood (>30 cm diameter)	LOG 3	0·5	0·9	0–4	5–8
Deadwood (all sizes)	LOG 4	35·4	15·2	8–64	28–67
Litter depth (cm)	GRC 1	0·9	0·9	0–3·9	1·5–2·8
Litter cover (%)	GRC 2	30·4	21·8	0–99	73–96
Plant cover (quadrat method) (%)	GRC 3	16·1	15·0	0–64	39–49
Tree canopy cover (%)	C 1	28·1	19·4	0–75	52–81
Plant cover (Levy rod method) (%)	C 2	45·2	22·7	0–99	70–94
Plant cover density (total)	C 3	4·9	4·0	0–17·2	2·6–8·1
Plant cover density (0–24·9 cm)	C 4	1·2	0·9	0–3·7	1·2–1·7
Plant cover density (25–49·9 cm)	C 5	0·6	0·6	0–2·2	0·4–1·0
Plant cover density (50–74·9 cm)	C 6	0·5	0·6	0–2·2	0–0·6
Plant cover density (75–99·9 cm)	C 7	0·5	0·6	0–2·3	0–0·6
Plant cover density (100–124·9 cm)	C 8	0·4	0·5	0–2·3	0–0·6
Plant cover density (125–149·9 cm)	C 9	0·4	0·6	0–2·5	0–0·5
Plant cover density (150–174·9 cm)	C 10	0·5	0·7	0–2·7	0–0·4
Plant cover density (175–199·9 cm)	C 11	0·4	0·6	0–2·6	0–1·7
Plant cover density (>200 cm)	C 12	0·5	0·3	0–1·0	0·6–0·8
Transect plant species richness	PL 3	17·0	6·8	0–22	20–38
Transect plant species diversity	PL 1	0·70	0·29	0–1·11	0·97–1·23
Plot plant species diversity	PL 2	0·80	0·27	0–1·14	1·19–1·32
Plot plant species equitability	PL 4	0·66	0·21	0·22–0·96	0·80–0·83

Physical factors

At equal distances along each transect, ten recordings were made of soil temperature (5 cm depth) and air temperature (5 cm and 2 cm above ground) using a telethermometer. At each of the ten intercepts relative humidity, using a sling hygrometer held at 2 m above ground, and incident light intensity, using a Lunasix® electronic light meter with light integrator cone in position and held vertically at 2 m above ground, were also recorded. Five soil cores (10 cm deep) were taken at 20-m intervals and sealed in tins for subsequent percentage moisture determination. All meteorological recordings were taken between 07.00 and 08.00 hours, repeated between 12.00 and 13.00 hours and the average taken.

Simultaneous recordings of all the above-mentioned measurements were taken in adjacent tracks or clearings. After calculating the mean values for each set of recordings,

the open area means were subtracted from the plot transect means in order to express the data as the degree to which revegetation had buffered temperature, relative humidity, incident light and soil moisture. This method of data treatment also minimized the effect of changed weather conditions throughout the study period.

Soil hardness was measured at ten points on each transect using a penetrometer.

Vegetation survey

One metre square quadrats were established at 10-m intervals along each transect. Within each quadrat the depth and percentage of ground covered by litter and also the percentage plant cover density were recorded. The numbers of individual plants of each species occurring within the quadrats were also recorded. Percentage tree canopy density was measured above each quadrat using a hand-held densiometer.

The vegetation structure and density was further investigated using a 2-m rod, modified by Levy & Madden (1933), which was divided into 25-cm intervals. Fifty equidistant rod placings were made along each transect. The numbers of contacts of vegetation touching the rod at each 25-cm interval were counted, and records were made of incidence of tree canopy situated vertically above the rod. Various parameters were calculated from the resulting data. Percentage area cover of vegetation (trees and understorey) was obtained by calculating the percentage of the fifty recordings which touched any plant. Plant cover density, a measure of the thickness of vegetation in places where it occurred, was obtained by dividing the total number of plant contacts by the number of rod placings which resulted in any vegetation contact. This calculation was performed for the total length of the rod in order to obtain an overall measurement of cover density and, also, for each 25-cm interval in order to construct a vertical profile of cover density.

An assessment was also made of logs and other dead wood by counting the number of pieces within a 2-m wide strip adjacent to each transect. Wood was divided into three categories: 1–9·9 cm, 10–29·9 cm and >30 cm diameter. The items in each category were also summed to give a measure of total dead wood.

Ant survey

Four complementary sampling methods were utilized to survey the ant fauna. Forty pitfall traps, consisting of 18-mm interval diameter Pyrex® test tubes containing 5 ml of alcohol/glycerol (70/30 v/v), were installed along each transect. Traps were operated for 7-day periods. Further details of the design and performance characteristics of this trap are given in Greenslade (1973), Greenslade & Greenslade (1971) and Majer (1978b). Ants associated with vegetation were sampled by two methods. Herbs and shrubs were sampled by sweeping a 20-m long swathe of vegetation using a 30-cm diameter calico net. Ten trees along each transect were also sampled using a 0·42 m^2 beating tray to dislodge arboreal foraging species. Hand collections were also performed since all the above three techniques have inherent sampling limitations (Southwood 1966). Since some plots were small (Table 2), and of irregular shape, it was not convenient to collect separately from each half of the mined area. Therefore, collections were made over the entire plot for 2 man-hours during the morning and 2 man-hours at night.

Treatment of data

The transect means for all physical and vegetation recordings were calculated. Composition of vegetation was further examined by summing the plant species lists collected along each transect.

The sum of species along each transect is referred to as transect plant species richness (PL3). The diversity was also investigated using the Shannon and Weaver (1949) H' index. This is calculated by the following formula:

$$H' \text{ (decits)} = (N \log N - \sum_i ni \log ni)/N$$

where N = total number of individuals and ni = the importance value of the ith species. Pooled transect data were used for the calculation and the index is here termed plot plant diversity index (PL2). It was also calculated for the individual transects, although the combined value was considered to provide a more accurate representation of the plant community of each mined area. Plot plant diversity index was also used to calculate the plot plant equitability index (PL4). The equitability of the apportionment values among species in each plot is obtained by the following formula:

$$J' = H' \text{ (decits)}/\log S$$

where S is the total number of species in the population.

