*Australian Journal of Ecology* (1993) **18**, 385–394

# Recolonization by Collembola of rehabilitated bauxite mines in Western Australia

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**Abstract** The collembolan faunas of 30 bauxite mines rehabilitated by a range of different methods between 1966 and 1977, and three forest plots were surveyed in the spring and summer of 1978–79 with the aim of studying the restoration of decomposer activity in degraded areas. The rehabilitation methods included seeding and planting with a variety of native or exotic plant species. Physical and botanical parameters of the plots were also measured. Sixty species of Collembola were collected from the rehabilitated areas; nine of the 28 species found in the forest plots were not present on the mined sites. Principal components analysis suggested that the species richness of the collembolan community in rehabilitated areas is positively correlated with plot age. A parametric correlation analysis using a number of collembolan community characteristics revealed that, among other factors, the development of a species rich collembolan fauna is positively correlated with plant species richness and diversity, and also with percentage plant cover. These results provide directions for improving rehabilitation practices.

## INTRODUCTION

There have been a number of reports from sites outside Australia on the rate of recolonization by Collembola of revegetated mine or quarry sites (Dunger 1964, 1965; Dindal & Wray 1977; Hutson 1972, 1974, 1980a,b; Hutson & Luff 1978; Usher & Jefferson 1991). These studies have shown that Collembola were primary colonizers of disturbed sites and, because composition of the fauna changes with time, are useful for monitoring the progress of rehabilitation. For instance, on rehabilitated coal mined areas in Germany, Collembola were dominant during the pioneer period and remained so up to the tenth year of rehabilitation (Dunger 1989). It has also been pointed out that, by determining the rate and type of soil formation, microarthropods such as Collembola, may considerably influence the structure and species composition of the surface vegetation (Parr 1978) However none of the earlier studies attempted to revegetate mined areas with native forest cover. In this paper we report on the collembolan fauna found on sites that have undergone a range of rehabilitation options. Most of these were designed to rapidly restore areas mined for bauxite to a condition that resembled, as closely as possible, the original undisturbed forest and to produce restored vegetation that is self-sustaining and stable.

Bauxite mining alters the soil by compacting it, removing the lower layers, mixing the profiles and lowering nutrient status through the breakdown of organic material during topsoil storage. This disruption results in loss of soil animals, soil nutrients, organic matter, viable seeds and micro-organisms such as vesicular-arbuscular mycorrhizal fungi (Jasper *et al.* 1987). The rate of redevelopment of a soil fauna, in particular those elements such as the Collembola, which constitute part of the decomposer complex, could reflect the success of re-establishment of the forest, and also its sustainability.

The jarrah (*Eucalyptus marginata*) forests of Western Australia occupy approximately 1.75 million ha of the southwest corner of the State. The forests overlie significant deposits of bauxite, which occur in pockets (average area 10–20 ha) and cover some 7–8% of the forest area. Mining of the area started in 1973 but only 3–5% of the available bauxite will be mined (Nichols & Slessar 1991).

Accepted for publication December 1992.

The mining process involves clearing the forest, removing topsoil (50 mm) and overburden (0–1 m), blasting a cemented caprock layer and mining to an average depth of 2–5 m. This leaves a compacted clay pit floor, ready for rehabilitation. The rehabilitation procedure has gradually evolved over the years. In the earliest examples, a variety of trees including several *Eucalyptus* and *Pinus* species were planted, but no understorey seeding or soil ripping was carried out. The current procedure involves fresh topsoil return, soil ripping, reseeding of native understorey plants and planting or seeding of native tree species. For the rehabilitation to be self-sustaining, it is important that colonization by invertebrates involved in the development and maintenance of a good soil structure, decomposition, herbivory, pollination, seed dispersal and other ecosystem processes should occur.

For the past 14 years investigations have been carried out on the rate of recolonization by invertebrates of Alcoa's rehabilitated bauxite mines in Western Australia. The general patterns of animal succession on rehabilitated mined sites have been reviewed by Majer (1990). More specific information on the recolonization by vertebrates and invertebrates to mined areas in southwestern Australia has been summarized by Nichols *et al.* (1989). Initially, animal recolonization was studied in three areas that had been rehabilitated in different ways; first by replacing topsoil but not revegetating, second by planting with *Eucalyptus calophylla* (marri) and third by seeding with mixed native plants. Majer (1981) reported on the colonization by ants, identified to species, and other invertebrates, identified to order or family, during the first 2 years of rehabilitation. Ants are the dominant soil and ground living macroinvertebrate on these sites. Greenslade and Majer (1980) recorded and commented briefly on the collembolan species that had colonized these plots. A later study of recolonization of mined sites by invertebrates under a larger number of rehabilitation regimes was carried out. The patterns of ant colonization were described in Majer *et al.* (1984). Here we give the first report on recolonization of these sites by a decomposer group, the Collembola. The aim of the study was to examine the effectiveness of rehabilitation practices for restoring the biological processes of decomposition and nutrient cycling in degraded mine sites.

