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An investigation of the Acarine fauna of rehabilitated bauxite mines in the Northern Jarrah Forest

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AN INVESTIGATION OF THE ACARINE FAUNA OF REHABILITATED BAUXITE MINES IN THE NORTHERN JARRAH FOREST

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USE OF THESIS

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DECLARATION

I certify that this thesis does not incorporate, without acknowledgment, any material previously submitted for a degree or diploma at any institution of higher education; and that to the best of my knowledge it does not contain any material previously published or written by another person except where due reference is made.

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30 November 1997

ABSTRACT

The northern jarrah forest relies on efficient nutrient cycling for its growth and long term sustainability. The decomposition of organic matter and the recycling of nutrients in such ecosystems are facilitated through the interaction of microflora with a myriad of invertebrates. The recolonisation of invertebrate fauna to rehabilitated bauxite mines is thus of critical importance to the long-term success of rehabilitation.

This study investigated the soil and litter mite fauna, important components of the invertebrate community well known for their numerical dominance and high biodiversity. A spring sampling of the mite fauna was undertaken, employing standard soil and litter sampling techniques and temperature controlled heat extraction. The effect of time since rehabilitation was investigated in 2, 5, 10 and 20 year old sites, chosen to represent successional-like stages in rehabilitation. A neighbouring forest control site was selected for comparison. Selected environmental variables known to influence mite abundance and diversity were also measured.

The abundance and species richness of the mite community in soil and litter increased with age of the rehabilitated site. The litter habitat of the 10 and 20 year old site displayed similar abundances to those of the forest control site.

At the Ordinal level, the Astigmata and Prostigmata were most abundant in the younger sites where vegetation was sparse and canopy cover was minimal. The Cryptostigmata were the numerically dominant Order once the litter and canopy cover developed, in total accounting for 70% of all mites sampled.

Distinct species-suites were identified for both the soil and litter, which could be related to the age sequence in litter development of rehabilitated sites. This included a 'generalist' suite that displayed insensitivity to environmental conditions across all sites. An intermediate suite of species that required successional-like development of

site characteristics, may indicate level of habitat development. A site-specific group of species that were restricted to the undisturbed forest site, represent species sensitive to habitat conditions.

The study has implications regarding level of taxonomic detail applied, when assessing the success of invertebrate recolonisation in rehabilitated sites. Although mite distribution at the Ordinal level was similar, analysis at the Family and species level revealed clear differences between the rehabilitated sites and the forest control.

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1.0 INTRODUCTION

1.1 Thesis Introduction

The northern jarrah forest, located in the south-west of Western Australia, exhibits a high floral diversity and supports numerous endemic fauna. The close proximity of the forest to the metropolitan region has made it an important conservation and recreation area which is highly regarded by the community. The forest region is managed by the Department of Conservation and Land Management (CALM) under the multiple-use concept, with current land-use practices including timber production, water production, conservation reserves, recreation reserves and mining all competing for resource use. The sustainability of land-use occurring within the jarrah forest is of prime importance. CALM utilises the concept of Ecological Sustainable Development in managing land-use within the jarrah forest. The ultimate aim of such a policy is the long term preservation of the jarrah forests' unique biological diversity and ecosystem services (Conservation and Land Management, 1992).

Mining is one of the most controversial land-use practices occurring within the northern jarrah forest. Since 1966, Alcoa of Australia Ltd has undertaken extensive bauxite mining operations in this area (Bartle & Slessar, 1989). The highly visual impact of bauxite mining and the associated destruction of landscape form, floral and faunal communities and ecosystem function may potentially affect the biodiversity of the forest. To Alcoa's credit, early recognition of the importance of maintaining the region's biodiversity led to the development of techniques for ecosystem restoration of mined sites. Although the science of ecosystem restoration is relatively new, Alcoa is recognised as a world leader, with a listing in 1990 by the United Nations Environment Program on its' 'Global 500' honour role (Environmental Protection Authority, 1995).

The first step in Alcoa's mine-site restoration was the re-establishment of vegetation primarily as timber plantations (Bartle & Slessar, 1989). Over time, techniques were developed to increase the diversity and abundance of the plant community, including

the introduction of important leguminous species in order to increase nutrient availability (Nichols, Koch, Taylor & Gardener, 1991). Further improvements in techniques have led to the re-establishment of floral communities comparable in diversity to un-mined jarrah forest, providing habitat and food requirements critical to faunal recolonisation (Nichols *et al.*, 1991).

The ability to predict the development of a multi-species community following a large scale disturbance, such as mining, remains relatively unknown (Cancela Da Fonseca, 1984). Thus, monitoring of faunal community development, following the development and assessment of vegetation, is essential for establishing the success and sustainability of rehabilitated sites.

To date, the majority of Alcoas' invertebrate faunal recolonisation investigations of rehabilitated bauxite sites have concentrated on the ant fauna (Majer, 1978; Majer *et al.*, 1984). Ant fauna were used as potential indicators of invertebrate return as they a are diverse and abundant component of the forest ecosystem, have a number of specific habitat requirements and are relatively well understood (Majer *et al.*, 1984). General trends from the studies suggest that the return of a diverse ant fauna within rehabilitated areas is dependant upon plant species diversity and abundance, litter, canopy cover and time.

The majority of a developing ecosystem's above ground primary productivity flows into the below ground soil community. As a result, the long-term sustainability of a restored site is dependent upon establishing a functioning soil ecosystem, in particular soil biota (Coleman & Crossley, 1996). The soil mesofauna contribute to important soil ecological functions such as decomposition and nutrient cycling and are suggested as potential bio-indicators of environmental conditions (Greenslade & Majer, 1993). The Acari (mites) and Collembola are often the most abundant element of the soil mesofauna and are part of the critical decomposer community. The return of the decomposer community to Alcoa's rehabilitated bauxite mines has received little attention. One such study by Greenslade & Majer (1993) identified that recolonisation

trends for Collembola were similar to those from previous ant investigations. In particular time since rehabilitation, high plant diversity and cover were associated with highly diverse and abundant collembolan fauna. Importantly the study also suggested that considerable time may be required for the return of a full complement of species, thus raising management considerations (Greenslade & Majer, 1993).

1.2 Research Objective

Knowledge of mite communities within the jarrah forest and rehabilitated areas is limited, with the majority of investigations considering the fauna at the Ordinal level. Thus, an investigation of the fauna at a Family level, will add to the limited knowledge of the decomposer community of restored mine sites. The examination of a range of development stages (age since rehabilitation) and alternative techniques, may also determine factors influencing mite recolonisation. An assessment of neighbouring jarrah forest mite fauna will provide base line criteria for assessing the success of rehabilitation techniques in fostering the development of mite fauna.

To describe the acarine (mite) communities of soil and litter in rehabilitated bauxite mines and determine the extent to which they approach the structure of communities of neighbouring un-mined northern jarrah forest.

1.2.1 Specific Aims

I. To describe the species abundance and diversity of mites in four rehabilitated bauxite mines and neighbouring northern jarrah forest site.

II. To determine to what extent the age of the sites and the method of rehabilitation influence the composition of acarine communities.

III. To describe selected environmental variables known to impact on soil diversity:

   A. litter depth and continuation;

   B. surface soil organic carbon content; and

   C. degree of canopy shading.

IV. To identify associations between acarine community parameters and the selected environmental variables.

V. To identify the most significant environmental factors of those described which contribute to the diversity and abundance of acarine communities.

VI. To develop a voucher catalogue of the mite fauna of an un-mined jarrah forest for future reference.

2.0 BACKGROUND TO THE STUDY

2.1 The Soil Environment

The soil is a complex heterogenous substrate derived over time from the interaction of climate, the abiotic matter and the biota. In fact, the soils' abiotic and biotic components are interdependent and give the soil ecosystem cybernetic properties. Soil organisms interact upon and affect the soil structure and vice versa (Lal, 1991; Lebrun, 1979; Moore & Walter, 1988; Richards, 1974). The soil environment is critical to a range of ecosystem functions including the decomposition of organic matter and the cycling of nutrients (Giller, 1996). Up to 90% of above ground primary productivity flows into the below ground soil community. Thus, the primary productivity of a terrestrial ecosystem is dependent upon soil ecosystem function (Coleman & Crossly Jr, 1996).

2.1.1 The Abiotic Component

The abiotic components of the soil consist of a mineral fraction, an organic fraction, soil water and the soil atmosphere. The abiotic soil components are interrelated, thereby affecting soil structure and ultimately soil quality.

A soil texture is defined according to its mineral fraction. The mineral fraction is made up of particles that vary in size, shape and chemical composition. The mineral fraction is classified according to particle size. Particles range from gravel with the largest particle size (greater than 2 mm), followed by coarse sand (2 mm to 0.2 mm), fine sand (0.2 to 0.02 mm), silt (0.02 to 0.002 mm) and clay, the smallest particles (0.002 mm or smaller). The percentage of each particle size type is used to classify soil types. A range of soil types exist, for example a sand (greater than 90% sand content) or loam (70% sand, 15% clay and 15% silt) (Coleman & Crossly Jr, 1996; Richards, 1974). In normal circumstances soil particles tend to aggregate into different sizes.

Soil organic matter consists of plant and animal components and is the primary resource of the soil ecosystem. The highly diverse nature of soil organic matter is a consequence of above ground plant and animal community diversity (Aoki, 1967; Mitchell, 1979). Plant organic matter may include leaves, twigs, flowers, bark and sloughed roots. The animal components may include faeces, other exuviae and body residues. The transformation of soil organic matter into humus and the subsequent release of nutrients occur via a range of interactions between the soil biota (Coleman & Crossly Jr, 1996; Richards, 1974).

Water is an important factor in the soil, influencing its physical and chemical properties. The maintenance of water within the soil matrix is controlled by a range of forces described as soil water potential. Weather condition, soil texture and structure may all determine soil water potential (Richards, 1974). The water potential of soils is critical to the maintenance and growth of the range of soil biota.

The ability of air to circulate through the soil is described as the soil atmosphere. A series of complementary processes influence the soil atmosphere. These may include respiration by plant roots, utilisation of oxygen by soil organisms and the associated production of carbon dioxide (Richards, 1974).

2.1.2 The Biotic Component

All soil biota have important roles which influence soil function. As a community the soil biota are critical to many ecological processes such as nutrient cycling, litter decomposition, soil aeration, seed dispersal, seed predation and as a diet for other soil animals (Coleman & Crossly Jr, 1996; Torgersen, *et al.*, 1995). The description of the soil biotic community encompasses microhabitat utilisation, distribution in the soil profile and organism body size. The size of a particular soil organism is the generally accepted method of classification, with groups being the microflora, micro-, meso-, and

macrofauna (Richards, 1974). The groups operate at various successional levels, interacting and influencing one another to varying degrees within the soil mosaic (Torgersen *et al.*, 1996). The particular contribution of each component of the soil fauna varies according to ecosystem type.

The soil microflora consists of a diverse and highly abundant community of bacteria and fungi which are directly responsible for the processes of decomposition and nutrient cycling. The microflora require moisture for survival and therefore inhabit the aquatic portion of the soil environment. Microflora may also affect soil structure through the production of organic elements that assist soil aggregation (Coleman & Crossley Jr, 1996; Richards, 1974).

Microfauna consist of organisms less than 200μm in length and include protozoans, small nematodes and rotifers. As with the microflora, moisture is essential for their activity, therefore they are restricted to water films in the soil. The feeding activity of the group may affect microflora populations, thus indirectly influencing nutrient dynamics (Richards, 1974). Protozoa display greatest abundance in upper soil portions and may influence decomposition indirectly through feeding on bacteria. Nematodes are an extremely abundant part of the microfauna and display highest abundance in the root zone. Nematodes exhibit a variety of feeding preferences including bacteria, fungi, Protozoa and living plant roots and therefore may also influence decomposition. Furthermore, nematodes also provide an important food source for a range of soil biota (Coleman & Crossley Jr, 1996).

The mesofauna represent the intermediate group of the soil biota with a size range of 2 mm to 1 cm. The group contains a diverse assemblage of organisms including, Nematoda (larger species), Collembola, Acari, Enchytraeidae (smaller species), and a range of other Arthropoda. As a whole, the soil mesofauna inhabit, and are restricted to, air-filled pore spaces. The highly diverse nature of the mesofauna influences decomposition, nutrient cycling and soil structure in a number of ways and will be discussed later in further detail. The Acari and Collembola are the dominant groups of

mesofauna with numerical abundances often accounting for up to 95% of mesofauna (Coleman & Crossley Jr, 1996).

The macrofauna is a diverse group made up of organisms greater than 1 cm, such as the Isopoda, Chilopoda, Araneae, and Oligochaeta. The macrofauna include highly mobile organisms whose movement throughout the soil creates pore spaces. Macrofauna have important effects on nutrient cycling as a result of the fragmentation of litter and subsequent stimulation of microfloral activity. However, the group is better recognised for contributions to soil structure. Their activity through the soil creates soil pores, mixes organic matter with micro-organisms and redistributes detritus. Other contributions to soil structure occur through humification and production of faecal pellets which have effects on soil aggregation. (Coleman & Crossley Jr, 1996; Richards, 1974).

2.1.3 The Importance of Soil Biota Biodiversity

One of the community attributes of the soil biota often described as distinctive is the considerable degree of organism diversity (Beare, *et al.*, 1996). Biodiversity commentators agree soil biota displays one of the highest species diversity of all terrestrial ecosystems. However, actual estimates are somewhat speculative and may vary considerably (Giller, 1996).

Moore & De Ruiter (1997) suggest high biodiversity within the soil community contributes to soil ecosystem stability. Interaction between the suite of soil organisms and microhabitats results in complex 'aggregate' formations of biota. The biota-aggregates are based on the similarity between organisms forming along niche overlaps. It is suggested that the development of such biota-aggregates assists with stability of the soil system (Moore & De Ruiter, 1997).

Despite the increasing recognition that the soil environment is highly organism-diverse, little is known of the factors influencing the conservation and management of soil communities (Andre, Noti, & Lebrun, 1994; Giller, 1996). To date, the soil community has lost out to a focus on 'cute, furry, and cuddly' terrestrial fauna (Andre *et al*, 1994; Saunders, 1987). In addition, a range of problems are associated with the study of soil fauna. In particular, they include the opaqueness of the soil medium, the small size of the organisms, high levels of abundance and diversity of soil biota, the lack of taxonomic knowledge and specialists for species identification and a relatively low level of awareness of their central ecological role (Giller, 1996; New, 1987; Saunders, 1987).

Increasingly, the protection of biodiversity is called for on an ecosystem level, emphasising the protection of habitats, species and their functions *in situ*. This notion, together with the strong functional link between the soil biota and above ground plant community, emphasises the need for increased attention to the function and role of soil community biodiversity (Moore & De Ruiter, 1997).

2.1.4 The Soil Mesofauna

The soil mesofauna, as previously mentioned, display large organism diversity. As a group the mesofauna have important roles in nutrient dynamics and soil structure. Decomposition and nutrient cycling are affected by mesofaunal regulation of microfloral, micro- and mesofaunal populations and via the physical fragmentation of plant tissue. Soil structure may be affected by mesofaunal production of faeces, biopores, humification and mixing of elements (Coleman & Crossley Jr, 1996).

2.1.5 The Soil Acari

The free living mites are the most diverse and abundant taxa of the mesofauna and provide important ecological functions in the soil environment (Coleman & Crossley Jr, 1996; Wallwork, 1967). The numerical dominance of mites is a product of their

ecological tolerance of heterogenous soil niches and the range of trophic levels they occupy (Aoki, 1967; Moore & Walter, 1988). The use of the term soil mites in this discussion refers to both soil and litter mites as they are often the subject of concurrent studies and from an ecological point of view, are part of the 'below ground' community.

The soil mites belong to several hundred Families which are classified into the four Orders of Cryptostigmata, Prostigmata, Mesostigmata and the Astigmata. In the majority of soils the Cryptostigmata are the most abundant and are generally small and slow moving (Seastedt, 1984; Wallwork, 1967). The Cryptostigmata generally require a high humidity environment and tend to be most abundant in moist organic soil layers. Cryptostigmata display greatest abundance in rich forest humic soils, accounting for up to 75% of the Acarine fauna (Torgersen *et al.*, 1995; Wallwork, 1967). Seasonal fluctuations in population size and structure are greater in the Cryptostigmata than the Mesostigmata and Prostigmata. The Cryptostigmata are often the subject of mite investigations due to their importance in forest soils, and their uniqueness as a soil faunal group (Coleman & Crossley Jr, 1996; Wallwork, 1967). The high numerical dominance, display of juvenile polymorphism and a slow reproductive rate are three unique characteristics of the Cryptostigmata (Coleman & Crossley Jr, 1996).

The Prostigmata and Mesostigmata are generally more active and therefore more widely distributed through the soil layers. The Prostigmata occupy a range of trophic levels including predatory. The Mesostigmata are generalist predators, and important regulators of mesofauna populations, containing specialist predators of nematodes and collembolans. The Mesostigmata are less abundant than Prostigmata and Cryptostigmata in the soil. (Huhta, 1996; Wallwork, 1967). The Astigmata are generally not common in the soil. They are associated with drier conditions and perturbed soils, such as agroecosystems and other modified ecosystems (Coleman & Crossley Jr, 1996).

Mite abundance for forest ecosystems may reach 250 000 m^{-2} individuals, with species richness values of 75-100m^{-2} (Moldenke & Lattin, 1990a). However, recent investigations suggest these estimates are extremely conservative. Andre *et al.*, (1994) in an investigation of sand dune soils which used new and highly efficient extraction techniques, obtained abundances and species richness values far exceeding any recorded in the soil to date. As such the study highlights the need for greater investigations of the environmental determinants of soil mite abundance and diversity.