A checklist of ants for each transect was obtained by combining the collection data from the four sampling methods. The entire-plot hand collection data were used for each transect. Hand collections added few additional species to the transect ant lists so this action was unlikely to diminish the differences in ant species composition between transects. The total species obtained for each transect is referred to as ant species richness (ANT 2).

Only pitfall trap samples afforded quantitative data on abundance of individual species. Pitfall trap catches are not a faithful representation of species abundance since they are influenced by the relative activity of species (Southwood 1966). However, they were considered to provide an approximate representation of ant community composition, and accordingly the Shannon-Weaver diversity (ANT 6) and equitability (ANT 7) indices for the transect pitfall trap samples were calculated.

The analysis performed so far does not take into account which species were present in the various plots. Principal components analysis ordination was employed to investigate this aspect of the study. Each sample is defined by the particular species occurring within it. The composition of the fauna within these samples may be influenced by environmental factors. The ordination technique used here first compares the species content of the samples using Orloci's (1966) weighted similarity coefficient:

$$\text{WSC} = \sum_{i=1}^{n} (xij - \bar{x}i)(xih - \bar{x}i)$$

where xij, xih are the species scores for samples j and h, $\bar{x}i$ is the species score for the average stand and n is the number of samples. Then the samples are arranged along axes, termed components, so that the samples with the least similar species content occur farthest apart. The first component represents the combination of variables with maximum variance, subsequent components represent ones with lessening variance. The components may then be identified with environmental factors since it is these which contribute to the variation in species composition. The resulting ordination is therefore a valuable tool for investigating the relative influence of factors on fauna composition.

Computations were initially performed using species presence/absence data for each sample. Austin & Greig-Smith (1968) found this provided as much information as quantitative data. This form of information also minimized the influence of extremely

abundant species. A second computation was performed using the quantitative pitfall trap data for each transect although numerical data were standardized to unit variance in order to minimize the influence of abundant species. An attempt was then made to identify the components of the ordination by plotting factors associated with the samples on the ordination diagram and noting which factors correspond with the variation in sample positions along the axes.

RESULTS

Basic data

The mean, standard deviation and range of physical factors measured in the plots are shown in Table 2. With the exception of soil hardness (S1), all values are expressed as difference from unvegetated open areas. There were great variations between plots in the microclimate variables. In some cases a greater degree of microclimate buffering was observed in mined areas than in the forest control plots (e.g. air temperature at 5 cm (AT2) in plots 6, 8, 9 and 10, relative humidity (AT4) in plots 5, 8, 14 and 28 and light intensity (AT5) in plots 13, 18 and 20). This was probably associated with the high density of vegetation in the lower strata, a characteristic of recently rehabilitated mined areas.

The mean, standard deviation and range of vegetation recordings for each transect are also given in Table 2. Once again inter-plot variation in these parameters was great and few generalizations may be made. It is noteworthy that logs of the large size class (LOG3) were virtually absent in the mined area plots.

The checklist of ants, obtained by all four methods, is shown in Table 3. Many species are not named at the species level. In such cases they are either coded with Western Australian Institute of Technology (JDM) code numbers or, if voucher specimens are deposited there, with Australian National Insect Collections (ANIC) codes. Summary data for the ant fauna are provided in Table 4.

Data analysis

All mined area information, physical data means, vegetation data values (Table 2) and the eight ant variables (total species richness, total species from pitfall traps, total species from sweeps, total species from beats, total species from hand collections, total ant individuals per transect collected in pitfall traps, transect ant species diversity and transect ant species equitability), were entered on to a computer file. Except where mentioned, all computations were performed with the forest control plots excluded since, for many parameters, there was a large discrepancy between forest and mine values. The two transect values for each plot were treated separately in the analyses in order to provide a reflection and indication of within-plot variability.

The eight ant community parameters, described in the basic data section, were initially screened by canonical analysis using SPSS CANCORR (Nie *et al.* 1975). The thirty-seven variables shown in Table 2 were a priori grouped into eight sets which were considered to carry related information. For example, a set of nine variables pertaining to stratification of plant cover density was identified (C4–C12) and another set contained the plant species diversity parameters PL1–PL4. Each set of variables was considered with the set of eight ant variables, and linear combinations from each of the sets derived in such a way that the correlation between the two linear combinations was maximized.

In six out of the eight correlations performed, the variable ant species diversity (ANT6) produced the greatest canonical variate coefficient. Ant species richness (ANT2)

TABLE 3. Species of ants found in rehabilitated area plots arranged by the age of the rehabilitated area in which they first occurred. Species present in forest controls only are also shown

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Iridomyrmex sp. J D M 505	*Rhytidoponera inornata* *R. violacea* *Cardiocondyla nuda* *Camponotus* sp. J D M 105 *C.* sp. J D M 199 *C.* sp. J D M 287 *Iridomyrmex agilis* *I. purpureus* *I. conifer* *I. darwinianus* *I.* sp. J D M 200 *I* sp. J D M 506	*Brachyponera lutea* *Tetramorium* sp. 5 (ANIC) *Monomorium* sp. 2 (ANIC) *Melophorus* sp. 1 (ANIC) *M.* sp. J D M 221 *Iridomyrmex glaber* *I.* sp. J D M 172	*Myrmecia* sp. J D M 154 *Crematogaster* sp. J D M 42 *Monomorium* sp. 1 (ANIC) *Camponotus* sp. J D M 183 *C.* sp. J D M 213	*Trachymesopus rufonigra* *Pheidole latigena* *Melophorus* sp. 3 (ANIC) *Camponotus michaelseni* *C.* sp. J D M 104	*Myrmecia* sp. J D M 153 *Cerapachys* sp. J D M 205
Year 7/8	Year 9	Year 10	Year 11	Year 12/13	Only present in forest controls
Meranoplus sp. 12 (ANIC)	*Solenopsis* sp. J D M 34 *Stigmacros aemula* *Iridomyrmex* sp. 19 (ANIC)	*Crematogaster* sp. 3 (ANIC) *Podomyrma* sp. J D M 365 *Camponotus calcius* *C.*sp. J D M 110 *Diceratoclinea* sp. J D M 211		*Iridomyrmex* sp. J D M 373	*Myrmecia* sp. J D M 5 *Myrmecia* sp. J D M 38 *Leptogenys* sp. J D M 88 *Podomyrma* sp. J D M 504 *Iridomyrmex* sp. 18 (ANIC)