## METHODS

### Sampling and ecological classification of Collembola

The sampling of Collembola was carried out in 1978–79 on 30 rehabilitated plots and three forest plots carrying *Eucalyptus marginata* (jarrah), situated at Jarrahdale (32°18′S, 116°05′E) or Del Park (32°39′S, 116°01′E). The sites, which are described in detail in Majer *et al.* (1984), were selected to include plots that had been rehabilitated in different years and where different rehabilitation methods had been used. Two 100 m transects were marked out in each plot to provide replicated collembolan samples. Thirty-seven physical, botanical and rehabilitation technique parameters were recorded for each transect; these are described elsewhere in a paper reporting on the ant faunas of these plots (Majer *et al.* 1984).

Three complementary sampling methods were used to collect Collembola. Forty pitfall traps of 18 mm internal diameter Pyrex® test tubes, containing 5 mL of alcohol/glycerol (70/30 v/v), were inserted along each transect at equidistant intervals (Majer 1978). Traps were left open for 7 day periods in summer (December 1978–February 1979).

The soil and litter Collembola were also sampled during spring (August–October 1979). Handfuls of litter were taken haphazardly along each transect until approximately 2 kg dry mass of litter had been collected. The samples were extracted in Tullgren funnels. Each funnel held a 43 × 43 cm mesh (1.2 × 1.6 mm mesh size) allowing passage of small invertebrates. The temperature above the litter was raised from ambient to 40°C over a 1 week period. Twenty soil cores (54 mm diameter, 97 mm deep) were also taken from beneath the litter at equal distances along each transect and the soil extruded into a plastic sleeve of 54 mm internal diameter and with a mesh base of 3 mm mesh size. The samples were extracted using a multiple canister heat extractor (Southwood 1966) subjected to the same temperature regime as was used for the leaf-litter extraction.

The Collembola from all three sampling methods were sorted, identified to species and counted. Species were distinguished with reference to the extensive collections of the South Australian Museum, which includes data on associated habitats. Voucher specimens from this collection are deposited in the Museum. Even at the intensity of sampling used in this study, it is likely that some rare collembolan species were not collected. However the intensity of sampling across all plots was consistent and it is assumed that the data represent real differences between the faunas of the different areas.

Data for species associated with grasses, understorey heath-like vegetation, leaf litter and humus were amalgamated either singly or in various combinations to form informative variables of both decomposer activity and development of the vegetative cover. Some Collembola have been introduced since European settlement and, because they tend to be associated with disturbed habitats, their abundance can provide a measure of the level of disturbance of a site. The number of species and abundance of introduced taxa therefore formed further variables. Table 1 gives each of the 19 variables, the portion of the collembolan community they represent and, in some cases, the seasonal

**Table 1.** Description of 19 variables used to describe various aspects of the collembolan fauna in each plot and used in multiple regression analysis