2.1.5.1 Major Factors Influencing Abundance and Distribution

Investigations of soil mite abundance and diversity suggest that on a macro scale, annual precipitation is the key controlling factor. Abundance of soil mites decreases with increasing aridity, particularly in Mediterranean type climates which are characterised by cool wet winters and hot dry summers (Di Castri & Vitali-Di Castri, 1981; Kinnear, 1991). The limited Australian investigations to date support this general trend (Table 2.1). On the same continental scale, soil organic matter content has also been linked to soil mite abundance and diversity. Abundance and diversity are higher in soils displaying high organic levels, particularly in arid environments (Di Castri & Vitali-Di Castri, 1981; Kinnear, 1991; Spain & Hutson, 1993). However, it is important to recognise that the identification of a single controlling environmental factor is somewhat complicated by the degree of interaction between factors. For example the organic matter content of the soil is derived primarily from the above ground plant community which, in turn, is influenced by the area's prevailing climate (Klironomos & Kendrick, 1995).

At the individual community level, soil heterogeneity mediates soil mite abundance and diversity. The potentially unlimited combinations of primary resources such as leaf matter, rotting wood, and the physical components create a patchy soil mosaic. In response to the heterogeneous soil environment, mites display vertical and horizontal migrations in search of resources such as food and shelter. The greatest vertical migrations are in response to soil moisture changes (Di Castri & Vitali-Di Castri; 1981,

Huhta, 1996). Soil mites, as with most other soil fauna, display their greatest abundances in the top 4 cm of the soil (Holt, 1985; Wallwork, 1967). Mites, like many soil fauna, display a contagious horizontal distribution. This non-random distribution is often referred to as aggregated (Usher, 1976).

Mite abundance and diversity at the community level is commonly assessed against the factors of soil temperature, soil moisture, litter quality, quantity and extent of coverage, pH and soil organic carbon content (Holt, 1985; Klironomos & Kendrick, 1995; Mitchell, 1979; Torgersen *et al.*, 1995). Research on the influence of such factors on soil mites within Australia is limited (Hutson & Veitch, 1987).

In Mediterranean climates mites exhibit strong seasonal population fluctuations. Minimum population and activity levels co-occur with maximum temperature levels and/or minimum moisture levels (Di Castri & Vitali-Di Castri, 1981; Hutson & Veitch, 1987). Mite peak abundances in Mediterranean soils occur primarily in spring, with an occasional second peak in autumn and minimum populations in summer. Table 2.1 highlights that overall such trends hold true in the limited Australian investigations. For example, Postle (1989) and Hutson & Veitch (1987) both recorded spring peak mite abundances.

The relative densities of Cryptostigmata, Prostigmata and Mesostigmata in soils are often found in distinct ratios according to ecosystem type. The ratios are primarily influenced by the prevailing climate with moisture a key determinant (Di Castri & Vitali-Di Castri, 1981; Wallwork, 1967). Research suggests Prostigmata display larger densities than Cryptostigmata in arid environments (Di Castri & Vitali-Di Castri, 1981; Kinnear, 1991). The above ground plant community and subsequent resource inputs into the soil are other factors suggested to influence relative densities (Di Castri & Vitali-Di Castri, 1981). Di Castri & Vitali-Di Castri (1981) suggest a progressional decrease in the abundance of Cryptostigmata relative to Prostigmata in Mediterranean Chilean soils, as one proceeds from deciduous through to coastal shrubland. The

Location	Rainfall (annual)	Mite faunal density Nos.m^{-2}	Peak density	Sampling depth (cm)	Author
Mallee, semi-arid Eastern Goldfields Western Australia	254 - 350	2 500 - 16 000	n/a	5	Kinnear (1991)
E. obiqua / E. Baxter South Australia Hale Cons. Park Engelbrook Nat. Trust Reserve	 635 690 1050	 9 556 - 64 979 19 563 - 76 122 20 745 - 71 785	Spring	8	Hutson & Veitch (1987)
Jarrah forest Dwellingup Western Australia	1000	37 691 - 126 441	Autumn	9.7	Postle (1989)
Tropical Rainforest North Queensland Dianbulla Gadegarra Pin Gin Hill	 1450 n/a 3250	 21 129 - 33 310 21 017 - 22 349 10 469 - 26 127	n/a	4	Holt (1985)

Table 2.1 Soil mite densities of Australian sites of varying annual precipitation.

relative densities, therefore, appear to broadly relate to the soils resource quality, primarily the quantity and degree of litter cover. Such general patterns have been found in the Australian investigations, with Prostigmata dominance in arid mallee woodlands and Cryptostigmata dominance in moister tropical forests (Holt, 1985; Kinnear, 1991).

In summary, climatic conditions and litter cover effect on soil/litter microclimatic conditions, together with soil organic matter, are the key controlling factors influencing the abundance and distribution of mites in the soil environment.

2.1.5.1 *Contributions to Soil Processes in Ecosystem*

Soil mites, in particular the detritus species (Cryptostigmata), play an important role in soil fertility. Mite activity indirectly influences decomposition and nutrient cycling. Their activity directly influences microfloral, micro- and mesofaunal populations and

soil structure. As a result, mites are increasingly suggested as indicators of soil quality (Lebrun 1979; Moore & Walter, 1988; Wallwork, 1967).

Mite comminution of organic matter may be direct or indirect, occurring during microfloral feeding (attached to the detritus). The effect of the comminution is the physical breakdown of plant detritus producing an increase in surface area available for microbe utilisation, thus indirectly increasing nutrient mineralisation and humification (Lebrun, 1979; Moore & Walter, 1988). As mite comminution makes little or no chemical change to the substrate, the process initially appears wasteful. However, Lebrun (1979) highlights that organic matter decomposition is five times faster where there is a mite-microbe interaction than where microbes are solely responsible for decomposition. However, the importance of mite comminution varies according to ecosystem type. For example, mites are particularly important in some forest soils, with the Cryptostigmata responsible for up to 50% of annual leaf comminution (Moore & Walter, 1988). The comminution of plant litter by mites is also beneficial to soil structure, as a result of mixing the detritus, often in various stages of decomposition, with microflora through the soil profile. Consequently, lower soil layers are enriched and soil particle aggregation is enhanced (Wallwork, 1967).

A complex interrelationship exists between mites and microfloral populations. The impact of acarine grazing on fungi may be extensive. McBrayer (cited in Lebrun, 1979) found up to 56% of fungi net production was consumed by mycophagus species. Mites may therefore directly effect the growth rate of fungi. Mite grazing may also be highly specific and result in the consumption of select fungal species, with subsequent changes to fungal community structure. The possible effect of both grazing types is a change to decomposition and subsequent mineralisation and/or immobilisation in soil ecosystems (Lebrun, 1979; Moore & Walter, 1988).

Mite activity in the soil also contributes to the transport of elements in the soil. As previously mentioned, the mixing of elements by comminution may deposit nutrient rich resources lower into the soil profile. Movement by mites through the soil profile

may also assist in the dispersal of microfloral propagules, for example passively via adhesion to the cuticle or through the gut. Benhan & Hill, cited by Moore *et al* (1988) found that Cryptostigmatid mites carried propagules from over 20 fungal species. Dispersal may result in increased microflora distribution, provision of resource substrates and may effect competition. Therefore, the dispersal of propagules may result in changes to community structure, subsequently affecting decomposition and nutrient dynamics (Moore & Walter, 1988).

The high diversity and abundance of edaphic mites make them valuable indicators of soil quality (Lebrun 1979; Moore & Walter, 1988). Mites have been suggested as useful indicators in soil classification, humification analysis, determining microhabitat variation, and preventative bioassays (Hutson, 1989; Lebrun, 1979). From an Australian context, recognition of the indicator value of mites is acknowledged by their inclusion in a national list of seventeen invertebrate indicator species (EPA, 1995).

2.1.6 The Impact of Disturbance on Mesofaunal Communities

The wide variety of land-use practices such as agriculture, forest management and mining have recognised detrimental effects on the soil biotic community, in particular the mesofauna. Overall, the effects are dependant upon the degree of perturbation, in particular the quantity and quality of vegetation and litter removed.

It is increasingly recognised that agroecosystem practices affect soil mesofauna both qualitatively and quantitatively (Franchini & Rockett, 1996; Roper & Gupta, 1995). One agroecosystem practice widely investigated is the impact of tillage. The abundance and biomass of mesofauna from a range of studies are higher in non-tillage systems as opposed to conventional tillage systems (Franchini & Rockett, 1996; Hendrix, Parmelee, Crossley Jr, Coleman, Odum & Groffman, 1986; Roper & Gupta, 1995). Furthermore, Franchini & Rockett (1996) found that Cryptostigmata species diversity was reduced in conventional tillage and reduced tillage as compared to a non-tillage

practice. The effect of conventional tillage practice in decreasing plant resources and hence food and habitat availability is suggested as the main reason for decreases in mesofaunal numbers (Roper & Gupta, 1995).

Forest management practices are often the subject of much controversy. Nowadays, this includes the effects of such practices on the soil, in particular the potential impacts on soil biota. The perturbation resulting from forest management practices such as timber extraction, regeneration, fire management and recreation management all have varying effects on soil mesofauna. Studies have suggested that the practices drastically reduce the abundance, diversity and community structure of soil fauna (Moldenke & Lattin, 1990a). In their (1990a) study of coniferous forests, clear-felling and regeneration burning reduced total mesofaunal abundance by as much 90% (Moldenke & Lattin, 1990a). Furthermore, investigations comparing old growth and regrowth forests suggest that for the abundant species common taxa are few until the new canopy is well developed, for example after 20 to 40 years (Moldenke & Lattin, 1990b).

Cancela Da Fonselca (1990) also investigated a range of forest regeneration practices. His study established that the greater the management level, the larger the impact on litter characteristics such as moisture, organic matter and nitrogen content. Decreases in the three litter characteristics were correlated with decreases in densities of Cryptostigmata, Prostigmata and Mesostigmata. The average density of the three mite orders decreased steadily with increasing degree of perturbation (Cancela Da Fonseca, 1990). The greatest impact was on the Mesostigmata abundance, in some cases resulting in total absence of the Order, thus affecting the Mesostigmata's primary regulative role of decomposer organisms (Cancela Da Fonseca, 1990).

In forest ecosystems the removal of vegetation has been found to alter light infiltration and in certain conditions (after rainfall) accelerate breakdown of litter on the forest floor (Poinsot-Balaguer, 1996). The potential of such effects may be magnified according to climate. In Mediterranean climates it may result in changes to microclimatic conditions,

with soil and litter conditions being drier, warmer and lighter in summer and more moist and colder in winter (Poinsot-Balaguer, 1996). Such changes may potentially effect soil faunal abundance and community structure.

The impact of fire on soil fauna has been the subject of a range of investigations both within Western Australia and overseas. In one of the first Western Australian investigations into the effects of prescribed burning on soil/litter mesofauna in a forest, McNamara (1955) found that the practice reduced mesofaunal numbers at the Ordinal level. Springett (1976a), in a similar investigation of Dwellingup forest soil faunal community, found that prescribed burning affected the abundance and species diversity of mesofauna. In addition, it was found that the suggested fire regime of 5-7 years was inadequate for the recovery of the fauna to pre-burn levels, with 20 species m^{-2} sampled in the burnt jarrah forest as compared to 40 species m^{-2} in the unburnt jarrah forest. Springett (1979) continued the research in Dwellingup forest with an investigation of short-term effects of high intensity prescribed burn on soil fauna. The outcome of the study was that burning reduced the total number of soil mesofauna and simplified the community structure.

A study by Majer (1984) considered the return of soil and litter mesofauna after fire over the short-term (13 months). As with Springett's (1976a, 1976b, 1979) findings, he found the majority of soil fauna at the Ordinal level displayed decreased abundances. The investigation found that at least six months elapsed before soil mite densities (at the Ordinal level) in the burnt area fell to levels below those in the unburnt site. Likewise, the litter mites in burnt and unburnt sites were comparable until nine months after the fire, when burnt densities fell below those of unburnt (Majer, 1984). Abbott (1984) conducted a similar investigation over an extended period (3 years), and found that at the Order level, all soil and litter fauna (excluding 3), recovered in density within the study period. Potential effects on mite community structure were unknown as both Majer (1984) and Abbott (1984) studies only considered mites at the Ordinal level.

The overall trend from these limited Australian investigations of fire effects on soil and litter fauna is a short-term reduction in the abundance, diversity and structure of the fauna. Apparent conflicts between studies such as Springett (1976a, 1976b,1979) and Abbott (1984) are related to the level of taxonomic identification. Springett considered fauna to the species level, whereas Abbott's investigation extended only to Order level. To date, the impact of fire perturbations on mite communities remains poorly described.

The open-cut method of bauxite mining results in the total destruction of landform, floral and faunal communities and ecosystem processes. The potential results of such activity include a decrease in the abundance and diversity and change in the community structure of soil fauna (CSIRO, 1997). The replacement of ecologically complex ecosystems with simpler systems may potentially result in ecological modifications to the soil faunal community.

2.2 The Northern Jarrah Forest

2.2.1 The Physical and Biological Environment

The study area is part of the Northern Jarrah forest, a unique feature of the Western Australian environment. The region experiences a Mediterranean climate of cool wet winters and hot dry summers, with an average rainfall of 1100 mm per annum (Gentilli, 1989). The study area lies on the ancient surface of the Darling Plateau. The soils are lateritic, made up of various elements derived from *in situ* erosion and therefore are low in nutrients (Churchland & Dimmock, 1989). However, the cemented upper profile of the soil may contain economical quantities of bauxite (Ward, Slessar & Glenister, 1993).

The study area is dominated by jarrah *(Eucalyptus marginata)* / marri *(Corymbia calophylla)* type vegetation as described by Beard (CALM, 1987). The forest displays

high floral diversity, and although a number of species are undescribed, coarse estimates are put at almost 800 species. The most common families include the Myrtaceae, Proteaceae, Papilionaceae and Orchidaceae (Bell & Heddle, 1989). The jarrah forest ecosystem displays the lowest nutrient status of all Australian eucalypt forest ecosystems, with the majority of nutrients contained in the vegetation and litter (Ward & Koch, 1996). The soil born pathogen *Phytophthora cinnamomi* (dieback) occurs throughout the forest. The effect of dieback on both tree and understorey species dictates careful consideration in mining and rehabilitation of the forest.

As a result of broad studies, the Northern jarrah forests' vertebrate fauna is relatively well known, with a number of endemic species. Nichols & Muir (1989) reviewed the vertebrate fauna highlighting that a small number of species are well understood, but that the majority of species' roles in ecosystem function is poorly understood. On an Australian scale the soil/litter invertebrates of the Northern Jarrah forest are relatively well known at the Ordinal scale (CALM, 1992). To date, soil/litter invertebrate studies in jarrah forest have focused on quantitative analysis and assessment of the impacts of various land-use practices including mine rehabilitation (Greenslade & Majer, 1993; Postle, 1989; Springett 1976a, 1976b, 1979; Majer, 1984; Majer & Abbott, 1989; Nichols & Burrows, 1985).

2.2.2 Resource Use

The close proximity of the Northern Jarrah forest to the metropolitan region has made it an important community asset with twenty percent of the forest set aside for conservation in 'A' class reserves (Nichols, Koch, Taylor & Gardner, 1991). CALM is primarily responsible for the forest region and uses a concept of multiple-land use to accommodate the various demands for the region. Timber production, water protection, recreation, tourism, conservation and educational research, and mining are just some of the activities competing for use of the forest. CALM applies the concept of ecological sustainable development in its management of the jarrah forest. In essence the concept

aims to meet the requirements of the current generation without comprising the potential of future generations (CALM, 1992). The application of the concept aims to ensure land-use is sustainable thereby preserving the ecosystem processes and the biological diversity of the forest. Within the northern jarrah forest a range of the land-uses are complementary, whilst others by their nature exclude other land-uses (CALM, 1992). Mining is one of the most controversial uses as the resulting perturbations involve the total destruction of landscape form and ecosystem processes and therefore may be detrimental to the maintenance of the regions' biodiversity.

2.2.3 Bauxite Mining

Alcoa of Australia operates three open cut bauxite mines in the northern jarrah forest, with extensive mining reserves (Figure 2.1). Alcoa's current annual production of bauxite is approximately twenty million tonnes (Elliott, Gardner & Butcher, 1996). The mining process is well outlined by Nichols *et al* (1991) and essentially results in the complete destruction of landscape form and ecosystem processes (Bartle and Slessar, 1989). The extensive nature and detrimental impact of the open cut method, together with the potential for increases in dieback and salt mobilisation were important considerations requiring initial redress by Alcoa.