TABLE 4. Selected measurements of ant fauna sampled in study plots. The total ants, species diversity and species equitability data are based solely on pitfall trap samples. Richness values are based on total ants obtained by all sample methods

Plot no.	Total ants in pitfall traps (ANT8)		Species richness (ANT2)		Species diversity index (H') (ANT6)		Species equitability index (J') (ANT7)	
Transect no.	T1	T2	T1	T2	T1	T2	T1	T2
1	127	179	9	7	0·821	0·785	0·861	0·929
2	128	244	5	4	0·269	0·347	0·384	0·577
3	201	283	10	11	0·819	0·863	0·819	0·829
4	292	168	14	7	0·614	0·648	0·536	0·766
5	295	475	11	10	0·889	0·869	0·852	0·869
6	490	673	8	8	0·613	0·544	0·679	0·602
7	171	220	13	11	0·927	0·857	0·832	0·823
8	236	355	10	12	0·812	0·870	0·812	0·807
9	433	378	12	11	0·841	0·817	0·779	0·784
10	403	169	10	11	0·662	0·862	0·662	0·828
11	209	197	6	8	0·618	0·666	0·794	0·730
12	329	293	7	10	0·596	0·761	0·705	0·761
13	464	528	11	11	0·829	0·790	0·796	0·760
14	556	425	12	10	0·848	0·840	0·790	0·840
15	657	789	14	10	0·868	0·799	0·757	0·798
16	273	294	7	8	0·738	0·683	0·872	0·756
17	449	266	12	9	0·878	0·858	0·814	0·899
18	325	296	8	7	0·783	0·699	0·867	0·827
19	182	242	11	13	0·806	0·949	0·774	0·857
20	247	155	9	7	0·669	0·477	0·702	0·564
21	100	191	5	5	0·667	0·529	0·954	0·758
22	292	146	7	7	0·690	0·674	0·817	0·798
23	465	307	9	9	0·724	0·759	0·758	0·795
24	347	264	12	7	0·561	0·496	0·520	0·587
25	421	223	10	7	0·793	0·597	0·793	0·706
26	1	0	1	0	0·000	0·000	0·000	0·000
27	545	485	14	12	0·922	0·872	0·805	0·809
28	898	856	15	17	0·957	0·913	0·814	0·742
32	277	225	6	6	0·613	0·376	0·788	0·484
33	234	—	9	—	0·594	—	0·703	—
F1	111	148	7	10	0·725	0·763	0·858	0·763
F2	201	251	14	15	0·879	0·880	0·767	0·922
F3	359	192	18	13	1·047	0·713	0·833	0·747

produced the highest value in the other two correlations performed. These two parameters were therefore considered to be the most representative parameters of the ant community. The parameters, ant species richness (ANT2) and diversity (ANT6) are good complementary measures of the ant community. Species richness represents the total species obtained along the transect by all sampling methods. Species diversity is based on a slightly less complete census of the total species present although it provides information on the number of species (richness component) and also the degree of apportionment of individuals among the species in the area (equitability component). Subsequent analyses were therefore performed twice, using first richness and then diversity as the dependent variable.

A correlation matrix was calculated for all variables. From this, all variables significantly correlated with ant species richness and ant species diversity ($<0·01$ level) were extracted. All variables significantly associated with these were also noted. The only

significant negative correlations were ripping depth (RIP) with both ant parameters, and reduction in percentage soil moisture(S2) with ant species diversity.

Analysis of simple correlations provides some insight into the variables influencing the ant community although the inter-correlations between variables may suggest relationships which are in fact spurious or may mask the causal effects of other variables Stepwise regression analysis using SPSS REGRESSION (Nie *et al.* 1975) was employed to examine the relative contribution of key variables to variations within the ant community. The contribution of specific variables to the final equation was assessed by the increase in unaccounted for variation on deletion of the variable from the model.

Ant species richness was first selected as the dependent variable and, initially, all thirty-seven independent variables were included in the analysis. Assessment of the correlations existing between variables led to consideration of a reduced regression model which included independent variables screened as being relatively important carriers of information about ant species richness.

Data on rehabilitation measures such as tree thinning consisted of 0/1 (no/yes) values. These data were considered unsuitable for inclusion in the second regression analysis because of the tendency for the treatment to be either present, or alternatively absent, in a large proportion of the cases. In addition, the inclusion of these 0/1 variables tended to mask the contribution of other variables of interest.

Inclusion of ripping depth (RIP) resulted in its entering the regression with a relatively high R^2 value and negative regression coefficient. This result arose because deep ripping was a relatively recent introduction to the rehabilitation procedure. Consequently it was associated with a short time-span since rehabilitation, and corresponding low values of ant

TABLE 5. Summary of multiple regression analysis performed on ant species richness (ANT2) with transect plant species richness (PL3) time since rehabilitation (TIME2) and plant cover % (C2), showing contribution of each variable to the final regression equation. Number of cases = 59.

	Variables			
	PL3	C2	TIME2	R^2
Regression with three independent variables				
Regression coefficients	0·279	0·047	0·377	0·523
S.E. of reg. coeffs	0·068	0·019	0·134	
Regression with two independent variables				
(i) Regression coefficients	0·361	0·059	—	0·455
S.E. of reg. coeffs	0·065	0·019	—	
R^2 (proportional decrease)	—	—	0·125	
(ii) Regression coefficients	0·286	—	0·453	0·468
S.E. of reg. coeffs	0·071	—	0·137	
R^2 (proportional decrease)	—	0·128	—	
(iii) Regression coefficients	—	0·051	0·615	0·376
S.E. of reg. coeffs	—	0·021	0·137	
R^2 (proportional decrease)	0·236	—	—	

R^2 (*proportional decrease*) is decrease in explained variation due to omission of variable expressed as a proportion of variation unexplained by other two variables. It indicates the degree to which a variable accounts for removing variations unaccounted for by other independent variables.

The increase in residual sum of squares on omitting the variable under consideration was significant in each case at the 5% level as measured by

$$F = \frac{\text{increase in residual S.S. on omission of variable}}{\text{(residual S.S. for three variable model)/55}}.$$

species richness. This was reflected by the high negative correlation (−0·92) between ripping depth and time since rehabilitation. Accordingly ripping depth was also deleted from the regression analysis.