| Description | Interpretation |
|---|---|
| 1. Total species sampled using all three methods used | |
| 2. Total individuals sampled using all three methods used | |
| 3. Total immature entomobryids | An indicator of the amount of reproduction taking place |
| 4. Abundance of *Acanthomurus* sp. in soil and litter samples | This native species is of interest because it is a primary colonizer (Greenslade and Majer 1980) |
| 5. Abundance of *Acanthocyrtus* sp. in pitfall trap samples | This native species may also be a primary colonizer during drier periods |
| 6. Total numbers of individuals of introduced species in the plot | A measure of the degree of disturbance in the plot |
| 7. Number of introduced species | An alternative measure to abundance of introduced species |
| 8. Total number of adult native entomobryid individuals in litter samples | A measure of warm weather decomposer activity |
| 9. Total number of adult native entomobryid species in litter samples | An alternative measure to abundance of entomobryids |
| 10. Total number of adult native isotomid and sminthurid individuals (excluding *Acanthomurus*) sampled by all three methods | A measure of cooler weather decomposer activity |
| 11. Total number of adult native isotomid and sminthurid species | An alternative measure to abundance of isotomid and sminthurids |
| 12. Total number of decomposer individuals sampled, regardless of season, sampling method or country of origin | Total decomposer activity |
| 13. Total number of decomposer species sampled, regardless of season, sampling method or country of origin at all seasons | An alternative measure of decomposition to abundance of decomposer species |
| 14. Total number of individuals known to be associated with the shrub layer | An indicator of the degree of development of the shrub layer |
| 15. Total number of species known to be associated with the shrub layer | An alternative measure to abundance of shrub layer fauna |
| 16. Total number of individuals known to be associated with grasses and sedges | An indicator of the degree of development of the grass layer |
| 17. Total number of species known to be associated with grasses and sedges | An alternative measure to abundance of grass associated species |
| 18. Total number of individuals known to be associated with shrubs, grasses and sedges | An indicator of the degree of development of the ground and shrub vegetation |
| 19. Total number of species known to be associated with shrubs, grasses and sedges | An alternative indicator to abundance of shrub, grass and sedge associated species |

activity of each category and their presumed contribution to nutrient cycling. Since the data for most of the collembolan variables used depended on a single sampling method (i.e. all species living on plants were collected in pitfalls), any bias caused by bulking data from several sampling methods was minimal. This does not apply to the variable 'total individuals' and must be taken into account in the parametric correlation matrix for this variable.

### Data analysis

Transect means and variances for all physical, vegetation and rehabilitation measurements for each plot are listed by Majer *et al.* (1984). The two transect means for each measurement, including Collembola, were combined, because the data available were otherwise insufficient for analysis, and then allocated to the categories listed in Table 1.

Principal components analysis (PCA) was performed using the plot species presence/absence matrix, which was obtained from the pitfall trap, soil and litter sampling as described in Williams (1976) and using Orloci's (1966) weighted similarity coefficient (WSC):

$$\mathrm{WSC} = \sum_{i=1}^{n}(x_{ij}-\bar{x}_i)\,(x_{ih}-\bar{x}_i)$$

where $x_{ij}$ and $x_{ih}$ were the species scores for the plots j and h, $\bar{x}_i$ was the species score for the average plot and *n* was the number of plots. The components were related to environmental factors by visually inspecting the plot groupings on the graph, by inspecting the trends in certain plot parameters along axes or by correlating plot environmental variables with the plot's principal component score. Only plots where data from pitfalls, litter and soil samples were complete (21) were included.

To examine the relationship between the 19 collembolan characteristics (Table 1) and the physical, vegetation and rehabilitation parameters of the plots, a parametric correlation matrix was calculated for all variables (Sokal & Rohlf 1989). Where pitfall trap, soil or litter samples were missing for any plot, that plot was excluded from the analysis of that particular sampling method. Statistical correlation does not necessarily imply cause and effect, since inter-correlations between variables may suggest relationships that are spurious, or they may mask the causal effects of other variables. Consequently Williams (1976) suggests that PCA can be seen as a 'system for generating hypotheses not testing them'.

## RESULTS

Over 18 000 individual Collembola were determined to species, most of which were undescribed, and 68 species belonging to 40 genera were distinguished in the samples. Twenty-eight species were collected from the forest plots, while 60 species were found in the 30 rehabilitated plots (mean = 17.6 per plot; Table 2).

Nine species of Collembola have cosmopolitan distributions and are assumed to be relatively recently introduced to Australia (see King *et al.* 1985). The rest are native or endemic. Only 13 of the 59 native or endemic species are described. Because sampling was carried out either in spring or summer, few of the winter-active Neanuridae, which inhabit the litter, were trapped. By contrast, the herbaceous and surface-active species which are active in both cool wet seasons (*Arrhopalites*, *Stenognathellus*, *Polykatianna*, *Parakatianna* and *Katianna* species) and hot dry seasons (*Corynephoria* and *Rastriopes* species) were present (Greenslade 1986). By far the most abundant family was the Entomobryidae (85% of individuals collected), of which *Acanthocyrtus* sp. was most numerous (24% of individuals collected).