2.2.4 The Development of Rehabilitation Techniques

Mining of the jarrah forest by Alcoa is a temporary landuse, which requires extensive planning and the implementation of restoration technology, to return the mined areas to a sustainable forest ecosystem. The northern jarrah forests' uniqueness has resulted in a problematic transfer of rehabilitation technology. To overcome this, Alcoa established extensive research programs focussing on incorporating a wide variety of rehabilitation techniques. Until 1995, Alcoa cleared 9 300 ha of jarrah forest and clears a further 450 ha per annum (Elliott *et al.*, 1996; Ward & Koch, 1996). A range of techniques have

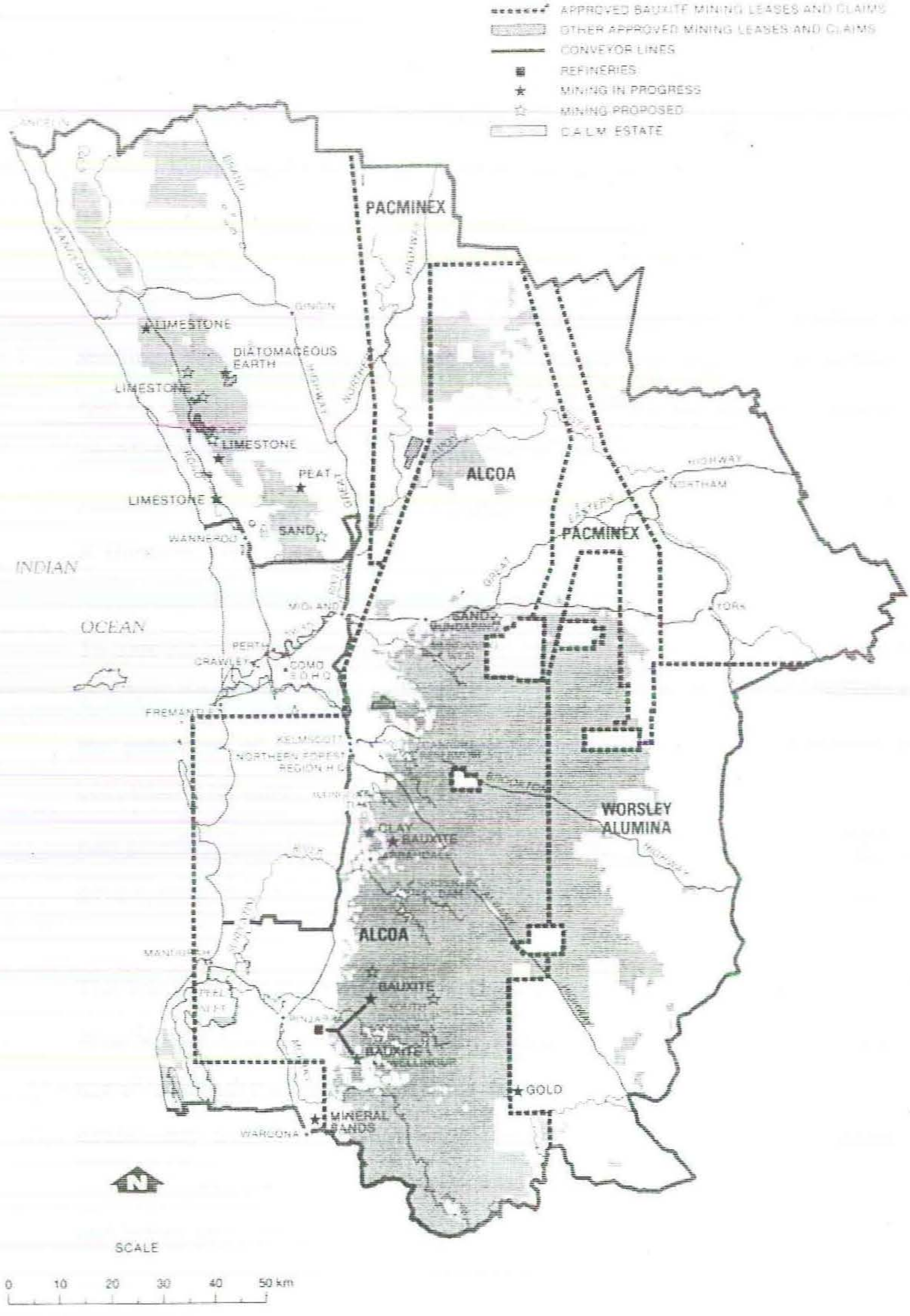


Figure 2.1 The extent of Alcoa's bauxite mining leasehold and current mining operations within the northern jarrah forest.

been employed in the 7 120 ha rehabilitated to 1995, thus the type of ecosystems restored and the degree of success varies accordingly (Elliott *et al*, 1996).

The initial aim of Alcoa's revegetation (1966) was to simply establish timber plantations for subsequent harvesting. *Pinus* and eastern states *Eucalyptus* species seedlings were planted primarily for their resistance to *Phytophthora cinnamomi.* and also for their potential timber value (Elliott *et al.*, 1996). The techniques employed to establish plantations paid little attention to pit reconstruction and soil handling, resulting in below average tree growth and in some cases a wind-throw of trees (Nichols & Burrows, 1985; Tacey, 1979).

To improve vegetation establishment, from 1970 landscaping techniques were adopted to enhance the compatibility of mined pits with the surrounding landscape. In addition the procedure of pit-floor ripping was introduced to reduce compaction effects associated with mining and restore subsoil channels for drainage. As a result greater root growth penetration occurred, thereby improving tree and understorey stability and development (Nichols & Burrows, 1985).

The low viability of plantations from both a management and economic perspective soon became apparent (Tacey, 1979b). Consequently, the research focus shifted to the use of local understorey and overstorey species in revegetation. In 1976 techniques for establishing leguminous understorey species were introduced. The results were increased understorey, ground cover, improved soil stabilisation, nitrogen availability and habitat provision (Nichols *et al.*, 1991).

The next major improvement in rehabilitation was the product of 1977 trials investigating techniques for handling the biologically active topsoil. The upper 50 mm of jarrah forest soils may contain the highest levels of micronutrients, organic matter and inoculum of vesicular arbuscular mycorrhiza (Nichols *et al.*, 1991). Tacey and Glossop (1980) found that the removal of the topsoil (top 100 mm) layer from the

overburden and its reapplication (without storage) in profile, produced regenerating vegetation with species diversity most comparable to unmined jarrah forest.

Subsequently, further evidence of the importance in soil handling was established by Vlahos and Bell (1986), with their finding that approximately 750 viable seeds (per meter squared) representing 68 plant taxa may be found in jarrah forest soils.

Further improvements in rehabilitation methods involved changes to sub-soil techniques, resulting in improved site drainage (Nichols *et al.*, 1991). These improvements, in conjunction with the introduction of dieback hygiene measures, enabled the re-introduction of species sensitive to dieback (Nichols *et al.*, 1991). The ability to introduce dieback prone species was an important step forward in revegetation.

The evolution of Alcoa's rehabilitation strategies has enabled the re-establishment of jarrah forest vegetation that is comparable to the surrounding forest. The current techniques are well detailed by Ward *et al.* (1993) As a result, Alcoa's rehabilitation objective changed substantially over time and currently is to establish:

> *"a self-sustaining, forest ecosystem that maintains the water, timber, recreation and other values of the pre-mining forest".*

The ability of the current rehabilitation technology to restore a diverse, abundant plant community in a short period (10 years) is well recognised (Bartle and Slessar, 1989; EPA, 1995). However, the long term sustainability of the restored forest ecosystems has not yet been demonstrated due to the relative young age of current rehabilitation techniques (Bartle and Slessar, 1989). Nevertheless, Alcoa's current rehabilitation technology is well recognised for its excellence. As part of a Federal government initiative to achieve 'Ecological Sustainable Development' in mining, Alcoa's rehabilitation technology is employed as a national benchmark for 'Best Practice in

Environmental Management' (EPA, 1995). Recognition of Alcoa's revegetation technology and environmental management programme is global and culminated in 1990 with its listing by the United Nations Environment Program as a member of 'global 500' for environmental excellence (EPA, 1995; Ward *et al.*, 1993).

The final stage in the rehabilitation process involves the monitoring of sites and the assessment of trials. This step is a formalised part of Alcoa's rehabilitation procedure, as the monitoring and assessment are key components for meeting completion criteria objectives (Elliott *et al.*, 1996). Recently Alcoa reviewed the use of rehabilitation performance measures in consultation with the CALM, other government agencies and the community. In this process a range of broad principles have been developed to define rehabilitation completion criteria. In essence, the principles aim to develop monitoring techniques that assess the long term sustainability of revegetation and the ability of sites integration with surrounding land use (Elliott *et al.*, 1996).

2.3 The Impact of Rehabilitation on Soil and Litter Biota

As previously discussed the importance of invertebrates to a range of ecosystem functions is well acknowledged. Since Alcoa's rehabilitation aim is to establish a functionally diverse self sustaining ecosystem, invertebrate recolonisation is critical. To examine the success of invertebrate recolonisation, Alcoa have undertaken a number of comparative studies with un-mined forest. The primary aims of such investigations were to determine the effect of rehabilitation techniques on invertebrate recolonisation and to develop baseline criteria for assessing rehabilitation (Nichols *et al.*, 1991). The investigations have ranged from the decomposer community through to predatory invertebrates. In particular, ants, collembola and spiders have been assessed as indicators of rehabilitation success (EPA, 1995; Greenslade & Majer, 1993; Nichols *et al.*, 1991).

Majer (1978) considered a range of soil and litter surface dwelling invertebrates in a three year study of alternative rehabilitation techniques - no-revegetation, planting of marri seedlings, or seeding with a diverse range of natives. Increasing plant area cover, plant species richness, invertebrate abundance and ant abundance were associated with increased diversity of planting. In particular, ant fauna displayed a species structure most comparable to unmined forest at the native seeded site (Majer, 1978). Majer *et al* (1984) further investigated ant recolonisation in 30 alternative rehabilitated sites. Conclusions drawn from the study suggest that recolonisation by a diverse ant fauna is dependant upon range of factors. As previously identified high floral species richness and diversity was important along with the presence of a well developed canopy, the elapse of sufficient time, litter of adequate depth and continuation, and wood debris (Majer *et al.*, 1984).

The return of a range of soil invertebrate fauna to rehabilitated areas is critical as they are the diet for a range of predatory invertebrates. Predatory invertebrates often display reduced abundance in disturbed systems and therefore the range of important functions they perform may be affected (Cancela Da Fonseca, 1990). Investigations of Alcoa's rehabilitation by Nichols & Burrows (1985) also supports the notion of time as the essential component for the development of microhabitats that support a return of diverse and abundant predatory invertebrate fauna.

Greenslade & Majer (1993) investigated factors influencing the restoration of collembolan communities, a critical component of the decomposer community. Collembola are the only group of mesofauna (and true soil inhabitants) to receive attention in this context. A range of positive correlations between collembolan fauna and environmental variables were identified, similar to those found in the ant investigations (Greenslade & Majer, 1993). Time since rehabilitation, high plant diversity and high plant percentage cover were all associated with a highly diverse and abundant collembolan fauna (Greenslade & Majer, 1993). The identification of collembolan fauna to species level, revealed that decomposer species were only present in sites containing a well developed humus layer. The development of rich moist humus

is dependant upon the accumulation of litter and the closing of the canopy, both requiring time. Given the central role the decomposer community play in the continual productivity of forest ecosystems, the finding that the return of full species complement of collembolan may require extensive time is an important consideration in the management of rehabilitated areas (Greenslade & Majer, 1993).

Forest mite fauna are an important component of the decomposer community usually displaying numerical dominance. Their recolonisation of rehabilitated areas is essential to long term productivity of such sites. The mite fauna of undisturbed northern jarrah forest and perturbed forest is relatively unknown. Investigations to date are limited, with the majority simply recording presence of mites at the Order level. Postle (1989) as part of an investigation of nutrient dynamics and soil/litter invertebrates of Dwellingup jarrah forest determined mites accounted for 96% of soil and 77% of total litter invertebrates. Total mite abundance ranged from 37 691 - 126 441 m^{-2} (Postle, 1989). Postle's (1989) results are comparable with Springett's (1976a) *Eucalyptus/Banksia* woodland investigation with mite mean abundance of 77 000 m^{-2}. The ability of Alcoa to assess the development of mite fauna in rehabilitated areas is dependant on baseline criteria from typical neighbouring forest, no data at lower taxonomic levels exists.

From the invertebrate investigations to date a range of general trends emerge. Primarily, the successional development of a rich soil invertebrate fauna is dependant upon high plant diversity and biomass and the passing of sufficient time (Greenslade & Majer, 1993). The influence of the plant community structure in providing microhabitats for soil fauna exploitation is also recognised in the general literature (Aoki, 1967; EPA, 1995; Mitchell, 1979). Such factors have also been associated with investigations of eucalypt litter breakdown in rehabilitated bauxite mines (Ward *et al.*, 1991). As the age of Alcoa's rehabilitated sites (current techniques) are relatively young, limitations are placed on the interpretation of faunal recolonisation undertaken to date. There is a recognised need for further investigation of soil fauna recolonisation, in particular the

decomposer community, as the long term sustainability of the restored forests is dependant upon a diverse decomposer community (Greenslade & Majer, 1993).

3.0 METHODOLOGY

The study investigated the recolonisation of mite fauna in sites rehabilitated by a range of techniques at Alcoa's Jarrahdale mine site (32^{o} 18's , 116^{o} 05 'e) and a 'typical' neighbouring jarrah forest site. The investigation was restricted to Alcoa's Jarrahdale mine site in order to minimise potential variation in factors know to impact on soil acarine abundance and diversity.

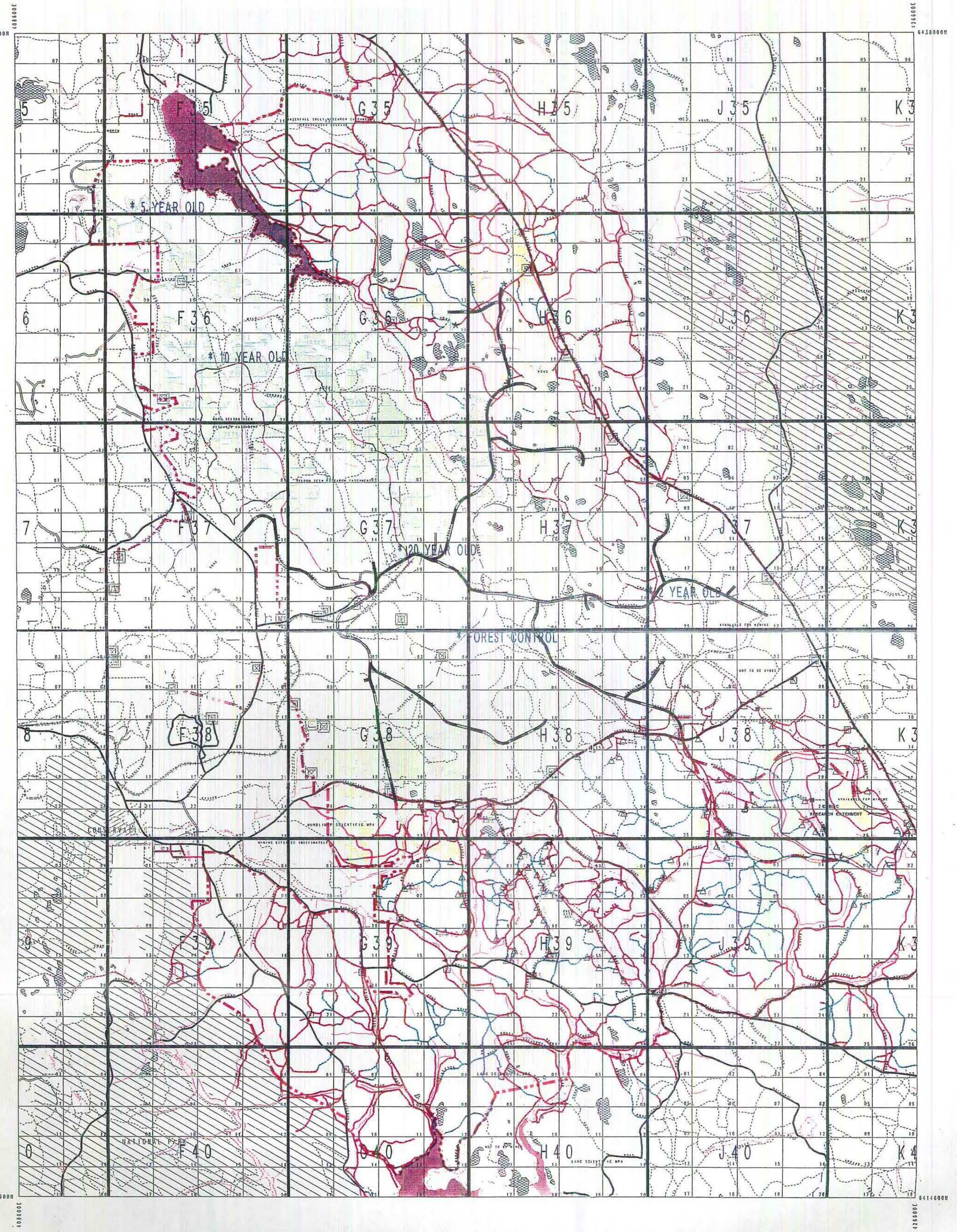
Four rehabilitated sites were selected over a range of age structures (2,5,10 and 20) previously suggested to represent distinct stages in rehabilitation development (Kabay and Nichols, 1980). In particular, the age (stage) of each site was selected to investigate the potential effects of microhabitat development on acarine recolonisation. The control site selected from the surrounding jarrah forest was chosen to represent a typical area of pre-mined forest. The forest control was selected to provide base line criteria, used to assess acarine recolonisation of rehabilitated areas. The site was selected as it was last salvage cut in 1983 and last burnt in 1989, thereby reducing potential extraneous variation.

Within each site two 100 m transects were established at random. The placing were made at least 50 meters from any disturbance, such as an access roads in order to minimise possible edge effects.

3.1 Site Descriptions

The overall locations of sites are displayed in Plate 3.1. Individual site characteristics are discussed below.

Plate 3.1 Alcoa Jarrahdale mine-site map displaying sample site locations.



JARRAHDALE AREA

Date : 24/04/1996

(field operations)

Scale 1:50000

2 year old

This 3.6 ha site is located on the corner of Peacock Rd & Chandler Rd , corresponding to Alcoa mine map reference J37 21, with rehabilitation completed in 1994 (Plate 3.1). The site represents 'stage 1' of revegetation development, with developing understorey and young saplings (Plate 3.2) (Kabay & Nichols 1980). This is the only study site rehabilitated by all current rehabilitation techniques (post 1988). In summary the methods consisted of: battering of the pit walls and ripping of the floor to correspond to surrounding landscape (September 1993); replacement of overburden and followed by the relaying of fresh topsoil (November 1993); topsoil ripping to a depth of 2 m using a winged tine (February 1994). A hand seeding of diverse native mix was sown in April 1994 and consisted of: 21 legume species at a rate of 0.700 kg/ha; 37 understorey species at a rate of 0.210 kg/ha; *Macrozamia riedlei* 1.2 kg/ha; *Eucalyptus marginata* at a rate of 2.2 kg/ha; *Corymbia calophylla* at a rate of 4.0 kg/ha (Alcoa, 1976 - 1994).

Plate 3.2 The youngest rehabilitation (2 year old) clearly showing the immature stage of vegetation characterised by developing under-storey and lack of canopy cover.