Similar considerations, and screening of independent variables, led to a selection of variables for inclusion in a regression model for ant species diversity (ANT6).

The variables considered in the reduced models were transect plant species richness (PL3), plot plant species diversity (PL2), percentage litter cover (GRC2), plant cover (Levy rod method) (C2), and time since rehabilitation TIME2).

The regression analyses revealed a regression model describing 0·523 of the variation in ant species richness (ANT2) (Table 5) with three significant independent variables. The contribution of each variable to the final equation was measured by the degree to which it accounted for removing variation unaccounted for by other independent variables included in the final equation. Plant species richness (PL3) accounted for 0·236 of the variation unaccounted for by plant cover (C2) and time since rehabilitation (TIME2). Similarly, the proportionate increases in explained variation accounted for by plant cover (C2) and by time since rehabilitation (TIME2) were 0·128 and 0·125, respectively.

The contributions of each of these independent variables to the final model were significant at the 5% level (as measured by increase in residual sum of squares on omission of variable).

Similarly, a regression model for ant species diversity (ANT6) with four independent variables described 0·673 of the variation in ANT6 (Table 6). Plant species diversity

TABLE 6. Summary of multiple regression analysis performed on ant species diversity (ANT6) with plot plant species diversity (PL2), plant cover % (C2), time since rehabilitation (TIME2) and litter cover % (GRC2), showing contribution of each variable to the final regression equation. Number of cases = 59

	Variables				
	PL2	C2	TIME2	GRC2	R^2
Regression with four independent variables					
Regression coefficients	0·287	0·532	0·023	−0·003	0·673
S.E. of reg. coeffs	0·063	0·001	0·005	0·001	
Regression with three independent variables					
(i) Regression coefficients	0·350	0·370	0·171	—	0·626
S.E. of reg. coeffs	0·062	0·001	0·005	—	
R^2 (proportional decrease)	—	—	—	0·126	
(ii) Regression coefficients	0·384	0·005	—	−0·001	0·554
S.E. of reg. coeffs	0·068	0·001	—	0·001	
R^2 (proportional decrease)	—	—	0·267	—	
(iii) Regression coefficients	0·354	—	0·021	0·001	0·473
S.E. of reg. coeffs	0·077	—	0·007	0·001	
R^2 (proportional decrease)	—	0·380	—	—	
(iv) Regression coefficients	—	0·006	0·032	−0·005	0·545
S.E. of reg. coeffs	—	0·001	0·006	0·001	
R^2 (proportional decrease)	0·281	—	—	—	

R^2 (*proportional decrease*) is decrease in explained variation due to omission of variable expressed as a proportion of variation unexplained by other three variables.

The increase in residual sum of squares on omitting the variable under consideration was significant in each case at the 1% level as measured by

$$F = \frac{\text{increase in residual S.S. on omission of variable}}{\text{(residual S.S. for four variable model)/54}}.$$

(PL2) accounted for 0·281 of the variation unaccounted for by plant cover (C2), time since rehabilitation (TIME2) and percentage litter cover (GRC2). Similarly, the proportionate increases in explained variation accounted for by plant cover (C2), by time since rehabilitation (TIME2) and by percentage litter cover (GRC2) were 0·380, 0·267 and 0·126, respectively.

The contributions of each of these independent variables to the final model were significant at the 1% level (as measured by increase in residual sum of squares on omission of variable).

The relationship between ant and plant species richness (Table 5) and ant and plant diversity (Table 6) is of interest and was investigated further. Since plant species richness and plant diversity are inter-correlated variables, the regression analysis selects only one of these variables for inclusion in the regression model, even though the other may also be correlated with the dependent variable. The relative significance of variability in ant species richness (ANT2) ascribable to plant species richness (PL3) and plant species diversity (PL2) was assessed by comparing their simple R^2 values relative to ANT2. This is equivalent to comparing the corresponding simple correlation coefficients with ANT2 (0·603 and 0·436, respectively).

The corresponding simple R^2 values for PL3 and PL2 are respectively 0·364 and 0·190 and, in a quantitative sense, the observed difference of 0·174 indicates that PL3 accounts for more variability in ANT2 than does PL2, in terms of linear relationships. A likelihood ratio test was also applied in order to assess the significance of the difference observed between the simple correlation coefficients mentioned above. This generated a chi-square value of 3.02 which compares with a tabulated chi-square value of 3·84 (for 1 degree of freedom and 5% significance level). Thus, the difference between the correlations is not quite significant at this level.

The difference in roles played by PL3 and PL2 on ant species diversity (ANT6) was not so marked. The simple R^2 values for PL3 and PL2 are 0·527 and 0·552, respectively. The likelihood ratio test was once again applied to the simple correlation coefficients and a chi-square value of 0·07 was obtained, confirming that the difference between the correlation PL3 and PL2 on ANT6 was not significant.

In summary, the plant species richness (PL3) measure is indicated to be the most important carrier of information on ant species richness (ANT2). There appears to be no difference in the influence of plant richness or diversity on ant species diversity (ANT6).

The inclusion of the three control plots in the regression of ANT2 on all thirty-seven variables resulted in an extremely different regression model with presence of logs having diameter greater than 30 cm (LOG3) being introduced as the most significant carrier of information and accounting for 0·42 of the total variation in ant species richness (ANT2). Substantially different values of key variables in the control plots relative to the mined plots account for this influence on the model. In particular, the preponderance of larger logs in the control plots relative to mined plots accounts for this influence on the model (Table 2) although the results do suggest the important role of logs in ant community composition.

The ordination diagrams of axes 1 versus 2 of the species presence/absence and standardized pitfall trap data are respectively given in Figs 1 and 2. Most factors were investigated for fit on the first, second and third axes of both ordinations. In neither ordination was it possible to identify axis 3.