The PCA graph of axes 1 versus 2 shows that the forest plot in the top right hand corner of the quadrant is well separated from most of the other plots (Fig. 1). Axis 1, which represents plot ages, accounted for 12.7% of the variance and axis 2, which probably separates out the oldest plots and the forest plot from the younger plots, accounted for 12.4% of the variance. Three groups can be distinguished. First, plots rehabilitated for 10 years or less are positioned in the lower part of the ordination diagram, while the second group consists of a smaller number of plots aged 11 years or more which are situated closer to the forest plot. The third group, in the lower right corner, comprised plots 18 and 10 only, both of which are of the same age (9 years) and had been planted with *Eucalyptus* species. Plot 10 had a rather high number of collembolan species associated with native grasses (three species of *Corynephoria*) and plot 18, in a

**Table 2.** Species of Collembola found in rehabilitated plots and the forest plot arranged by age of the rehabilitated plot in which they first occurred

| | | |
|---|---|---|
| Year 1<br>N = 7, C = 7, I = 2 | *Corynephoria* sp. 1<br>*Entomobrya unostrigata* (I)<br>*Drepanosira* sp.<br>*Acanthocyrtus* sp. | *Lepidocyrtoides* sp. 2<br>*Acanthomurus* sp.<br>*Brachystomella platensis* (I) |
| Year 2<br>N = 6, C = 13, I = 1 | *Entomobrya* sp. nr *lamingtonensis*<br>*Lepidosira* sp.<br>*Lepidocyrtoides* sp. 1 | *Folsomides* sp. 3<br>*Brachystomella* sp. 3<br>*Mesaphorura* sp. *krausbaueri* gp (I) |
| Year 3<br>N = 8, C = 21, I = 1 | *Sminthurinus* sp. 1<br>*Drepanura cinquilineata*<br>*Drepanura* sp. 2<br>*Entomobrya multifasciata* (I) | *Lepidosira* sp. nr *terraereginae*<br>*Pseudosinella* sp.<br>*Willowsia* sp.<br>*Isotoma* sp. 2 |
| Year 4<br>N = 5, C = 26, I = 0 | *Sminthurinus* sp. cf. *gloriosa*<br>*Katianna* sp. 1<br>*Pseudosinella* sp. 2 | *Lepidocyrtus* sp.<br>*Brachystomella* sp. 1 |
| Year 5<br>N = 9, C = 35, I = 1 | *Sphaeridia* sp.<br>n. gen. nr *Parakatianna*<br>*Corynephoria* sp. 5<br>*Sminthurinus* sp. 2<br>*Entomobrya* sp. | *Cryptopygus dubius*<br>*Cryptopygus* sp. *antarcticus* gp<br>*Folsomia candida* (I)<br>*Pseudachorutes* sp. |
| Year 6<br>N = 6, C = 41, I = 1 | *Katianna* sp. 2<br>*Corynephoria* sp. 2<br>*Folsomides* sp. 4 | *Isotoma tridentifera*<br>*Isotoma* sp. 2<br>*Hypogastrura* (*Ceratophysella*) *gibbosa* (I) |
| Year 7-8<br>N = 1, C = 42, I = 0 | *Parakatianna* sp. | |
| Year 9<br>N = 9, C = 51, I = 2 | *Arrhopalites caecus* (I)<br>*Sinella* sp. 1<br>*Folsomina onychiurina*<br>*Proisotoma minuta* (I)<br>*Cryptopygus caecus* | *Cryptopygus pilosus*<br>*Odontella* sp.<br>*Pseudachorutella* sp.<br>*Tullbergia* sp. |
| Year 10<br>N = 4, C = 55, I = 0 | *Stenognathellus* sp.<br>*Corynephoria* sp. 4 | *Folsomides exiguus*<br>*Depanura* sp. 3 |
| Year 11<br>N = 1, C = 56, I = 0 | *Folsomides sexophthalma* | |
| Year 12-13<br>N = 4, C = 60, I = 0 | *Arrhopalites* sp.<br>*Aneuempodialis cinereus* | *Rastriopes* sp. *dromedarius* gp<br>*Dicyrtomidae* sp. |
| Species only present in undisturbed forest<br>N = 9, C = 69, I = 1 | *Polykatianna aurea*<br>*Corynephoria* sp. 3<br>*Temeritas* sp.<br>*Sinella* sp. 2<br>*Isotomiella* sp. *minor* gp | *Folsomia loftyensis*<br>*Proisotoma* sp.<br>*Cryptopygus thermophilus* (I)<br>*Tomocerura swani* |

N = number of new species appearing in the year; C = the cumulative number of species in that year; I = the number of introduced species in that year. The cumulative species represents the total number of species that have been recorded by that age on its first appearance but not necessarily in all older areas.

low-lying area, an unusually high number of both native and introduced species associated with humid soil conditions.