5 year old

A 9.27 ha site, located north east of Haul Rd 1, 800m after Philips road, corresponding to Alcoa mine map reference F35 25 (Plate 3.1). The rehabilitation of the site was completed in 1991. The site is characterised by dense understorey, with emerging trees and (Plate 3.1) suggested to represent 'stage 2' of revegetation development (Kabay & Nichols, 1980). As with site 1, the pit floor was landscaped and overburden returned. An important difference in technique is that the site received stockpiled soil. A 2 m deep wing tine was used for ripping prior to hand seeding. The diverse native seed mix consisted of; 20 leguminous species at a rate of 1.0 kg/ha; 59 understorey species at a rate of 0.3 kg/ha; *Macrozamia riedlei* 1.0 kg/ha; *Eucalyptus marginata/Corymbia calophylla* at a ratio of 80:20 (Alcoa, 1976 - 1994).

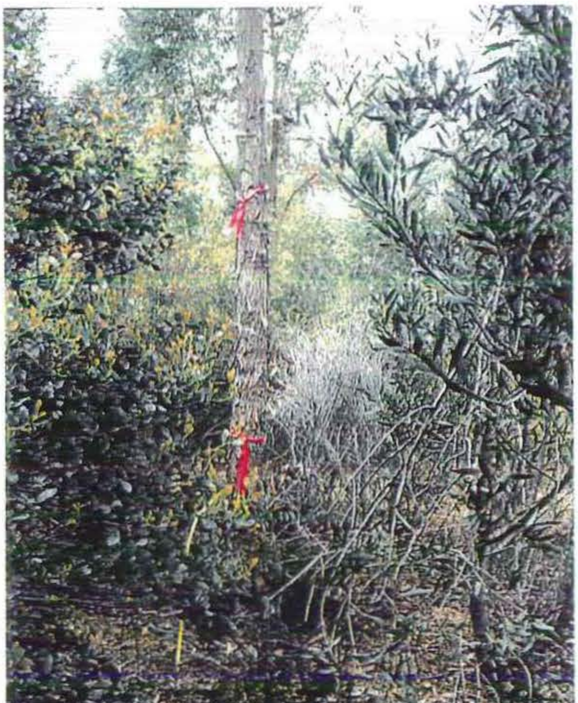


Plate 3.3 The 5 year old rehabilitation, jarrah trees emerging from dense understorey species.

10 year old

The rehabilitation of this 9 ha site was completed in 1986 and is located on the north-west side of Haul Rd 1 corresponding to Alcoa mine map F36 19. The site represents 'stage 3' of revegetation development characterised by well developed jarrah trees, high dense understorey and substantial litter cover (Kabay & Nichols, 1980). The rehabilitation details for the site are limited, however they were considerably different to those of the 2 and 5 year old sites (L Hantler, personal communication, May 21, 1997). As with the 5 year old site, the site received stockpiled soil. The site was planted with *E.marginata and C.Calophylla* (80:20) at a rate of 2 820 stems per ha rather than hand seeded (Alcoa, 1976 - 1994). This site represents the oldest rehabilitation that approximates current rehabilitation techniques investigated in the study.

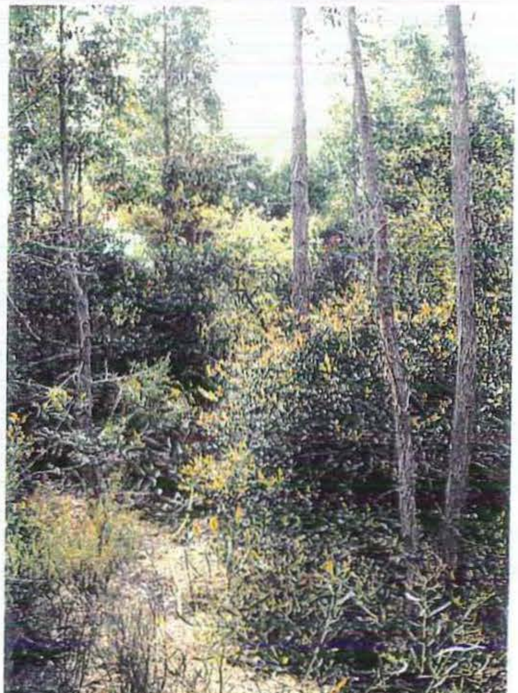


Plate 3.4 The 10 year old site, with well developed jarrah trees and both tall and lower understorey species present.

20 year old

This site rehabilitated in 1976 is often refereed to as the 'jungle' and has been the site of a range of invertebrate investigations. It corresponds to Alcoa mine map reference G37 19. Pit-floor, overburden and topsoil rehabilitation techniques are not available for the site. The site was an experimental site with revegetation consisting primarily of a hand spread acacia species of: *Acacia extensa* at a rate of 2.5 kg/ha; *A. saligna* at a rate of 0.75 kg/ha; *A. strigosa* at a rate of 0.5 kg/ha; *A. decurrens* at a rate of 2.0 kg/ha; *Albizia lophantha* at a rate of 1.0 kg/ha; *Bossiaea aquifolium* at a rate of 0.5 kg/ha (Alcoa, 1976 - 1994).

Plate 3.5 The 1976 rehabilitation dominated by *A.decurrens* is referred to as the jungle, characterisedby a well developed canopy cover with thick continuos litter.

Forest control

This was selected as the control site to reflect a 'typical' jarrah forest plot (O Nichols, personal communication, September 10, 1996) It is situated on Chandler Rd approximately 1.1 km (south-west) from the intersection with Peacock road and corresponds to Alcoa mine map reference G38 04. The area is dominated by *E.marginata* with *Banksia grandis* and *Xanthorrhoea preisii* understorey species. The site was confirmed as last logged in the 1970's decade and subsequently salvage cut in 1983. A prescribed burn was put through the area in 1988. (M. Smith, personal communication, November 14, 1997).

Plate 3.6 The forest control contains extensive litter cover, wood debris and rotting logs.

3.2 Faunal Sampling

Soil faunal investigations are extremely labour intensive and thus time constraints of an honours project allowed a single sampling of the study sites. However, the sampling (24th and 25th September 1996) was timed to coincide with peak mite abundances.

Along each transect ten soil cores were taken at approximately equi-distant intervals, but stratified such that five cores were taken at the top of ripping contours and five at the base. The soil cores (each 5 cm dia. x 10 cm depth) once sampled were carefully wrapped to minimise soil disturbance, kept cool and transported back to the laboratory for subsequent processing.

Utilising the same transect lines, two litter samples each of approximately 3 litres in volume were also taken at random, sealed in a plastic bags and transported to the laboratory for processing. Where the litter was sparse up to five random points were sampled to achieve the required volume.

3.3 Environmental Variables

A range of environmental variables were examined, primarily to determine potential impacts at the microhabitat level. Such data are important in determining likely factors contributing to mite fauna recolonisation, in particular effects on abundance and diversity.

3.3.1 Vegetation Analysis

The importance of vegetation to soil acarine communities is primarily the species contribution to litter and canopy. As a result the vegetation analysis was restricted to major contributors to litter and canopy cover, thus tree and shrub species were

assessed. Within each site (away from edges) three 10m by 10m quadrats were selected at random. The presence and abundance of each tree and shrub species was recorded. In the calculation of a similarity index used in the classification of sites, species recorded at only one site were excluded in order to minimise separation effects based on vegetation that may be a feature of revegetation technique.

3.3.2 Canopy Cover

The amount of isolation reaching the soil may be interpreted by estimating canopy cover. Such a measure is useful as canopy cover is an important factor in determining microclimatic conditions. The percentage canopy cover of plants greater than 1.5m was estimated with a hand-held densitometer. At equidistant points corresponding to soil core sampling points four estimates were made facing north, west, south and east respective, and the average of these recorded for each point along the transect.

3.3.3 Litter Cover

The degree of litter cover is well recognised as important determinant of soil and litter invertebrates. Litter cover was assessed at each of the twenty soil core sampling points per site in a in $1m^2$ quadrat. Four random points within each quadrat were measured and the average was scored.

3.3.4 Soil Compaction

To estimate the degree of soil compaction between sites a measure of soil strength can be used. Such measurements are commonly obtained with cone penetrometers (Archer & Marks, 1982). A cone penetrometer was used to measure the resistance of the soil to fracture by applied shear stress, in order to obtain comparative data between sites and

to demonstrate variability between soil layers. Preliminary measurements established that readings for the 0-3 cm, 3-6 cm and 6-9 cm were recorded as this concords with the soil sampling depth.

For each site, one transect was selected to assess compaction, at the ten points corresponding to soil core sampling recordings. At each of these points the cone penetrometer was pushed through the soil at constant speed and readings for of 0-3, 3-6, and 6-9 cm layers were scored. Measurements were converted from kgf to Mpa.

3.3.5 Soil Water Content

Soil water content was estimated on two occasions. Firstly with faunal sampling, where extra soil cores were taken at each sampling point to estimate soil moisture. The contents of each core was weighed and then dried at 70^{0} Celsius to constant weight. Water content was calculated as percentage loss in weight. The percentage soil moisture at time of penetrometer readings was also calculated in the same manner although only 10 measurements were taken corresponding to the penetrometer measurements.

3.3.6 Soil Organic Carbon & Nitrogen Content

To establish soil organic carbon and percentage nitrogen four core samples per site were taken at random. The soils total organic carbon was assessed by a total digestion method through Analabs Pty Ltd. The total nitrogen content analysis was carried out by Centre for Ecosystem Management (Edith Cowan University). The method employs a system known as Automated Nitrogen and Carbon Analysis - Gas Solid Liquid (ANCA GSL). Each two milligram sample is placed in the sample preparation unit, which through combustion, coverts the sample to gas and separates the elements. The sample is then passed through a mass spectrometer, providing analysis N_2 contents.

3.3.7 Soil Particle Size

The soil cores used in analysis of soil moisture content were used to estimate the proportions of soil particles at each site. Each core was dried to constant weight at 70° Celsius. A soil sieve shaker was used with a standard set of soil sieves to agitate samples for 10 minutes.

3.4 Faunal Extraction

The common method of behaviour modification for extracting soil mesofauna was employed. This involves the use of a kinetic stimulant (infra-red light source) that establishes a temperature and moisture gradient, from which the fauna move away from and down through the soil core or litter sample, eventually falling into a collecting vessel (Moldenke, 1994). Both the soil and litter sampled were extracted using these principles, in modified heat extractors based on the design by Kempson, Lloyd & Ghelardi (cited in Kinnear, 1991).

Each stored core sample was unwrapped, inverted and left for 24 hours to settle. Over ten days, temperature at the soil surface was gradually raised from room temperature to 50° Celsius, establishing a temperature gradient between top and bottom of the sample of 22-25° Celsius. As the fauna move away from the heat they were collected into saturated picric acid. The samples were then filtered, concentrated and stored in 70% alcohol. The litter samples were placed in sieves and extracted under the same conditions as the soil cores.

3.5 Taxonomic Identification

All samples were initially examined under a stereo microscope (up to 40x). Initially all acari specimens were identified to order using Dindal (1990). The non-mite fauna did not receive any further analysis, these specimens have been stored unsorted.

The process of identification involved the construction of a voucher collection with a unique Order code allocated for each individual. This was developed in the form of a reference catalogue, consisting of permanent mounts, unmounted specimens and taxonomic descriptions. The catalogue is housed at School of Natural Science, Edith Cowan University, Mount Lawley campus.

The Cryptostigmata were keyed to Family and Genera where possible (Balogh, 1983; Balogh 1988; Balogh; 1990; Norton, 1990). Similarly the Prostigmata were keyed to Family (Keithley, 1990). Individuals within orders were ascribed unique species status, though unnamed at this level. This was due to time constraints and in many cases, the lack of adequate taxonomic keys.

The Mesostigmata and Astigmata were identified using Recognisable Taxonomic Unit (RTU) principles. Krantz & Ainscough key (Dindal, 1990) was used in the determination of RTU characteristics. The Astigmata RTU characteristics were developed from Philips key (Dindal, 1990). The RTU technique is increasingly recognised as useful system in rapid biodiversity assessments. The method was recently evaluated and was found to produce reliable results for invertebrate assessments (Oliver & Beattie, 1993).

3.6 Data Analysis

Site-matrix spreadsheets were developed for faunal abundances and environmental variables using Excel (Version 5.0). The data were coded to enable efficient extraction of data either as a whole or according to discrete taxonomic and environmental variables at a transect or site level. The matrix's were exported to SPSS version 6.1 and/or PATN (Belbin, 1989) for further analysis. The data were checked for normality and where required, transformed by appropriate method prior to statistical analysis.

3.6.1 Environmental variables

Descriptive statistics were calculated in SPSS (version 6.1) at both an individual transect level and on a site basis. The results were used to compare environmental characteristics between and within transects/sites. The environmental means on site basis were graphed along with standard error for visual interpretation.

The tree and shrub species data was used to assess similarity between rehabilitated sites and the forest control. Classification routines were applied to these data using PATN (Belbin, 1989). The Bray-Curtis association measure was determined as most appropriate as is recommended for presence/absence data (Belbin, 1989). Hierarchical polythetic agglomerative clustering using flexible Unweighted Pair group ArithMetic Averaging (UPGMA) strategy was used for the production of a dendrogram (Belbin, 1989).

3.6.2 Acarine Analysis

This study is pseudo-replicative in design, and as clearly identified by Hulbert & White (1993) the design places restrictions on the use of inferential statistics. Thus statistical procedures requiring replication should not be applied. This study follows this advice.

SPSS (version 6.1) was used to calculate descriptive statistics of acarine abundance and diversity on a transect and site basis. SPSS (version 6) was used to determine Ordinal and site species patterns. The arithmetic mean per core (or litter sample) was used in calculations of acari abundance at a site/transect level.

Species diversity measures are often used in association with species richness data, as they may indicate if increases in species richness are associated with increased evenness in species distribution. As recommended by Peet, (1974) (as cited in Krebs, 1989) the exponential form of Shannon-Wiener (N′) function was calculated to

describe the site heterogeneity. This value is particularly useful as it is simply interpretable as the number of equally common species required to achieve the same diversity. Krebs (1995) Fortran programs for Ecological Methodology were used to calculate the index.

To identify and interpret patterns in species distribution between sites, the site-species matrix (with appropriate modifications) was imported into PATN. The procedures and recommendations of Belbin (1989) were applied for the Ordination and Classification of data and the construction of dendrogram.

3.6.3 Interaction between Acarine Community Structure and Environmental Variables

SPSS was used for correlation analysis in the identification of significant environmental correlates with acarine abundance and diversity. The analysis was performed on transect data on an individual basis for the soil and litter samples. Environmental variables that were significantly correlated at the 5% level with acarine abundance and diversity were further analysed by step-wise multiple regression.

4. RESULTS

4.1 Environmental Variables

4.1.1 Vegetation Analysis

Across all study sites 42 tree and shrub species were recorded. Species richness increased marginally with age of rehabilitation, with the exception of the 20 year old site (Table 4.1). The forest site displayed the greatest species richness (21), whilst the 5 and 10 year old sites were somewhat lower (16 and 19 respectively). The diversity of tree and shrub species varied substantially across the study sites. Diversity was very low in the 20 year old rehabilitation, whilst the 10 year old site recorded the highest diversity value. The 2 year old, 5 year old and forest control sites recorded comparable diversity.

	Rehabilitation sites				
	2 yr old	5 yr old	10 yr old	20 yr old	Forest
Species Richness (S)	14	16	19	7	21
Diversity (N′)	9.17	8.89	11.68	4.29	9.58

Table 4.1 Tree and shrub species richness and species diversity recorded at each of the rehabilitated sites and forest control site.

The dendrogram in Figure 4.1 displays the outcome of hierarchical agglomerative clustering of sites based on the presence/absence of tree and shrub species. The

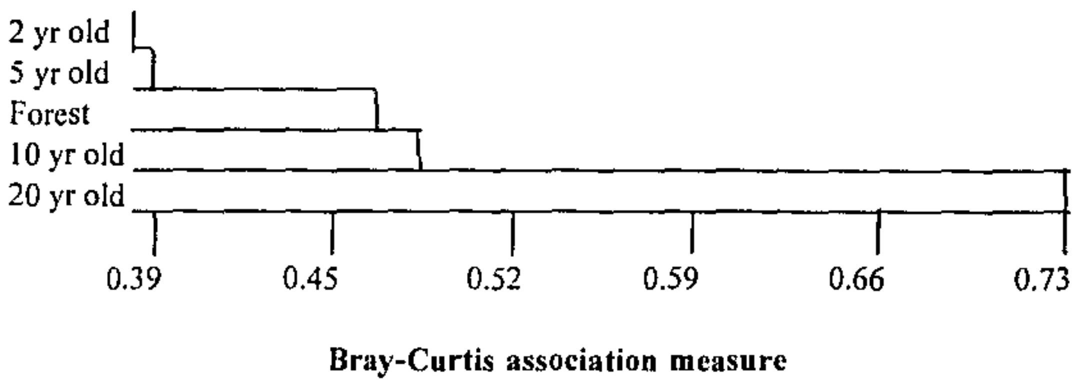


Figure 4.1 Hierachial agglomerative clustering of tree and shrub species sampled in quadrats at each of the rehabilitated sites and forest control site.

analysis considered 23 species common to all sites. The classification is suggestive of a clear separation of the 20 year old site from the remaining sites, and to a lesser extent the forest and 10 year old sites from the two youngest sites.

4.1.2 Canopy Cover

The degree of canopy cover increased with age of rehabilitation (Figure 4.2). Across all transects, canopy cover was strongly correlated with rehabilitation age ($r=0.8956$, $p<0.01$). The 20 year old site displayed the highest percentage canopy cover, primarily a result of the revegetation technique which was applied as outlined in section 3.1. The relatively immature 5 and 10 year old sites displayed comparable canopy cover to that of the forest site (Figure 4.2).