On the species presence/absence ordination, the forest controls occurred in a separate grouping from the mined area plots (Fig. 1). This also occurred in the pitfall trap data

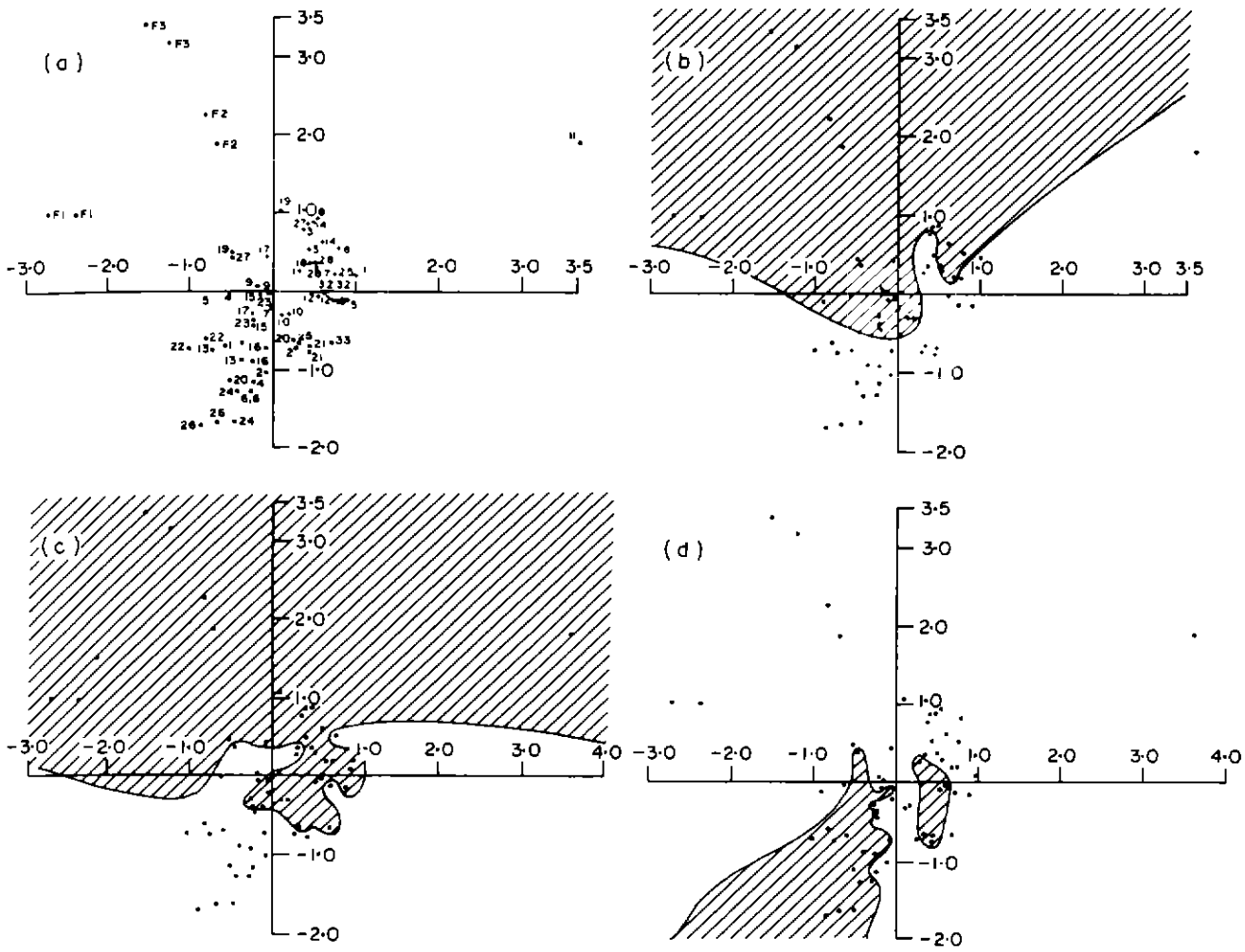

FIG. 1. First (vertical) and second (horizontal) axes of transect plot ordination derived using ant species presence/absence data. (a) Positions of the plots using codes explained in Table 1. Shaded areas in (b) & (c) show the 50% of plots which respectively have the highest ant and plant species richness. (d) Shading shows plots rehabilitated five or less years before the study was performed.

ordination (Fig. 2) although the separation of control and mined area plots was less distinct. No identifiable clustering within the mined plots was observed although it is important to note that in Fig. 1, both transects of plot 19 occurred closer to the forest controls than any other mined area plot. Although it was planted with *P. pinaster* in 1969, this area was never mined, so the original soil profile was not disturbed.

The positive part of axis 1 of the species presence/absence ordination was correlated with a higher ant and plant species richness (Fig. 1b, c). It was also possible to identify a group of plots rehabilitated five or fewer years before the study in the negative part of axes 1 and 2 (Fig. 1d). None of the other variables investigated produced identifiable trends on this ordination.

Three variables were associated with axes of the standardized pitfall trap data ordination. Plots with higher ant species richness and plant species diversity index values occurred on the positive part of axis 2 (Fig. 2b, c) and plots with low litter cover in the negative part of axis 1 (Fig. 2d).

In view of the fact that both the multiple regression and ordination analyses showed that time was an important factor in ant colonization, it is of interest to know the sequence of