A large number of positive correlations were found between environmental and the collembolan variables (Table 3). Total species was positively correlated with tree canopy cover and plant species richness. By contrast, total introduced species was negatively correlated with shrub and tree canopy cover, plant species richness and diversity and was

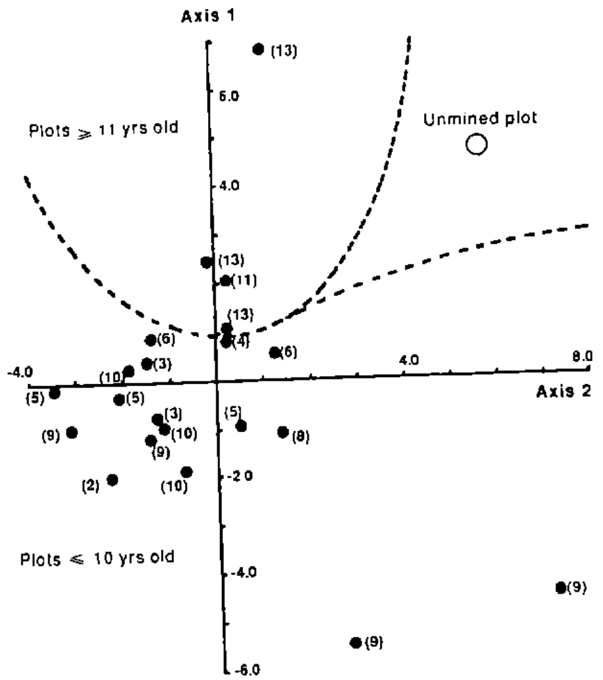

**Fig. 1.** First (F1 or Axis 1) and second (F2 or Axis 2) axes of principal components analysis derived from presence/absence data for Collembola collected from pitfall traps, soil and litter samples. Figures in parentheses give the number of years since revegetation commenced. All plots falling above upper concave dashed line are 11 years old or older; all plots below lowest dashed line are 10 years old or younger.

positively correlated with soil moisture. Total introduced individuals was also negatively correlated with tree canopy cover, plant species richness, diversity and evenness, as well as time since rehabilitation. The native decomposer species and individuals both showed a positive correlation with shrub cover and tree canopy cover, but decomposer individuals were also positively correlated with litter depth and litter cover. Litter species also showed a positive correlation with tree canopy cover and with plant species richness and diversity, which is the reverse of the effect of habitat on introduced species and individuals. Shrub species and individuals were positively correlated with time since rehabilitation and their abundance was also positively correlated with litter depth. This is assumed to be a time-effect. The number of individuals of grass species was positively correlated with shrub cover and species richness, but negatively associated with litter depth; again this is probably a time-effect. Combined grass and shrub species showed a positive correlation with time since rehabilitation and also plant species richness. However, the most abundant species, *Acanthocyrtus* sp., an entomobryid, showed a negative correlation with litter depth and cover. Since this species was so abundant, its contribution to the total individual variable is large and this probably accounts for the negative correlation of this collembolan variable with litter depth and cover. Other collembolan variables, namely immature Entomobryidae, total numbers of *Acanthomurus* sp., litter individuals, grass species and vegetation (grass and shrub) individuals showed no significant correlations. Two further measures of decomposer activity, total individuals and species of all litter- and humus-living Collembola (including introduced species) were either negatively correlated with litter depth and cover or positively correlated with plant species richness.

In Table 2, species records from rehabilitated plots of the same age are combined and species are listed in chronological order based on the age of the plot in which they first appeared. Note that once a species is encountered in a particular age of rehabilitation it does not automatically occur in all older areas. There was a fairly steady rate of accumulation of species with time, initially, with about 5–9 new species being recruited each year since rehabilitation. On plots older than 9 years, the annual rate of new species recruitment dropped to less than five. The widespread introduced or cosmopolitan species, such as *Entomobrya unostrigata*, *Entomobrya multifasciata*, *Brachystomella platensis* and *Mesaphorura* sp. *krausbaueri* gp, appeared early in the rehabilitation. By contrast, native and endemic species tended to appear later than introduced ones, and nine species found in the forest plot were never collected from the rehabilitated plots. Of these nine species, one was associated with rotting logs (*Temeritas*), one with ant and termite nests (*Sinella*), two with herbaceous vegetation (*Polykatianna aurea* and *Corynephoria* sp. 3) and the other five with a humid, well developed litter and humus layer (Greenslade 1991).