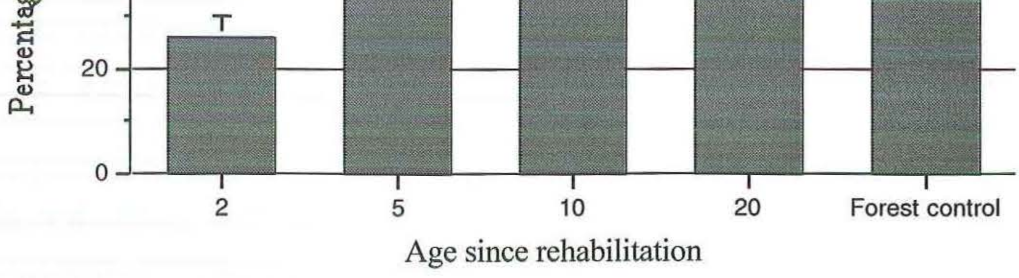


Figure 4.2 Mean percentage canopy cover recorded at each of the rehabilitated sites and forest control site. Values are means + 1 SE (n=20).

4.1.3 Litter Cover

The extent of litter cover was clearly influenced by the age of the rehabilitation. Litter quantity increased substantially as revegetation matured (Figure 4.3). Across all transects there was a significant correlation between litter cover and the age of rehabilitation ($r=0.9435$, $p<0.01$), and litter and canopy cover ($r=0.8459$, $p<0.01$).

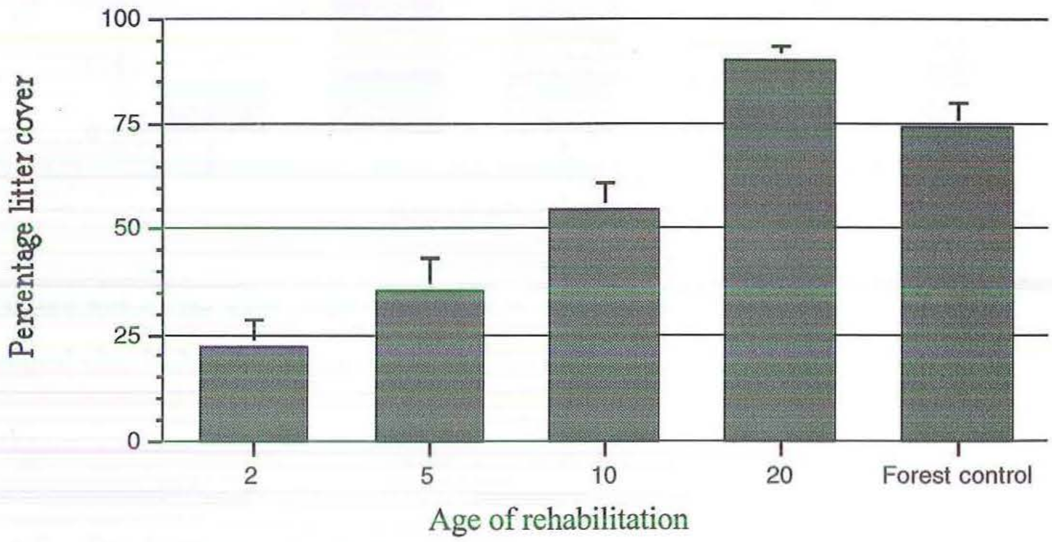


Figure 4.3 Mean litter cover for each of the rehabilitated sites and forest control. Values are mean + 1SE (n=20).

4.1.4 Litter Depth

As with canopy and litter cover, litter depth was found to increase with age of rehabilitation (Figure 4.4). The 20 year old site displayed larger litter depth values, approximately twice that of the forest site. The lowest litter depth was recorded in the youngest rehabilitation (2 years), whilst the 5 and 10 year old sites had litter depths comparable with that of the forest site. At the transect level (i.e. using transect means as the input values) of analysis litter depth was very strongly correlated with age ($r=0.9378$, $p<0.01$) canopy cover ($r=0.7481$, $p<0.01$) and litter cover ($r=0.7055$, $p<0.05$).

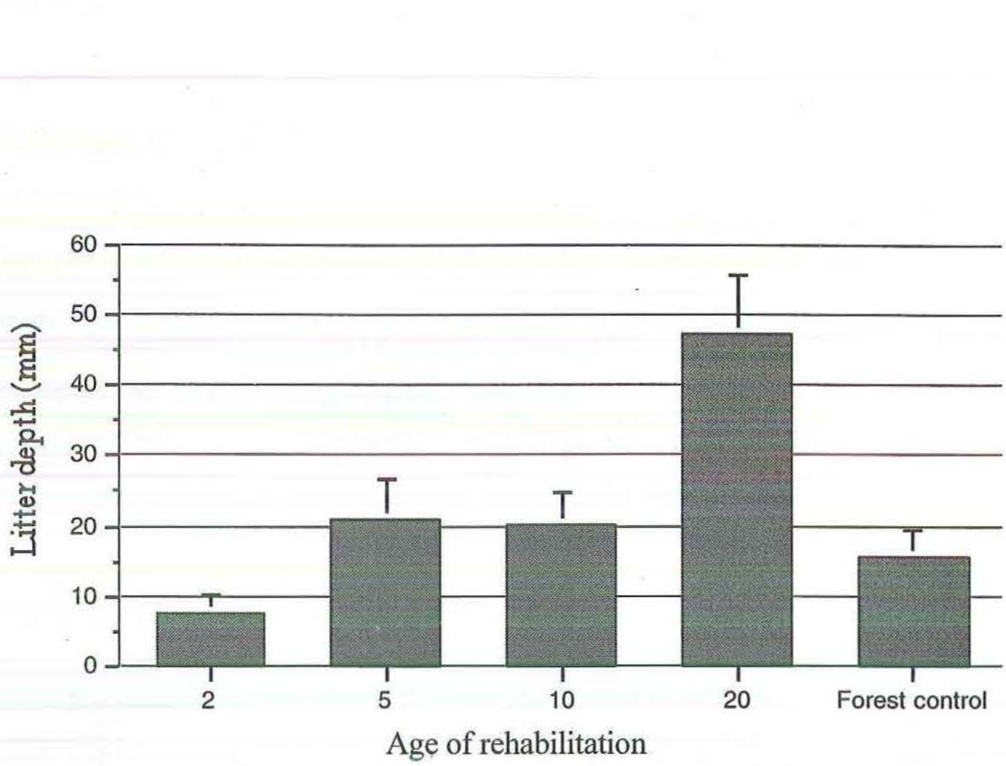


Figure 4.4 Mean litter depth recorded at each of the rehabilitated sites and forest control site. Values are mean +1 SE (n=20).

4.1.5 Total Organic Carbon

The total soil organic carbon values of the study sites fell into two broad categories. Soils of the younger rehabilitated sites (2, 5 and 10 years old) contained considerably lower organic carbon than the forest and 20 year old site (Table 4.2). At the transect level of analysis total organic carbon was correlated with litter cover ($r=0.7477$, $p<0.05$).

4.1.6 Soil Moisture

The percentage moisture content of soil at the time of sampling was comparable across the study sites sampled (Table 4.2). The 2 year old, 10 year old and forest sites were marginally drier than the 5 and 20 year old sites.

4.1.7 Soil Compaction

The penetrometer measurements indicate that compaction decreased with age of rehabilitation. The youngest rehabilitation (2 year old) displayed the greatest resistance to penetration (Figure 4.5). All other rehabilitation sites displayed comparable penetration resistance to that of the forest site.

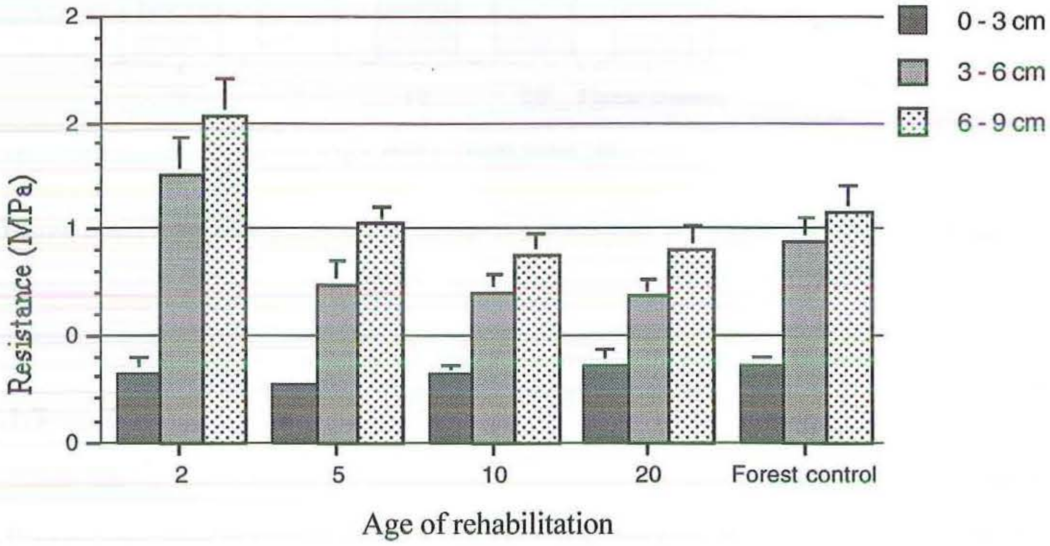


Figure 4.5 Mean penetration resistance of surface soil (0-9 cm) for each of the rehabilitated sites and forest control site. Values are mean +1 SE (n=20).

4.1.8 Particle Analysis

The proportions of particles in each size range in the surface soil (10 cm) were comparable between sites (Figure 4.6). The forest plot had the greatest percentage of gravel. The results describe all study sites as sandy soils.

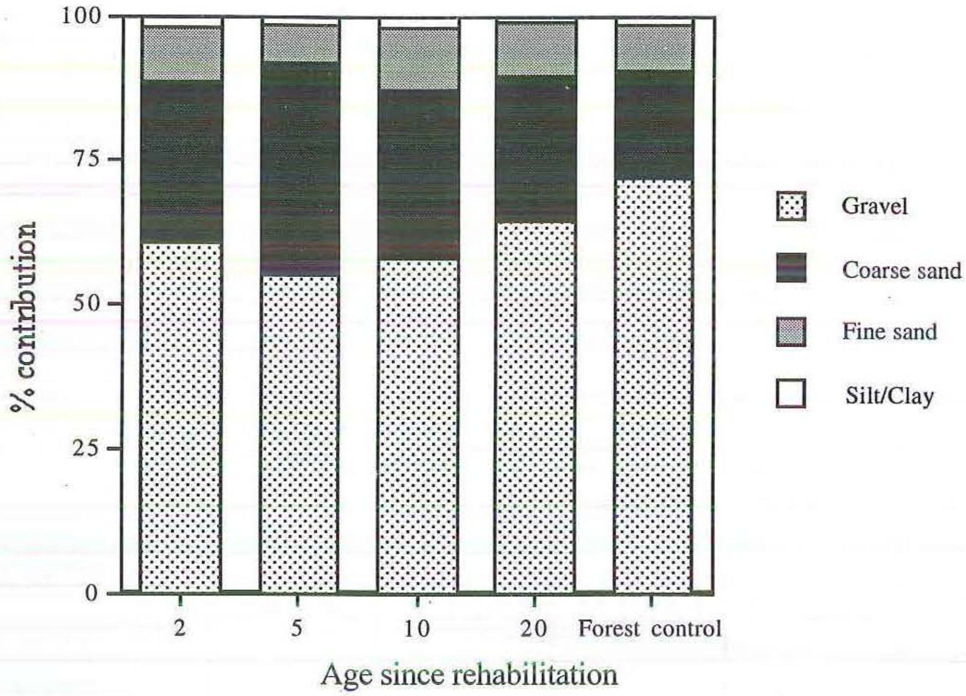


Figure 4.6 The soil composition of the rehabilitated sites and forest control site.

4.1.9 pH

All sampling sites recorded similar soil pH values (Table 4.2). The forest control and 2 year old sites recorded the lowest values of 5.6 and 5.7 respectively.

4.1.10 Total Nitrogen

The mean percentage nitrogen within soils varied across the study sites. The 20 year old site contained the highest percentage nitrogen, approximately twice that of the 5 year old and forest soils which contained similar percentages. The 2 and 10 year old rehabilitation sites contained the lowest percentage nitrogen.

4.1.11 Summary of Environmental Variables

The age of rehabilitation clearly influenced the values of some of the environmental parameters (Table 4.2). This was evidenced by significant linear correlation with age and litter cover ($r=0.9435$, $p<0.01$), canopy cover ($r=0.8956$, $p<0.01$), litter depth ($r=0.9378$, $p<0.01$) and organic carbon ($r=0.6563$, $p<0.05$). The mean values all of environmental variables measured are summarised in Table 4.2.

	Rehabilitation sites				
	2 yr old	**5 yr old**	**10 yr old**	**20 yr old**	**Forest**
Canopy cover (%) (n=20)	26.6 ± 4.2	43.4 ± 4.5	57.1 ± 4.4	71.7 ± 3.2	55.0 ± 3.6
Litter cover (% cover) (n= 20)	22.5 ± 5.8	35.5 ± 7.5	55 ± 5.9	90.2 ± 3.5	74.5 ± 5.6
Litter depth (mm) (n=20)	7.7 ± 2.5	21.1 ± 5.5	20.25 ± 4.5	47.5 ± 8.2	15.75 ± 3.86
Total organic carbon (%) (n=8)	2.90 ± 0.35	3.0 ± 1.75	3.27 ± 0.53	7.07 ± 0.80	7.21 ± 0.73
Total nitrogen (%) (n=8)	0.10 ± 0.01	0.17 ± 0.11	0.11 ± 0.02	0.33 ± 0.11	0.16 ± 0.01
pH (n=8)	5.7 ± 0.01	5.4 ± 0.04	5.4 ± 0.07	5.3 ± 0.02	5.6 ± 0.01
Soil Moisture (%) (n=20)	11.10 ± 0.26	14.95 ± 2.11	10.48 ± 1.35	15.66 ± 1.40	12.23 ± 1.52

Table 4.2 Environmental variables recorded at each of the rehabilitated sites and forest control site. Values are mean +1 SE.

4.2 Acarine Analysis

The Cryptostigmata and Prostigmata were numerically dominant in both soil and litter samples, and at all study sites, accounting for approximately 70 % and 15% of all mites respectively. The remaining 15% of acarine fauna was made up of individuals of Mesostigmata and Astigmata.

In the following section, the acarine communities of the soil and litter habitats are considered separately.

4.2.1 Acarine Abundance in Soil

A total of 2,362 mite specimens were extracted from soil samples. Mean total density of mites increased with age of rehabilitation (Figure 4.7). Densities in the younger sites (2 and 5 years) were well below those of the forest site. The 10 and 20 year old sites displayed higher densities, although values were still below that of the forest control site.

When mean density per transect was considered, total acarine density was linearly correlated with the age of rehabilitation ($r=0.8595$, $p<0.01$), degree of litter cover ($r=0.8852$, $p<0.01$) and total acarine species richness ($r=0.9827$, $p<0.01$). The correlation of abundance with age also held at the individual core level with mean density per core being correlated with age of the rehabilitation ($r=0.5220$, $p<0.01$). Step-wise multiple regression was carried out for the variables significantly correlated at the transect level with acarine abundance and species richness. Age since rehabilitation contributed significantly ($r^2=0.66$, $p<0.05$).

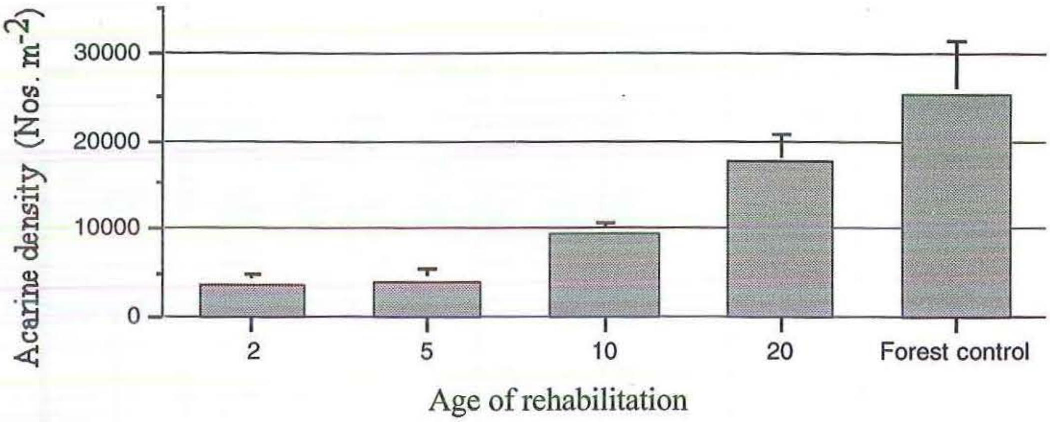


Figure 4.7 Mean density of soil acari (Nos. m^{-2}) at each of the rehabilitated sites and the forest control site. Error bars indicate + 1 SE (n=20).

The cryptostigmatid and prostigmatid mites represented approximately 90% all species found in the soil. The Cryptostigmata was the dominant order across all sites, with the exception of the youngest site where Prostigmata dominated (Figure 4.8). The increase in total mite density seen with site age is primarily due to an increase in cryptostigmatid density (Table 4.3). At the transect level of analysis, there was a very strong linear correlation between cryptostigmatid density and age of rehabilitation ($r=0.9758$, $p<0.01$). Cryptostigmatid density also displayed a strong linear correlation with litter cover ($r=0.9006$, $p<0.01$) as well as canopy cover ($r=0.7313$, $p<0.05$) and litter depth ($r=0.6433$, $p<0.05$). This outcome is not surprising, given that both canopy cover and litter depth were also strongly correlated with age of rehabilitation (Section 4.1).

In the 2 year old site the prostigmatid mites displayed the greatest relative abundance making up 53% of all mites found (Figure 4.8). Their densities were substantially lower in the 5, 10 and 20 year old sites where values were similar to the forest control site (Table 4.3).