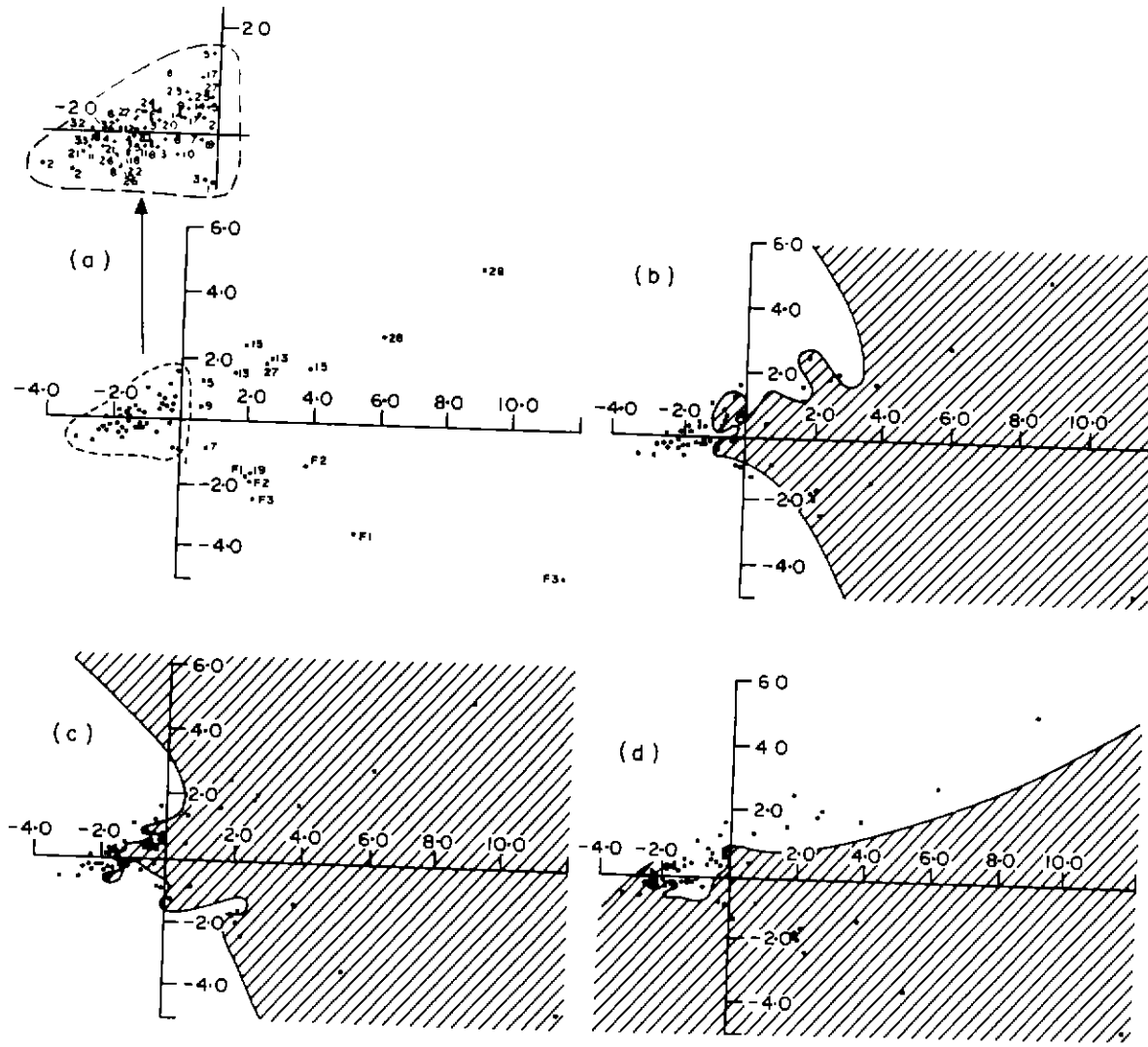

FIG. 2. First (vertical) and second (horizontal) axes of transect plot ordination derived using ant quantities in pitfall traps standardized to unit variance. (a) Positions of the plots using codes explained in Table 1. Shaded areas in (b) & (c) show the 50% of plots which have the highest ant species richness and plant diversity index respectively. (d) Shading shows plots with less than 40% litter cover.

colonization by different ant species. The use of a wide range of environmentally different plots does not provide a good basis for investigating this and the long-term study described in Majer (1978a) aims to provide this information. Nevertheless, the plots were arranged in chronological order and the year when a species was first recorded as present was noted. Table 3 shows species sequence of colonization by ants recorded in the present study Forty-two ants were recorded in the rehabilitated areas, of which twenty colonized in the first 3 years. A survey of the soil and litter fauna, which was completed in the winter of 1980 has since revealed the following species in certain plots: *Hypoponera congrua* (plots 20 and 9), *Amblypone australis* (plot 28), *Oligomyrmex* sp.JDM 440 (plot 1), *Iridomyrmex* sp.JDM 18 (plot 20) and *Tapinoma* sp.JDM 134 (plots 4, 22 and 23). The data suggest that only five species from the adjacent forest have so far failed to colonize any mined area. In fact more intensive sampling of the forest reveals that this figure is likely to be over seventy (J. D. Majer, unpublished data).

DISCUSSION

Bauxite mining creates a disturbance in the soil profile, hydrological regime, flora and fauna. On completion of the mining operation there commences a secondary succession of flora and fauna which is greatly influenced by the rehabilitation option used. This means that only limited knowledge of ant succession can be gained from this study as it is confounded by rehabilitation method. For instance, by the time four ant species had colonized the planted plot studied by Majer (1978a), thirteen ant species had established colonies in a seeded plot which was originally rehabilitated at the same time. What this study does provide, however, is information on how site factors, which are largely associated with rehabilitation time and method, contribute towards the recolonization of ant fauna. Although this study concentrates on the ant fauna, it should be remembered that a diverse and forest-like ant fauna probably reflects similar trends in the composition of the vegetation and other invertebrate fauna communities.

The results of the multiple regression analysis suggest that the richness of the ant fauna colonizing bauxite mined areas is principally accounted for by the richness of plant species present, the time which has lapsed since initial rehabilitation and the overall percentage plant cover. The situation changes slightly if the numbers of individuals of each species are also considered by using the ant species diversity index as a measure of recolonization. Here plant species diversity and plant species richness were both found to have a similar influence on ant diversity, with overall percentage plant cover, time since rehabilitation and percentage litter cover also being indicated as having a significant influence. Other variables not included in the final regression model probably also influence ant recolonization although the discussion will not pay detailed attention to these.

This part of the discussion therefore concentrates on what appear to be the most important determinants of ant colonization. It should also be noted that variables in the regression equation are inter-correlated. In view of this, no attempt has been made to construct a path diagram of causal factors since it is not possible to confidently say where the direct influences lie.

There is probably a number of ways in which the relationship between ant and plant richness and ant and plant diversity or plant richness operate. Certain ants have specific prey, Homoptera, plant nectar or seed requirements; they may also forage in particular strata and nest in specific shade regimes or in different parts of a plant. The existence of a greater richness of plants in the rehabilitated area is therefore likely to satisfy the requirements of an increasing number of ant species since the diversity of host specific prey and Homoptera, sap and seed sources would be increased as no doubt would be vertical and horizontal stratification of the environment. The correlation between ant and plant richness (0·603) relative to that of ant richness and plant diversity (0·436) is of interest. The presence of particular plants may result in particular ant species successfully colonizing the area. This would explain the correlation between ant and plant species richness. The plant diversity measure portrays information about the distribution of numbers of individuals within the community and hence, as far as ants are concerned, the relative availability of various food, foraging and nesting resources. This plant measure is therefore unlikely to be reflected by the simple measure of ant species richness.