Some rehabilitated plots that had been given treatments not used in other areas, showed faunal differences that were not apparent in the analyses above. For instance, only one plot (plot 27) rehabilitated with *Eucalyptus globulus*, had fresh top-soil added at the time of rehabilitation and, at 5 years, this plot had a higher species richness of Collembola than a 10 year old plot (plot 14) with the same eucalypt species.

Bitumenized straw had been added to one plot as mulch which had the effect of inhibiting the devel-

**Table 3.** Plot variables which are significantly correlated ($P \leqslant 0.05$, two-tailed test) with Collembola variables

| Collembola variable | Plot variable | Correlation |
|---|---|---|
| Total species | Tree canopy cover (%) | +0.35 |
| | Plant species richness | +0.46 |
| Total individuals | Litter depth | −0.33 |
| | Litter cover (%) | −0.41 |
| Immature entomobryids | No significant correlations | |
| *Acanthomurus* individuals | No significant correlations | |
| *Acanthocyrtus* individuals | Litter depth | −0.41 |
| | Litter cover (%) | −0.42 |
| Individuals of introduced species | Time since rehabilitation | −0.36 |
| | Tree canopy cover (%) | −0.43 |
| | Plant species diversity | −0.71 |
| | Plant species richness | −0.56 |
| | Plant species evenness | −0.67 |
| Numbers of introduced species | Reduction in % soil moisture | −0.43 |
| | Shrub cover (%) | −0.43 |
| | Tree canopy cover (%) | −0.31 |
| | Plant species diversity | −0.32 |
| | Plant species richness | −0.47 |
| Adult entomobryid individuals | No significant correlations | |
| Adult entomobryid species | Tree canopy cover (%) | +0.39 |
| | Plant species diversity | +0.37 |
| | Plant species richness | +0.46 |
| All native isotomid and sminthurid individuals | Litter depth | +0.43 |
| | Litter cover (%) | +0.46 |
| | Shrub cover (%) | +0.53 |
| | Tree canopy cover (%) | +0.64 |
| All native isotomid and sminthurid species | Shrub cover (%) | +0.35 |
| | Tree canopy cover (%) | +0.38 |
| Decomposer individuals | Litter depth | −0.31 |
| | Litter cover (%) | −0.41 |
| Decomposer species | Plant species richness | +0.35 |
| Individuals associated with shrubs | Time since rehabilitation | +0.31 |
| | Litter depth | +0.41 |
| Species associated with shrubs | Time since rehabilitation | +0.41 |
| Individuals associated with grasses | Litter depth | −0.33 |
| | Shrub cover (%) | +0.30 |
| | Plant species richness | +0.34 |
| Species associated with grasses | No significant correlations | |
| Individuals associated with shrubs, grasses and sedges | No significant correlations | |
| Species associated with shrubs, grasses and sedges | Time since rehabilitation | +0.49 |
| | Plant species richness | +0.35 |

opment of the native collembolan fauna, and permitting the development of a large population of an introduced species, *E. unostrigata* which comprised 60% of the individuals found on this 3 year old plot. Plots planted with *Pinus* species tended to have a less developed fauna than plots planted with *Eucalyptus* species of a similar age, carrying an average of 13 and 20 species in *Pinus* and *Eucalyptus* plots, respectively, within the 9–13 year range. No differences in Collembola species present were detected between plots planted with different *Eucalyptus* species of similar ages.

## DISCUSSION

Collembola are among the earliest colonizers of newly created habitats, such as rehabilitated mined sites, and the species composition of the fauna changes with the development of the habitat. As decomposers, they are a functionally significant group in the soil system. This study identified some of the factors that are positively correlated with the recolonization by Collembola of rehabilitated sites in Western Australia. Earlier work (Greenslade & Majer 1980), described changes with time on three rehabilitated sites of the same age. Here differences were found both between the rehabilitated sites themselves and between these sites and the forest plot. The composition of the fauna there was very similar to that in the present study, although slightly fewer species were collected. As in the present study, introduced cosmopolitan species were found to be associated with early stages of rehabilitation, but the native *Acanthocyrtus* sp. was also an early colonizer on mined plots. After 3 years, the faunas of unvegetated, planted and seeded plots still differed markedly in composition from that of the forest plot, perhaps because poor soil structure on the mined sites prevented colonization by many forest collembolan species (Greenslade & Majer 1980).