	Rehabilitation sites				
	2 yr old	**5 yr old**	**10 yr old**	**20 yr old**	**Forest**
Cryptostigmata	840 ± 228 (22.5)	2 596 ± 1 140 (64.5)	6 567 ±1 103 (69.7)	14 713 ± 3 223 (84.5)	20 618 ± 560 (80.7)
Prostigmata	1 985 ± 757 (53.0)	280 ± 162 (7.0)	1 349 ± 410 (14.3)	1 705 ± 454 (9.8)	2 418 ± 558 (9.5)
Mesostigmata	280 ± 254 (7.5)	255 ± 107 (6.3)	942 ± 209 (10.0)	738 ± 200 (4.2)	2 062 ± 489 (8.1)
Astigmata	636 ± 227 (17.0)	891 ± 317 (22.2)	560 ± 208 (6.0)	255 ± 130 (1.5)	433 ± 166 (1.7)
Site mean	3 742 ± 1 025	4 022 ± 1 370	9 418 ± 1 293	17 411 ± 3 521	25 331 ± 5 942

Table 4.3 Mean density (No. m^{-2}) (±SE) of acarine orders and relative abundances (%, in parentheses) in soil at for each of the rehabilitated sites and forest control site.

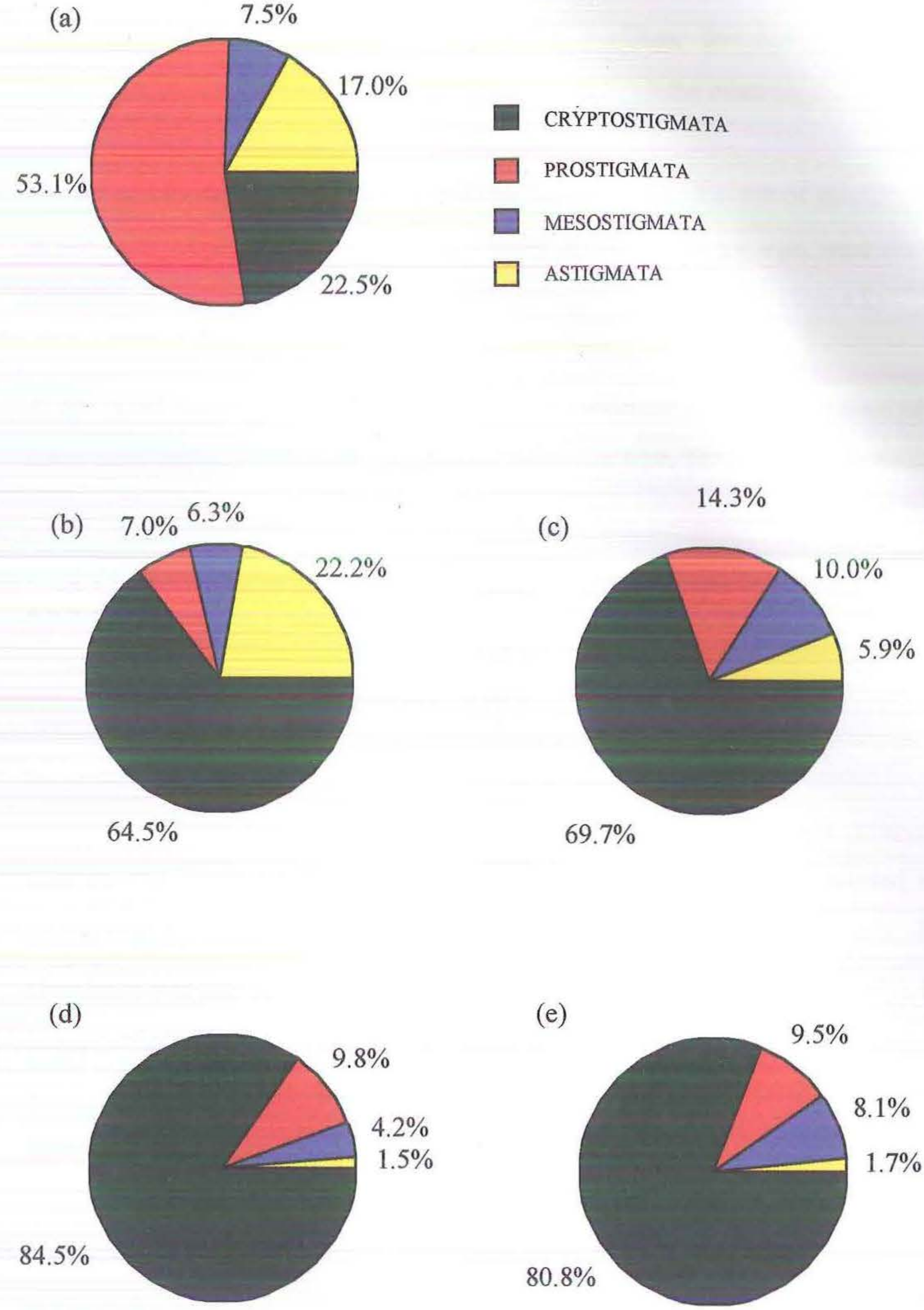


Figure 4.8 Percentage abundances of the acarine orders in surface soil (0 - 10cm) at the (a) 2 year old site (b) 5 year old site (c) 10 year old site (d) 20 year old site (e) forest control.

The relative abundance of Mesostigmata did not show strong age related patterns and the percentage contributions of mesostigmatid mites to the 2 , 5 and 10 year old sites were comparable to the forest site (Table 4.3). Thus, the mean densities of Mesostigmata across sites increased proportionately with the other orders.

The Astigmata decreased in relative proportion with increasing age of rehabilitation. In particular astigmatid mites within the forest and 20 year old sites were minimal components (1% and 1.5% respectively) of the mite communities (Figure 4.8).

At the broad taxonomic level of Order, the mite communities of the 20 year old and forest sites, although distinctly different in vegetation type, were similar.

4.2.2 Acarine Abundance in the Litter

The litter samples provided approximately 1,621 specimens. The youngest sites (2 and 5 years old) displayed considerably lower abundances than that recorded in older sites (10 and 20 years old). The mean abundance of these oldest sites was comparable with the forest control (Figure 4.9). When mean abundances were analysed on a transect basis, similar correlative outcomes occurred as those with soil. Mite abundance was strongly correlated with age of rehabilitation ($r=0.7750$, $p<0.05$), litter cover ($r=0.8095$, $p<0.05$) and canopy cover ($r=0.7354$, $p<0.05$). As with soil, Age since rehabilitation was the only significant variable found to contribution to abundance through step-wise regression modeling ($r^2=0.74$, $p<0.05$).

The Cryptostigmata accounted for 69% of all litter acari, followed by Prostigmata (11%), Mesostigmata (16%) and a small contribution by the Astigmata (4%). As with the soil acari, the Cryptostigmata were the dominant order, displaying the greatest relative abundance at all sites except the 2 year old site. At this youngest site, the contribution was low and comparable to the astigmatid mites (Figure 4.10). Cryptostigmatid abundance was lowest in the younger sites (2 and 5 years old)

(Figure 4.10) and the 10, 20 year old and forest site displayed higher but similar abundances with approximately 350 mites kg^{-1} dry weight. At the transect level of analysis, Cryptostigmata abundance was strongly correlated with age of rehabilitation ($r=0.7439$, $p<0.05$) and litter cover ($r=0.7416$, $p<0.05$).

Figure 4.9 Mean abundance of litter acari (Nos. kg^{-1} dry weight) at each of the rehabilitated sites and the forest control site. Error bars indicate +1 SE (n=20).

With regard to the Prostigmata, relative abundances decreased only marginally with age of rehabilitation (Table 4.4; Figure 4.10). The 2 year old site recorded the highest relative density. Prostigmatid mites were found across the remaining rehabilitation and forest sites in similar relative abundances.

The relative abundances of Mesostigmata ranged between 3.8% (5 year old) and 22.4 % (20 year old), with no discernible age related pattern (Table 4.4). The forest control and the 10 year old sites recorded similar relative abundances. The Astigmata displayed the lowest abundance of all orders in the litter and decreased with age of

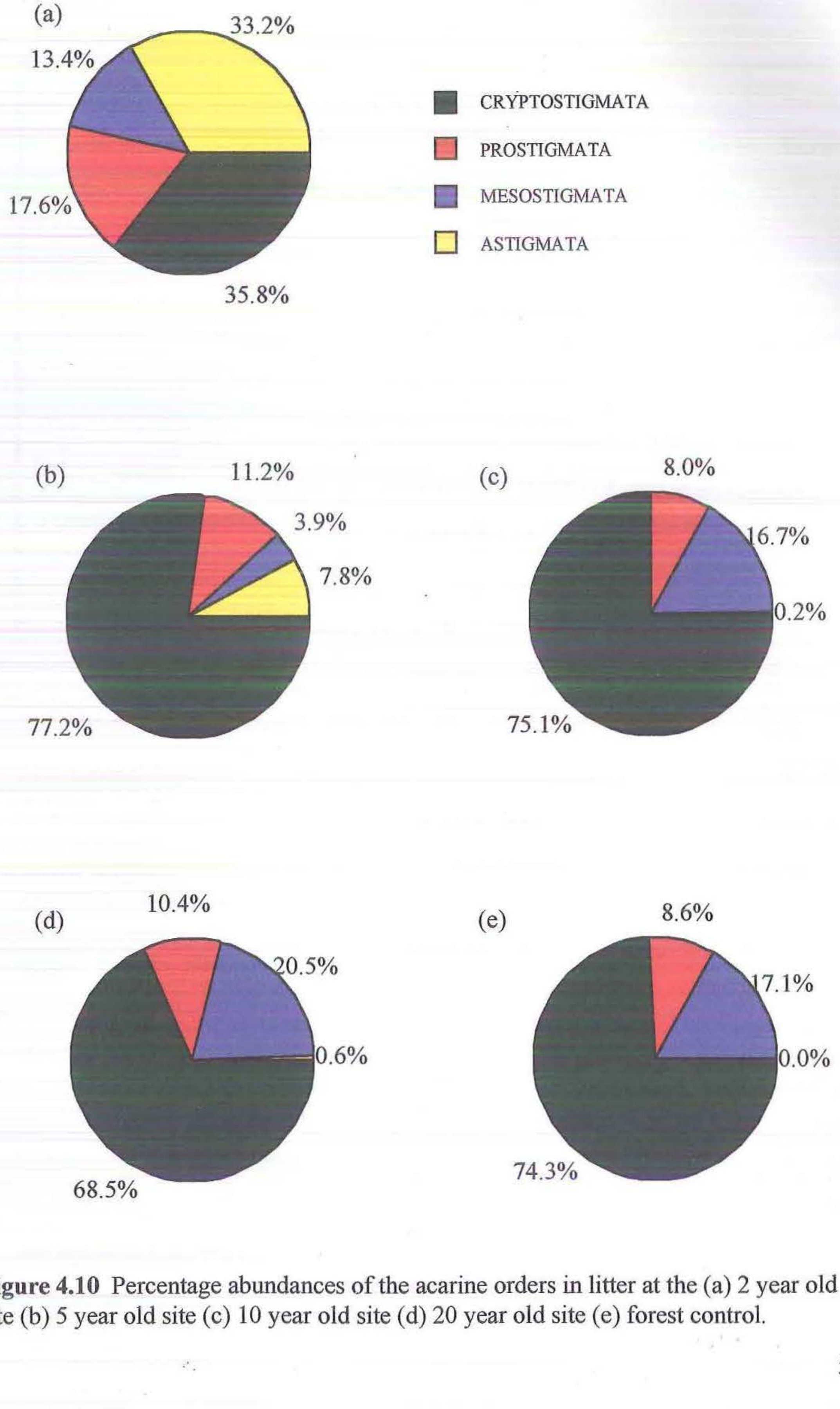


Figure 4.10 Percentage abundances of the acarine orders in litter at the (a) 2 year old site (b) 5 year old site (c) 10 year old site (d) 20 year old site (e) forest control.

rehabilitation. Astigmatid mites were a very high proportion of mites in the litter of the 2 year old site.

	Rehabilitation sites				
	2 yr old	5 yr old	10 yr old	20 yr old	Forest
Cryptostigmata	61 ± 27 (33.7)	159 ± 49 (77.2)	356 ± 173 (75.1)	341 ± 114 (74.5)	347 ± 114 (74.5)
Prostigmata	33± 20 (18.3)	23 ± 5 (11.2)	38 ± 13 (8.0)	52 ± 11 (10.4)	40 ± 15 (8.5)
Mesostigmata	25± 17 (13.8)	8 ± 4 (3.8)	79 (16.7)	102 ± 47 (20.4)	80 ± 34 (17.0)
Astigmata	62 ± 20 (34.2)	16 ± 7 (7.7)	1 ± 1 (0.2)	3 ± 3 (0.7)	0
Site mean	181 ± 47	206 ± 42	474 ± 210	498 ± 101	467 ± 137

Table 4.4 Mean abundance (Nos. kg^{-1} dry weight) and relative abundance (%, in parentheses) of acarine orders in the litter at each of the rehabilitated sites and forest control. Values represent the mean ± 1 SE (n = 20).

4.2.3 Species Richness

There were clear patterns in species richness which were related to the age of the rehabilitation. Total species richness of both soil and litter habitat increased with age of sites with the exception of the 20 year old litter sample (Table 4.5). At the transect level of analysis a strong linear correlation was found between soil species richness and age of rehabilitation ($r=0.9956$, $p<0.01$), canopy cover ($r=0.8776$, $p<0.05$) litter cover ($r=0.9339$, $p<0.05$) and mean abundance ($r=0.9827$, $p<0.01$). There were no such correlations found for litter species richness at the 5% significance level.

Soil species richness increased with the age of rehabilitation, from a low value of 7 at the 2 year old site to 31 at the 20 year old site (Table 4.5). In no rehabilitation site did the soil species richness approach the high values of the forest site, which was approximately 2.5 times that of the 10 year old rehabilitation (approximates current techniques).

With regard to the litter, species richness increased to maximum values by 10 years. Thus, species richness values were similar in the 10, 20 year old and forest control sites.

The total numbers of species found in soil and litter were similar. For example 36 cryptostigmatid species and 13 prostigmatid species were found in the soil and 29 cryptostigmatid species and 20 prostigmatid species were found in the litter.

The Cryptostigmata displayed the highest species richness overall with 39 species in total. Cryptostigmatid mites displayed the greatest species richness in all samples (soil and litter), with the exception of the two year old soil sample where overall species richness was very low (Table 4.5). The Cryptostigmata increased in species richness with the age of rehabilitation, with similar values recorded at the 10 and 20 year old site being similar. At a transect level of analysis, soil cryptostigmatid density and species richness were correlated ($r=0.9773$, $p<0.01$).

After the Cryptostigmata, the prostigmatid mites displayed the next largest species richness with 25. In the soil, species richness increased marginally with the age of rehabilitation (Table 4.5). Prostigmatid soil species richness was comparable in the 10 and 20 year old sites and the forest control site. In the litter samples, species richness varied, with no obvious age-related patterns. The forest litter contained the largest prostigmatid species richness followed by that of the 10 year old rehabilitated site.

	Rehabilitation sites								Forest	
	2 yr old		5 yr old		10 yr old		20 yr old			
	S	L	S	L	S	L	S	L	S	L
Cryptostigmata	3	5	9	14	13	16	18	16	32	20
Prostigmata	2	4	3	3	5	10	7	5	8	11
Mesostigmata*	1	2	1	2	3	7	5	7	8	6
Astigmata*	1	1	1	1	1	1	1	1	1	0
Total species richness	7	13	14	20	22	34	31	29	49	37

Table 4.5 Species richness within acarine orders sampled in soil (S) and litter (L) at each of the rehabilitated sites and forest control site. For orders marked with an asterisk, RTU 'identification' applies.

The Mesostigmata displayed low richness overall, with a greater number of RTU's in the litter. As with the prostigmatid mites the mesostigmatid richness was comparable in the 10 and 20 year old site and the forest control. The Astigmata are represented here by a single RTU across all sites. Specimens with the Order were difficult to separate with confidence and it is likely that this value underestimates the true value for Astigmata for these sites.

4.2.5 Species Diversity

Species diversity as estimated by Shannon-Weiner (N') varied considerably across the rehabilitated sites and was at a maximum in the forest control site. As with species

richness, soil diversity increased with the age of rehabilitation from the 2 year old through to the 10 year old site. The diversity of the 20 year old soil sample exceeded the 2 and 5 year old sites but displayed lower diversity than that of the 10 year old site, despite a higher species richness (Table 4.6). This indicates that the 20 year old sample had a less equitable distribution of species. The forest control site displayed considerably higher heterogeneity than all rehabilitation sites.

	Rehabilitation sites									
	2 yr old		5 yr old		10 yr old		20 yr old		Forest	
	S	L	S	L	S	L	S	L	S	L
Species Richness (S)	7	13	14	20	22	34	31	29	49	37
Diversity Index (N')	3.84	5.25	6.55	13.85	9.84	14.34	7.70	17.35	25.74	25.27

Table 4.6 Acarine species richness and species diversity in soil (S) and litter (L) at each of the rehabilitated sites and forest control site.

Species diversity of the litter habitats showed consistent increase with the age of rehabilitation (Table 4.6). However, as with the soil habitat, values remained well below that of the forest control site. In contrast to the soil diversity, the 20 year old site displayed higher heterogeneity than that of the 10 year old site.

4.2.6 Cryptostigmata and Prostigmata : a Further Analysis of Species Distribution

The two orders contributed the majority if the mite specimens, with a total of 22 Cryptostigmata and 17 Prostigmata Families were identified. The distribution and relative abundances of these varied considerably between soil and litter habitats, and across sites. The relative contributions of each of the cryptostigmatid and prostigmatid Families and the species within them are displayed in Figure 4.11 to 4.14

As is commonly found with soil and litter acari, a large number of species were represented by only a few individuals overall. This trend was also obvious at the Family level with only 8 of the 39 Families having site occurrences of greater than 5 percent (Figure 4.11 to 4.14). The most commonly occurring Families of the Cryptostigmata were Tegoribatidae, Oppiidae, Oribatulidae, Scutobelbidae, and two unknown cryptostigmatid species (1 & 2). The most commonly occurring Prostigmata family was Scutacaridae.