The contribution of plant diversity in the relationship with ant diversity (Table 6) supports this point since it suggests that the distribution of ant abundance between species reflects that between individuals within the plant community. A number of previous studies have compared the contribution of plant floral and structural diversity to faunal diversity. In their work on succession in old fields in Michigan, Murdoch, Evans & Peterson

(1972) noted a direct correlation between plant and insect diversity parameters although they were unable to resolve whether the floristic or structural aspects were the important factor. Pianka (1967) compared the influence of plant species diversity and plant volume diversity (which disregards species concerned) on the number of lizard species in flatland deserts. Only the latter plant measure was correlated with lizard species richness. The current study was not designed to separate the influence of these aspects of plant diversity. Field observations in the Jarrah forest (Majer 1982) suggest that certain seed-gathering ants require plants which produce seeds possessing elaiosomes (Berg 1975) while others require saps which are only produced in quantity by a narrow range of plant species. In such cases floristic diversity would enhance ant diversity. Other species of ants tend to forage in particular strata or nest under particular shade regimes. Thus, the provision of the appropriate foraging and nesting conditions for a wide range of species would be favoured by vegetation of high structural diversity. In summary, it is likely that both floral and structural aspects of plant diversity have a major influence on the diversity of the ant community.

The overall percentage plant cover also contributes to increasing ant species richness, and particularly ant diversity (Tables 5 & 6). This relationship may operate in a number of ways. First may be the fact that increased vegetation cover means more prey, saps and seeds for ants to feed on. One piece of evidence which supports this contention is that the abundance of shrub and tree associated invertebrates in the study plots was generally positively associated with plant cover density levels (Van der Linden 1979). Another factor which may contribute to this relationship is that plots with high plant cover tend to have more woody plant tissue which provides nesting sites for stem or dead wood nesting species such as some of the *Crematogaster* and *Iridomyrmex* species. Finally, increased cover probably leads to a more favourable microclimate within the rehabilitated area. Greenslade & Majer (1980) have already noted that during summer there is a much greater reduction in Collembola in recently rehabilitated areas than in the adjoining forest and attribute this to higher temperatures and lower humidities in the former areas. Ants are more tolerant to desiccation than Collembola, although microclimate would certainly directly limit some species. In addition, the open conditions in areas with low plant cover might limit certain ants by reducing the availability of microarthropods, such as Collembola, upon which many species feed.

The percentage litter cover significantly contributed to the final model for ant species diversity (Table 6) and was associated, although not significantly, with ant species richness. In both cases the simple correlation coefficient was positive with the negative regression coefficients in Table 6 simply reflecting the marginal effect on ant species diversity after taking into account the other independent variables in the model. Many species of ants feed on invertebrates occurring within the litter layer. An increased litter cover would therefore be expected to provide conditions for increasing this food source and hence the incidence and abundance of certain species of ant. On the other hand, increased litter can create shady ground conditions, unsuitable for nesting by other species, so these two effects may tend to cancel out the influence of litter in ant species richness.

Time since rehabilitation is the other factor involved in both regression equations. Once again, there is a number of ways in which the relationship may operate. The longer an area has been rehabilitated, the more chance there is of a species establishing colonies in an area and of colony size to build up. Time also allows plants to be recruited, grow, and produce litter. Thus, the time variable is either directly, or indirectly, associated with most of the other variables in the regression equation and would hence express itself in the composition of the ant community through these factors.

Kabay & Nichols (1980) have postulated four stages in vegetational succession within mined bauxite areas in Western Australia which have been rehabilitated using current methods. These are:

Stage 1. New plantings: small trees; sparse understorey; possible mulching (duration years 0–2)

Stage 2. Understorey development: thick high understorey; flowers and seed production; trees appearing above understorey (years 3–7)

Stage 3. Tree development: understorey suppression; leaf litter high (years 5–20(+))

Stage 4. Older trees with hollows and well developed bark; low understorey and leaf litter (years >20).

Most plots used in this study represent stages 1, 2 or 3 and a characteristic of all plots is the lack of senescing or dead trees and of logs. When the forest control plots were included in the regression analysis, the abundance of large logs was found to explain the most variation in ant species richness. Although this computation is not strictly speaking statistically valid due to the large discrepancy between forest and mined area values (Table 2), it does provide some insight into why the number of ant species in the rehabilitated areas is still less than that of the original forest. Many species, such as certain *Camponotus*, nest in or under logs and would be unable to establish colonies until these are present. This point will be returned to in a following paragraph.

The results of the ordination were less clear than those of the multiple regression. The distribution of plots on both ordinations was influenced by the richness or diversity of the ant fauna, so any analysis of these results tends to reiterate that of the multiple regression analysis. The zones of plots with high ant species richness, high plant richness and recent rehabilitation history do not simply overlap or complement each other on the species presence/absence ordination (Fig. 1). Likewise, on the quantitative data ordination (Fig. 2) the zones of plots with high ant species diversity, high plant diversity and low litter cover do not relate to each other in the manner expected from the results of the multiple regression analysis. This suggests that plant species richness, plant diversity, rehabilitation history and litter cover all influence the type of species present in an area as well as influencing the general community measures of ant species richness and diversity.

One further site factor which should be mentioned at this stage is the degree of disturbance to the soil profile. Both transects of plot 19, which was cleared of vegetation but never mined, were indicated on the species presence/absence ordination to have an ant fauna of relatively similar species composition to that of the forest controls (Fig. 1). Thus, destruction of the original soil profile in the remaining rehabilitated areas seems to have reduced the ability of the fauna to rapidly recolonize the mined areas. It is uncertain whether this is a direct physical effect or one which indirectly results from the early natural regrowth of vegetation. Fox & Fox (1978) have made similar observations on recolonization of the New Holland mouse, *Pseudomys novaehollandiae*, following sand mining. In their study, recovery of the mouse was much less rapid after mining than in areas where vegetation had been removed without disturbing the soil profile.

The discussion will now consider the species or genera of ants which have colonized the mined areas. Consideration at this level is confounded by the lack of published ecological information on Western Australian ants. The senior author and his associates have been gathering such data over the past 2 years. The unpublished information from these studies and the notes on genera provided in Greenslade (1979) are drawn on here. The ants which colonized in the first 2 years after rehabilitation were species of *Iridomyrmex*, *Camponotus*, *Rhytidoponera* and also *Cardiocondyla nuda*. The latter is a tramp species, probably of African origin, and has been spread throughout the warmer parts of the world;

it is never found in undisturbed Jarrah forest. Both *Rhytidoponera* spp. collect live or dead invertebrates and a wide variety of seeds. Members of the other two genera are omnivores which feed on invertebrates and plant or Homoptera produced saps. Most of these species nest in soil. Thus, all of the above species utilize nest sites which are unrestricted and are able to utilize a wide range of food. While abundant in the recently rehabilitated mines, species such as *I. purpureus* and *I. agilis* are either absent or present at low levels in undisturbed Jarrah forest.