In the present study, many of the plots were older than 3 years, but the PCA indicated that only after 10–13 years of rehabilitation did the fauna begin to approach that of one of the forest plots. This was the time when the trees attained a degree of canopy cover that resembled that of the forest values. The nine forest species which were not collected on the rehabilitated plots have habitat requirements, such as well-rotted logs, that may take up to 100 years to develop. Consequently, the time taken for optimum restoration may be extremely long.

Although a larger number of collembolan species (28) were collected from the forest plot than from any single one of the rehabilitated sites (mean 17.6), taking the total cumulative species from all 30 rehabilitated sites (60), there were 31 not found in the forest plot in this investigation. However, all these species, apart from the introduced exotic species, have been collected from native forest on other occasions.

A highly diverse plant cover was associated with a diverse collembolan fauna. High plant biomass, as indicated by canopy and shrub cover, and a large quantity of organic residues, as measured by litter depth and cover, were similarly associated with a diverse and abundant decomposer fauna in this study. The same factors were all associated with ant richness and diversity (Majer *et al.* 1984) but were negatively correlated with the introduced species and native primary colonizing Collembola such as *Acanthocyrtus*. The development of a litter layer or plant cover apparently is not essential before these species can successfully colonize an area. In Australia, other species in the genus *Acanthocyrtus* occur in association with open grassy habitats, often where rotten wood is abundant but deep leaf litter is absent, or under bark.

Certain collembolan species belonging to the genera *Rastriopes*, *Polykatianna*, *Aneuempodialis* and *Corynephoria* among the Sminthuridae, and *Lepidobrya* and *Willowsia* among the Entomobryidae, live on above-ground vegetation (Greenslade 1986). This may partly explain how plant diversity influences collembolan species richness. Because plant species richness is greater on older plots, it may lead to an increase in this component of the Collembola fauna. Moreover the species of plants used for rehabilitation is important since fast growing exotic plant species will be colonized nearly exclusively by introduced species of Collembola and not by species typical of forests. Collembola species classified as decomposers were associated with a well developed humus layer, and tree and shrub cover, both of which would protect soil and litter dwellers against desiccation. Ward *et al.* (1991), in an independent study on the same plots, found that these same factors positively influenced the rate of decomposition of eucalypt litter on rehabilitated bauxite mines.

The presence of suitable logs may be an important factor determining the return of some collembolan species. The presence of young logs on these plots was positively associated with ants (Majer *et al.* 1984) but not with Collembola. This may be because the ant and collembolan species involved require logs representing different stages of decay. Soil factors also appear to be important since high soil moisture is positively associated with high numbers of introduced species. Return of fresh topsoil also seems to be an important factor, possibly because this leads to improved soil structure and organic matter content, as well as to the introduction of collembolan and microbial propagules to the soil.

Finally, the stability or permanence of the fauna, as measured by those species that are dependent on a well developed herbaceous, grass or shrub layer, is positively correlated with time since rehabilitation and with the diversity of vegetation. Variables in the regression equation are often intercorrelated, hence the variables in Table 3, which are positively correlated with collembolan recolonization, are only indicators of the factors that might be manipulated or encouraged in order to accelerate the increase of this component of the fauna.

One factor that may possibly have operated against a rapid colonization by some species in this study is that the original dominant tree, *E. marginata*, was not planted on any of the sites examined because of its susceptibility to die-back caused by the fungus *Phytophthora cinnamomi*. Decomposer species, which are adapted to graze on microbial populations on decomposing jarrah leaves may not be able to survive on leaves of translocated eucalypt or other tree species. In turn, organisms adapted to decomposing organic matter from the translocated tree species are likely not to be present, resulting in an interruption to the processes of organic matter decomposition and nutrient cycling.

Recent rehabilitation techniques have advanced considerably since the sites examined in this study were revegetated. Double stripping and direct return of topsoil is widely used. More than 80 understorey species are now added as seeds, including legume species designed to provide rapid ground cover and nutrient build-up. Jarrah (*E. marginata*) is now the major eucalypt species planted (or seeded) on at least 70% of newly rehabilitated sites, and only local Western Australian eucalypts are used for rehabilitation. Once sites treated with the newer techniques are 5–10 years old, it will be valuable to compare their collembolan faunas with those reported here.

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