Sixteen cryptostigmatid and 7 prostigmatid Families were common to both soil and litter habitats. The cryptostigmatid Oppiidae was the only Family common to all study sites in both soil and litter (Figures 4.11 & 4.12). The Oppiidae and the Oribatulidae displayed the greatest relative abundance and provided the highest number of species (7 and 8 respectively). In the Prostigmata the Scutacaridae dominated overall relative abundance (Figures 4.13 & 4.14). The greatest numbers of species in the Prostigmata were found in the Raphignathidae and Caligonellidae.

An analysis of individual species patterns by site enabled the identification of distinct groups or 'species suites' which could be associated with either a particular site or set of sites. This then allowed inferences to be made with regard to the ability of specific mite species to colonise disturbed sites, and whether there might be

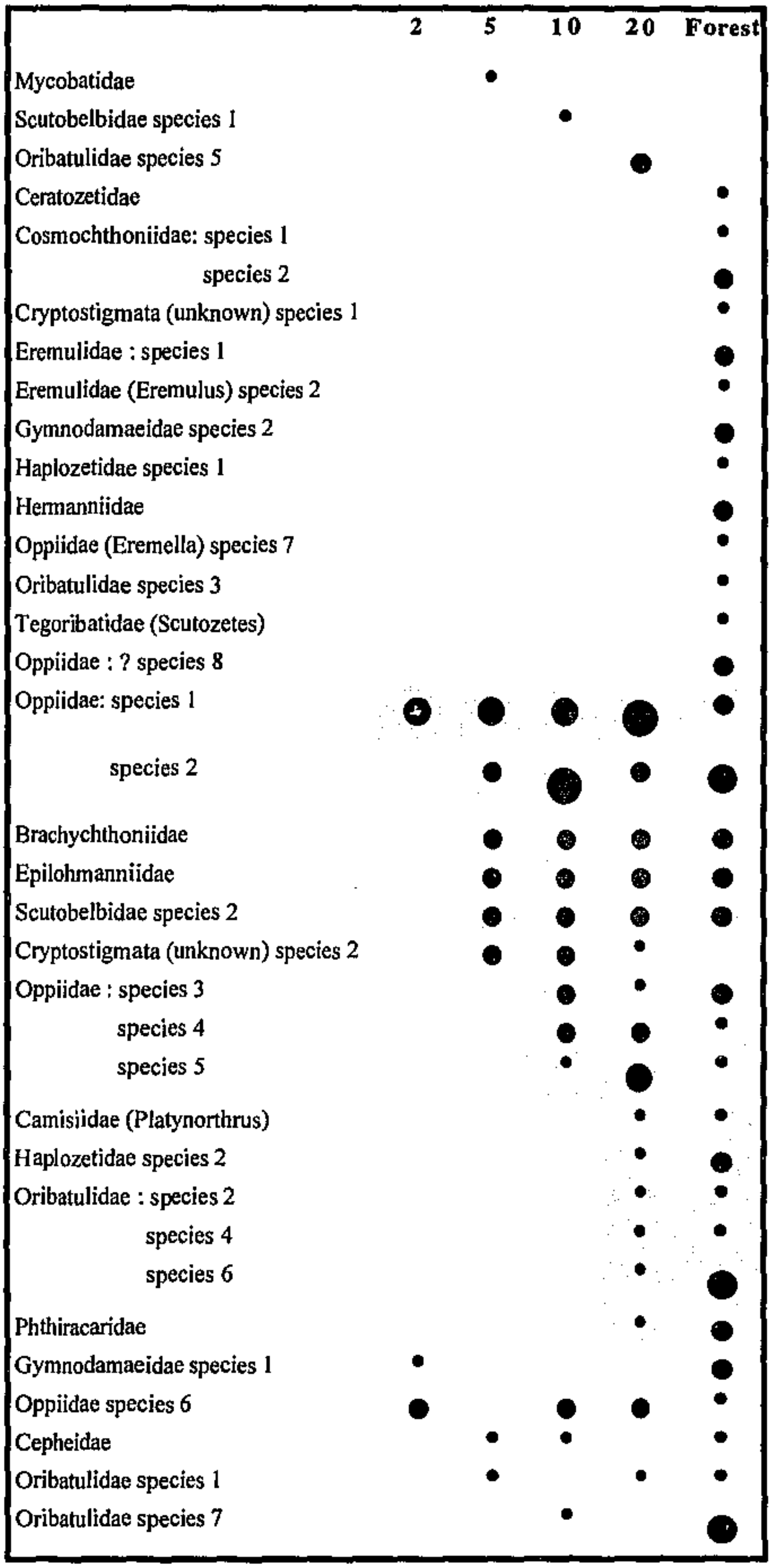


Figure 4.11 Relative abundance of cryptostigmatid species in surface soil (0-10cm) at each of the rehabilitated sites and forest control site.

(≤1% (•), >1% ≤ 5% (●),>5% ≤20% (●), >20% (●))

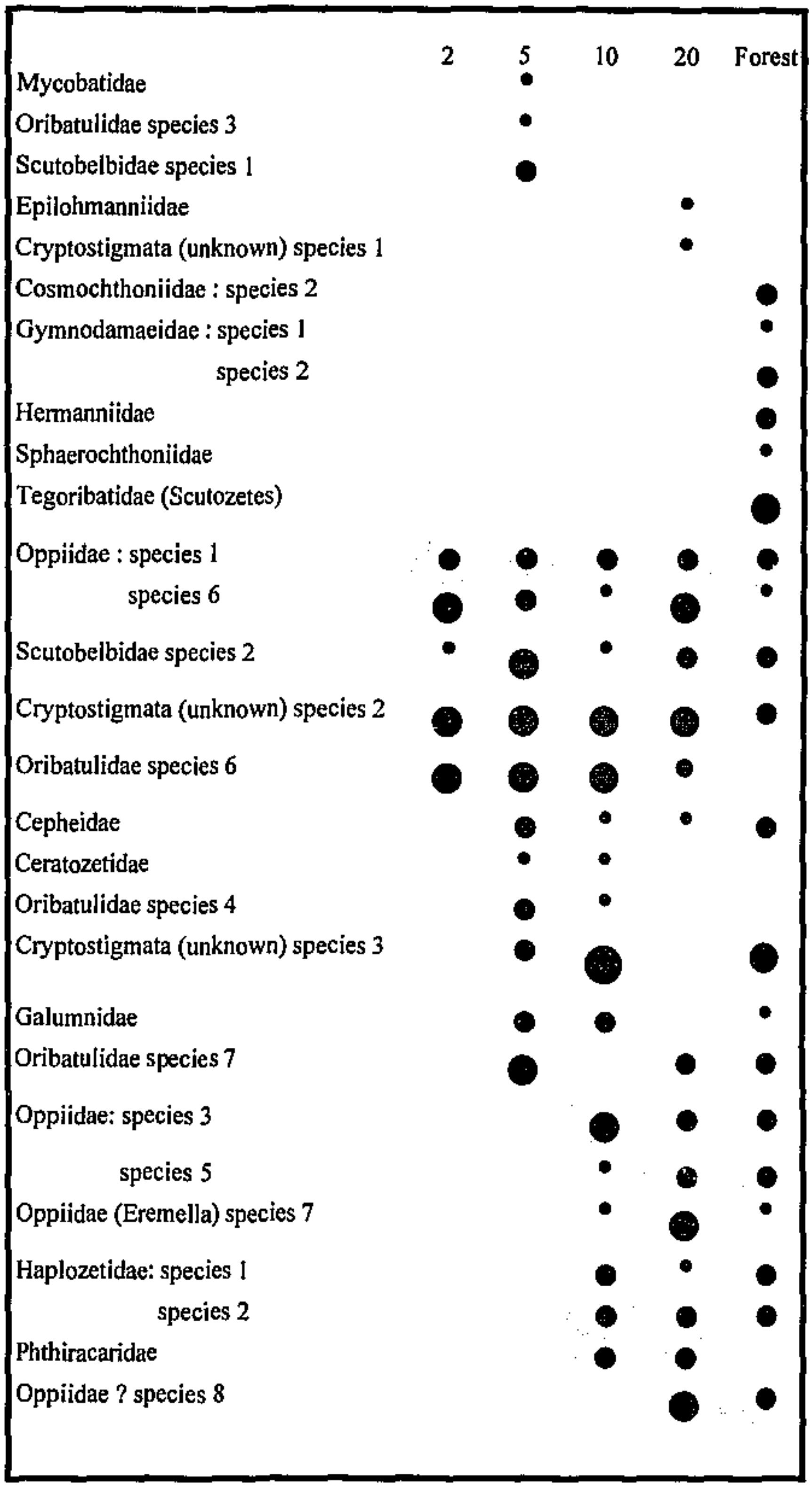


Figure 4.12 Relative abundance of cryptostigmatid species found in litter at each of the rehabilitated sites and forest control site.

($\leq$1% (•), >1% $\leq$ 5% (●),>5% $\leq$20% (●), >20% (●)).

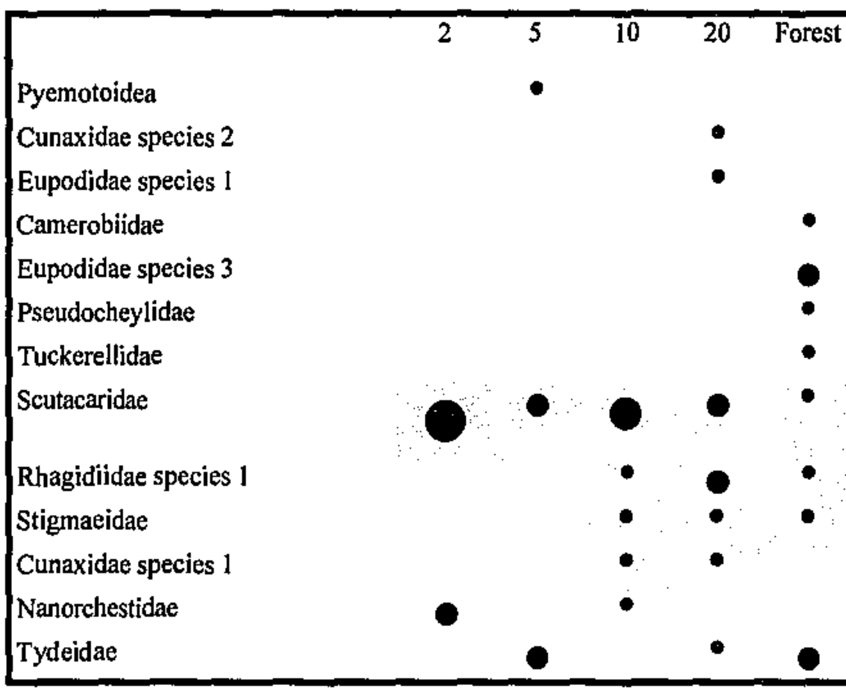


Figure 4.13 Relative abundance of prostigmatid species in surface soil (0-10cm) at each of the rehabilitated sites (years) and forest control site.

(≤1% (•), >1% ≤ 5% (●),>5% ≤20% (●), >20% (●))

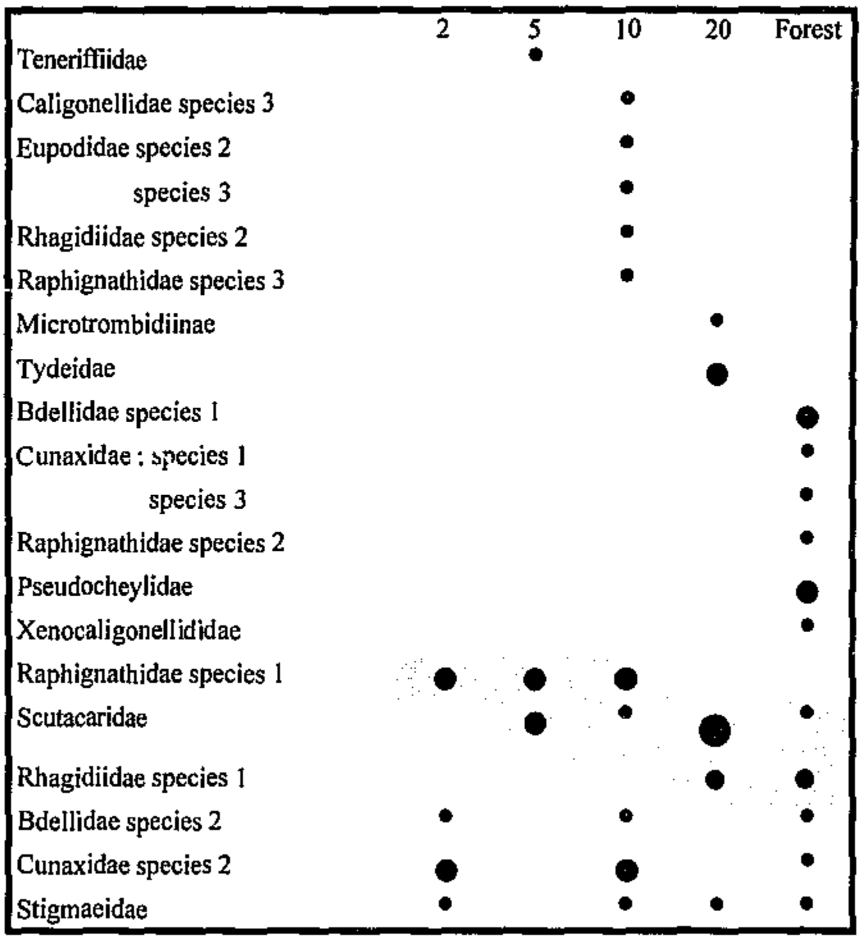


Figure 4.14 Relative abundance of prostigmatid species in litter at each of the rehabilitated sites (years) and forest control.
(≤1% (•), >1% ≤ 5% (●),>5% ≤20% (●), >20% (●))

recognisable species-suites which could be regarded as 'indicators' of level a of disturbance.

There were no species which could be specifically identified as colonisers of the younger rehabilitated sites.

There was a group of species that were non-selective, displaying comparable relative abundances in the soil and litter across all five sites. Such species could be called generalist colonisers in that they made up the major communities on the youngest, most disturbed sites and continued to occur at all or most of subsequent sites, including the forest site. These species are identified by shaded areas extending across all sites in Figures 4.11 to 4.13. They included Oppiidae (species 1 and 6), Scutobelbidae, Oribatulidae (species 6) and an unknown cryptostigmatid species (2).

The next most significant species-suite incorporated are those species only occurring in older rehabilitation and the forest control, but not found in the youngest most disturbed site. Across the 5, 10 and 20 year old and forest sites, they included individuals of Brachychthoniidae (species 1), Oppiidae (species 2), Epilohmanniidae (species 1) Cepheidae and Scutacaridae. These species are highlighted in Figures 4.11 to 4.14 by shaded areas extending from the 5 year old rehabilitation to the forest control.

Another group of species with a limited distribution made up a species-suite recorded only in the older rehabilitation (10 and 20 year old) and forest control sites. The Oppiidae species (3 & 5) species were found in this pattern in both habitats. Individuals of another Oppiidae species (4) were found exclusively in the soil microhabitat. The litter also contained individuals which fitted this distribution from Haplozetidae (species 1 and 2), Oppiidae (Eremella), Rhagidiidae (species 1) and Stigmaeidae, although they were also found in the soil.

The forest control site contained 16 site-specific species recorded in varying relative abundances. Common to litter and soil habitats were Cosmochthoniidae (species 2) Gymnodamaeidae (species 2), Hermanniidae, Tegoribatidae and Pseudocheylidae. Soil species included cryptostigmatid individuals of Cosmochthoniidae (species 1), Eremulidae (species 1 & 2) and Prostigmata species of Camerobiidae, and Tuckerellidae. In the litter habitat, individuals of Cryptostigmata included Gymnodamaeidae (species 1) and Sphaerochthoniidae. The site-specific Prostigmata species were Bdellidae (species 1), Cunaxidae (species 3), Raphignathidae (species 2), and Xenocaligonellididae(Figures 4.11 and 4.14).

4.2.7 Multivariate Analysis

Pattern analyses were carried out separately for soil and litter habitats. The dendrogram in Figure 4.15 summarises the outcome of hierarchical agglomerative clustering of mean abundances per transect of 29 species occurring in 95% of the soil samples. There is no definite clustering of the transects, though there is some suggestion of a grouping of the 2 younger sites and a second, grouping the transects in the 10 and 20 year old sites.

Ordination of the soil species abundance of transects in four dimensions produced an acceptable stress value of 0.05 (Clarke, 1993). The SSH ordination as displayed in figure 4. 17 supports the classification, with the younger sites clearly separating from the older sites, particularly along axis 2. The other axes did not contribute to any definite interpretable clusters.

Hierarchical agglomerative clustering of 24 litter species occurring in 95 % of samples grouped the transects of the youngest 2 year old site (Figure 4.16).

Ordination of the litter species abundance of transects in four dimensions produced an acceptable stress value of 0.05 (Clarke, 1993). As with the soil data, SSH ordination of axis 2 provided a clear separation of the younger sites from the older sites (Figure 4.18).