Species which largely forage on vegetation tended to establish themselves in the older rehabilitated areas (Table 3) where shrubs and trees are more likely to be abundant. Examples of ants in this category include *Crematogaster* spp., *Podomyrma* sp. JDM 365, *Camponotus calcius* and *Diceratoclinea* sp. JDM 211. This observation ties in with the earlier comments on the relationship between ant diversity and plant structural diversity.

Ants which rely more heavily on seeds for their diet, such as *Melophorus* sp. 1 (ANIC) (Majer 1980), and *Pheidole latigena* did not establish colonies until the third year after rehabilitation. This ties in with the observed fact that plants tend not to set seed in these areas for at least 2 years following their establishment.

It is interesting to note that *R. inornata, R. violacea, C. nuda, I. purpureus, I agilis* and *Melophorus* sp. 1 (ANIC) all colonized the sides of the Canning reservoir near Perth within 54 months of the water level dropping to expose new ground (Woodroff & Majer 1981). Thus these, and probably a number of the other species colonizing the mines, are pioneer species which commonly occur in disturbed areas.

Some insight into the question of colonization may also be gained by looking at the species present in the Jarrah forest which have *not* yet colonized the mined areas. The following is a list of species which were collected from similar vegetation to that originally present in the mined areas from study areas at Karragullen (25 km N of Jarrahdale) and near Dwellingup (30 km SE of Del Park).

Myrmeciinae

Myrmecia	(4 spp.)

Ponerinae

Cerapachys	(2 spp.)
Discothyrea	(2 spp.)
Eubothroponera	(2 spp.)
Heteroponera	(2 spp.)
Trachymesopus	(2 spp.)

Myrmicinae

Anisopheidole	(1 sp.)
Crematogaster	(1 sp.)
Epopostruma	(3 spp.)
Meranoplus	(6 spp.)
Monomorium	(2 spp.)
Gen. nr. *Monomorium*	(1 sp.)
Pheidole	(1 sp.)
Strumigenys	(1 sp.)
Tetramorium	(4 spp.)

Formicinae

Acropyga	(1 sp.)
Camponotus	(7 spp.)
Melophorus	(5 spp.)
Notoncus	(2 spp.)
Notostigma	(1 sp.)
Plagiolepis	(1 sp.)
Plagiolepidini	(1 sp.)
Polyrhachis	(1 sp.)
Prolasius	(3 spp.)
Stigmacros	(7 spp.)

Dolichoderinae

Bothriomyrmex	(1 sp.)
Diceratoclinea	(1 sp.)
Hypoclinea	(1 sp.)
Iridomyrmex	(6 spp.)

The absence of certain species in the rehabilitated areas may result from the restricted sampling period since certain species are more active, and hence easy to find, in the winter. The more recent winter survey of the soil and litter fauna revealed five additional species in a few of the mined areas. With the exception of *Iridomyrmex* sp. JDM 18, these are species which occur in humid microhabitats and all are, as yet, of restricted occurrence in the rehabilitated areas.

The absence of some species may no doubt be explained partly by the great variation in species which occurs over relatively short distances; certain species are extremely restricted in their distribution. Many species in the list are, however, widespread in the Jarrah forest and hence their absence from mined areas is worthy of note.

A number of species nest in dead standing timber or logs (e.g. certain *Camponotus* spp., *Crematogaster* sp. and *Diceratoclinea* sp.) while others often nest under logs (e.g. *Trachymesopus* spp. and *Epopostruma* spp.). The paucity of dead wood in the rehabilitated areas might therefore explain the absence of certain species from these genera. Certain other species which are absent from the rehabilitated areas are specialized feeders. For instance, the *Cerapachys* spp. are specialized predators of other ants, *Anisopheidole* sp. may feed on termites while *Acropyga* sp. probably tends root aphids. The absence of certain species from these genera and the preponderance of genera with a broader food base such as *Camponotus* spp., *Melophorus* spp. and *Iridomyrmex* spp. suggests that the rehabilitated areas have, as yet, largely been colonized by generalists. Another major category of ants which is depauperate in these areas is that of the litter dwelling species. Included here are *Discothyrea* spp., *Heteroponera* spp., certain *Trachymesopus* spp., *Epopostruma* spp. and *Strumigenys* spp. Although there are exceptions, the rehabilitated areas tended to have a lower percentage litter cover (GRC2) which was of less depth (GRC1) than the forest controls (Table 2). In addition, the deep ripping and hence furrowing of the mine floor meant that the litter tended to collect in the depressions and form long narrow strips. It therefore appears that although litter has been sufficient to contribute to the return of certain species (Table 6), its low depth and cover values are still limiting the presence of other species. A number of other species not yet found in the mined areas are not common in the Jarrah forest (e.g. *Bothriomyrmex* sp., *Hypoclinea* sp. and certain *Iridomyrmex* spp.). Their absence from the rehabilitated areas may reflect the low chance of their being found within the immediate locality. The absence of a number of *Myrmecia* may reflect a low ability to colonize new areas since few alates are produced from individual colonies.

The results of this study may be concluded by saying that the factors which contribute to the return of a rich ant fauna of high species diversity into a rehabilitated bauxite mine are:

(i) vegetation of high species richness and diversity;
(ii) a high plant cover;
(iii) an adequate period of time since rehabilitation commenced;
(iv) a thick, widespread litter cover over part of the area;
(v) the presence of some logs and dead standing wood.

Although the earlier rehabilitation attempts were not particularly suitable for providing these conditions, the more recent approaches of double stripping and direct seeding (Tacey & Glossop 1980) produce conditions which satisfy the first of these four criteria. Kabay & Nichols (1980) have also realized the importance of logs in the re-establishment of vertebrate fauna and, as a result, the leaving of tree thinnings *in situ* and the placement of old logs in rehabilitated areas is now being investigated on an experimental basis.

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