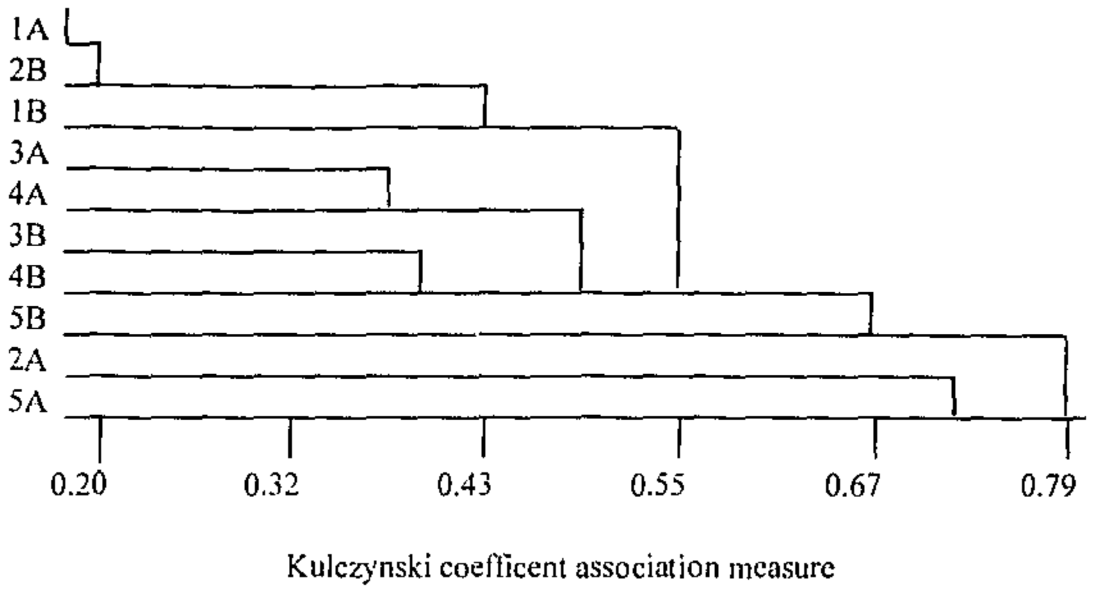


Figure 4.15 Hierarchical agglomerative clustering of soil species (found in 95% of samples) of the transects sampled in rehabilitated sites and forest control. (1A, 1B: 2yr old; 2A, 2B: 5 yr old; 3A, 3B; 10 yr old; 4A,4B: 20 yr old; 5A, 5B: Forest control).

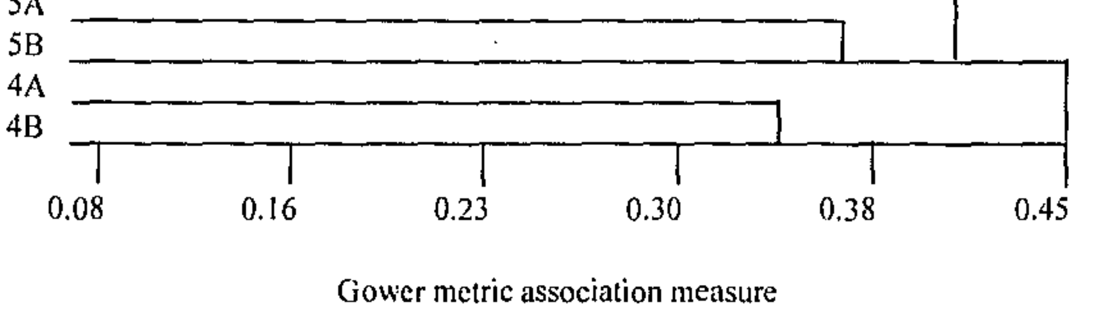


Figure 4.16 Hierarchical agglomerative clustering of litter species (found in 95% of samples) of the transects sampled in rehabilitated sites and forest control. (1A, 1B: 2yr old; 2A, 2B: 5 yr old; 3A, 3B; 10 yr old; 4A,4B: 20 yr old; 5A, 5B: Forest control).

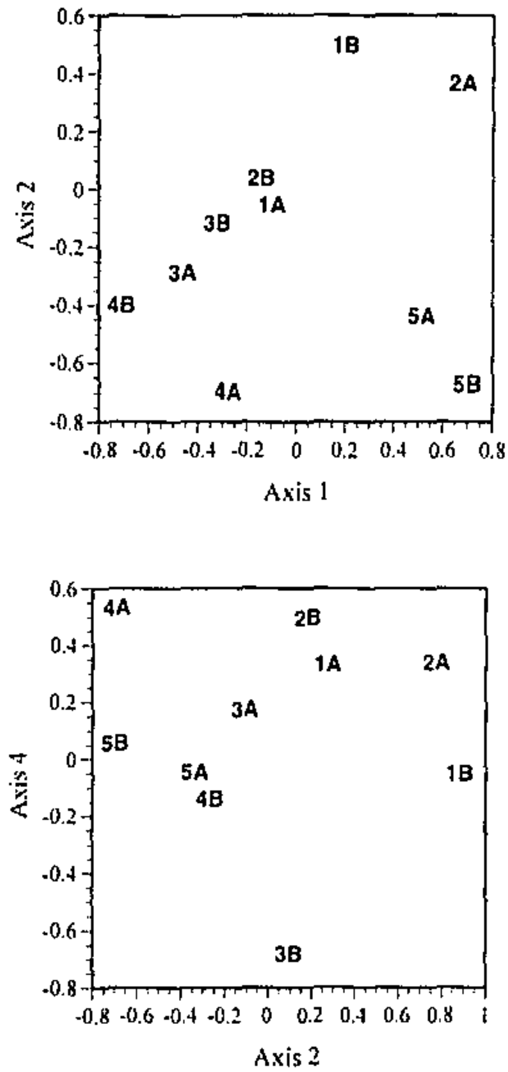
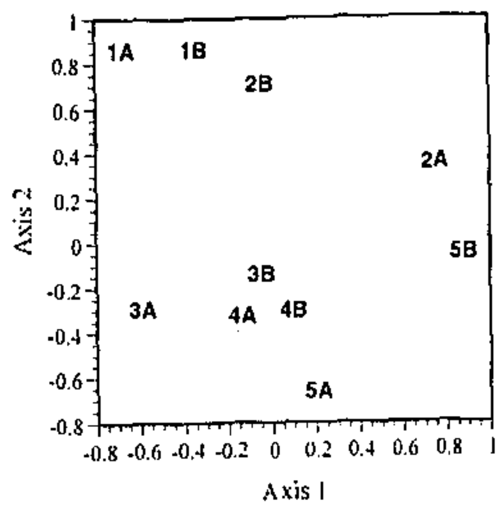


Figure 4.17 SSH ordination of acarine communities of soil samples at each of the rehabilitated sites and forest control. (1A, 1B: 2 yr old; 2A, 2B: 5 yr old; 3A, 3B; 10 yr old; 4A, 4B: 20 yr old; 5A, 5B: Forest control). Values ordinated are the transect means of species found in ≥ 95% of samples. Stress = 0.05.



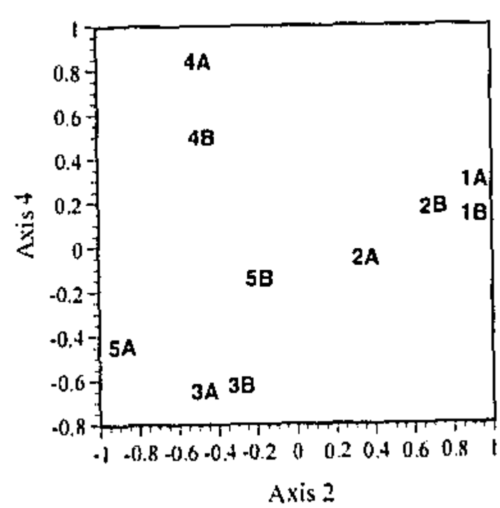


Figure 4.18 SSH ordination of acarine communities of litter samples at each of the rehabilitated sites and forest control. (1A, 1B: 2 yr old; 2A, 2B: 5 yr old; 3A, 3B; 10 yr old; 4A, 4B: 20 yr old; 5A, 5B: Forest control). Values ordinated are the transect means of species found in ≥ 95% of samples. Stress = 0.06.

5.0 DISCUSSION

5.1 Habitat Influence on Acarine Abundance and Diversity

The results of this study clearly suggest that certain habitat features, such as litter and canopy cover in rehabilitated areas are primary determinants of the degree of recolonisation by mesofaunal communities. The primary action is likely to be through the appropriate microhabitat development and climatic amelioration.

The results of this study clearly indicate that the elapse of sufficient time is critical to the development of vegetation at rehabilitated sites, the primary driver of litter cover development, an important determinant of microhabitat conditions. As the vegetation aged, the majority of environmental variables measured began to approximate those of the forest control site. Similar trends have been reported in a wide range of Alcoa's rehabilitation sites (Greenslade & Majer, 1993; Kabay & Nichols, 1980; Majer, 1990; Mawson, 1986).

As revegetation matured the rehabilitated sites displayed distinct changes, likely to result in changes in soil and litter microhabitat conditions. The change in canopy cover and subsequent increase in litter quantity, buffers the soil and litter from insolation and climatic extremes. The effect of this is a reduction in daily fluctuations in temperature and moisture, providing more stable conditions for soil and litter fauna. In addition, the successional development of vegetation involves increasing the amounts of dead wood and logs on the surface soil, increasing the available niches. This development of complexity in litter characteristics provides more stable environmental conditions and increases available habitat and food resources.

The vegetation analysis indicated species richness increased with age of rehabilitation in all cases bar the 20 year old site. The site variation in species richness was large

with the 2 year old site displaying twice the species richness of the 20 year old site. Such variation is likely the result of both differing revegetation techniques and the successional stage of the revegetation. The 2 year old site was revegetated with a diverse seed mix and represents 'stage 1' type rehabilitation, with dense vigorous understorey and emerging saplings (Kabay & Nichols, 1980). In comparison the 20 year site was revegetated with a reduced number of species (predominantly Acacia) and is characteristic of 'stage 4' type rehabilitation with a well developed *A.decurrans* upperstorey and extensive quantities of senescent understorey Acacia species forming a thick litter layer (Kabay and Nichols, 1980).

A comparison of vegetation species richness of the 10 year old (19 species) site with the forest (21 species) revealed similar species richness, though only 7 species were shared, suggestive of quite distinct vegetation communities at the two sites. The subsequent production of 'different' litter, may be a contributing factor to the differing mite communities at these sites.

The correlations of acarine abundance and species richness with environmental variables of canopy cover, litter cover and depth reflect the relationship between diverse faunal communities and the microhabitat complexity and its associated climatic amelioration. Previous investigations of invertebrate recolonisation in Alcoa's rehabilitated sites report the same synergistic relationship between microhabitat development and faunal communities (Greenslade & Majer, 1993, Majer *et al* 1984; Majer, 1990; Mawson, 1986; Nichols & Burrows, 1985). The primary factors identified by the present study to be the major correlates with acarine abundance and species richness were the inter-correlated variables of canopy cover, litter cover and soil organic carbon content.

5.2 The Acarine abundances

The sampling of surface soil and litter at the rehabilitated sites clearly revealed differences in acarine abundances suggesting degrees of sensitivity of the fauna to successional changes in microhabitat conditions.

The low abundances found in the younger sites (2 and 5 years old) are most likely a result of the harsh nature of the microclimatic conditions and the limited niche variety at the sites. The reduced complexity of microhabitats present in the younger rehabilitation is analogous with conditions resulting from perturbations associated with other forest management practices such as prescribed burning and harvesting. Although controversy surrounds the effects of these practices, increasingly, studies indicate abundances of acari and other soil invertebrates decline after such practices, as a result of habitat simplification and the increased range of microclimatic conditions (Cancela Da Fonseca, 1990; Moldenke & Lattin, 1990b; Springett, 1976b). Postle *et al* (1991) in their, investigation of soil and litter invertebrates and litter decomposition dynamics in *P.cinnamomi* affected forest, determined that the degradation of microhabitat conditions associated with the presence of *P.cinnamomi* resulted in reduced faunal abundances. Similarly the harsh microhabitat conditions of the younger rehabilitated sites in this study resulted in reduced acarine abundance.

A 'return' of acarine abundance which is associated with the development of rehabilitated revegetation appears to be slower in the soil than in the litter habitat. The abundance of acari in the soil of 10 and 20 year old sites remained considerably lower than that in the forest control site. This suggests that the soil microhabitat, as a habitat for soil fauna, requires considerable time for restoration. This is certainly the case with regard to organic carbon content, with the forest control displaying total organic carbon levels 2 times that of 2, 5 and 10 year old sites. Ward and Koch (1996) reported organic carbon levels in a 15.5 year rehabilitation similar to those found in the 2, 5 and 10 year old sites. Thus, the variance in soil organic carbon content may be a limiting factor in the abundance of soil acari found in rehabilitated sites as

compared to the forest control. This trend is consistent with general literature, where soil organic carbon levels have been correlated with abundance (Spain & Hutson, 1993).

In contrast, abundances in the litter were comparable in 10 and 20 year older rehabilitation and forest control. This is most likely the result of the similar canopy and litter cover characteristics and their direct effect in ameliorating the microclimate.

There are very few studies of jarrah forest acarine abundances, with Postle's (1986) work providing some data for comparative analysis. He determined a population range of 37 000 - 126 000 mites m^{-2}, though caution is required because of differences in sampling intensity and extraction (Postle, 1986). In particular a greater range of habitats and seasons were sampled. The variation associated with sampling is an important difference as Postle (1986) recorded autumn peak abundances, with the spring abundance values the third highest recorded. The results of the forest control are considerably lower, although are within the orders of magnitude recorded in Postle's spring sample (1986). Another potential explanation of considerable differences is the natural variation of the populations associated with the habitats sampled.

In summary, the 'return ' of an abundant mite community in soil and litter is dependant on rehabilitation practices that promote the accumulation of litter. The effect of canopy and litter development is an amelioration of microclimatic conditions, an increase in organic inputs and provision of habitat niches critical to the 'return' of acari.

5.3 Relative Abundance of Acarine Orders

The relative contribution of acarine orders within the sites are characteristic of those often described for forest ecosystems, with Cryptostigmata numerically dominant

followed by Prostigmata, Mesostigmata and then Astigmata (Spain & Hutson, 1993; Springett, 1976b; Toregerson, 1995).

The Prostigmata displayed their greatest relative abundance in the immature, harsh conditions of the 2 year old site, where canopy and litter cover is sparse and surface soil is exposed to high temperatures. The change in relative abundance of Prostigmata and Cryptostigmata, recorded in this study as litter and canopy cover increase has also been described on both continental and global levels of scale (Di Castri & Vitali-Di Castri, 1981; Kinnear, 1991; Noble, 1996).

The Cryptostigmata are of particular importance to this study because of their potential to provide 'indicator' species and because the increase in acarine abundances which occurs as a result of age of the rehabilitation was primarily due to an increase in the cryptostigmatid component. As the vegetation matured, producing an effective canopy and litter cover, and consequent soil organic carbon increases, the sites became more favourable to the Cryptostigmata. This group is well known to favour stable and regulated habitats. As such, they behave as k-strategists. The Cryptostigmata as major fungal feeders and litter comminution (a niche very similar to the Collembola) increased with complexity of the soil and litter habitat. Increases of this magnitude would be expected to enhance decomposition processes, particularly in drier climates such as this, where dry periods reduce Collembolan activity, but would be expected to have less effect on mite activity.

The Astigmata normally represent minimal components of undisturbed forest acarine communities. They show higher abundances in drier ecosystems, but particularly in perturbed environments, such as agricultural dryland and irrigated systems (Philips, 1990). The Astigmata in this study displayed such a pattern and could be classed as r-strategists, with large number found in the in the younger sites and then decreasing substantially in older rehabilitation to minimal numbers approximating that found in the forest control.

The predatory Mesostigmata traditionally reach peak abundances in moist, rich soils where litter characteristics are relatively stable. The absence of any clear-age related patterns in this study may reflect the lack of complexity in rehabilitation. Such a trend is consistent with forest management disturbance patterns on their abundance (Cancella Da Fonseca, 1990).

5.4 Species Diversity

A total of 75 species were recorded across all sites in the soil and litter. This result is likely to be an under-estimate, particularly for the Astigmata and because of time constraints which prevented sampling on a seasonal basis. Postle *et al.* (1991) recorded comparable species with 65 species in his spring samples of jarrah forest, and the 109 species recorded across all seasons.

As with the abundance pattern, the species diversity (N′) was positively related to the maturation of vegetation, a factor of time. Thus the considerably lower diversity determined in the rehabilitation is likely due to low heterogeneity of soil and litter habitat.

The relationship between increasing species richness with age since disturbance or revegetation, and with improvements in microhabitat conditions found in this study is well supported in the literature. Springett's (1979) investigation of invertebrate population of *Pinus pinaster* Ait plantations at Gnangara demonstrated a species increase with age of the plantations. Greenslade & Majer (1993) in an investigation of the collembolan communities determined that time was a correlated variable with species richness at sites. Majer *et al* (1984) recorded similar time dependency for ant species colonisation.

The mite communities of the forest soil samples were the most species-diverse. In contrast, the rehabilitated the litter samples produced species diversity at least 1.5 greater than those recorded in the rehabilitated soils, in all sites bar the 20 year old.

Thus, as with acarine abundances, the ameliorative effects of increased canopy cover and litter cover and result in more suitable habitat for mite recolonisation.

5.5 Cryptostigmata and Prostigmata : an Analysis of Species Distribution

These orders made up the greater part of soil and litter communities and analysis at this taxonomic level yielded further insight into the pattern of species return to the sites.

The trend for the litter habitat to harbour a greater diversity of mite Families than soil at the rehabilitation sites was true for both Cryptostigmata and Prostigmata. In this context, the Family diversity mirrored species diversity and further supports the contention that litter cover is an important and early determinant of mesofaunal diversity. The somewhat slower development of a diverse soil community is understandable given the time required for decomposition and other soil processes to effect soil development.

An analysis at the Family level may be used to assess the success of rehabilitation in effecting a return of a diverse mite community. The most appropriate comparison is the 10 year old rehabilitation with the forest control, as the 10 year old site represents the oldest site rehabilitated with techniques that are most comparable to current techniques. The comparisons reveal only a relatively small number of shared Families (7). So even an analysis at this lower taxonomic level (in comparison with order) reveals differences in mite communities between the oldest rehabilitated site and forest site. It is not easy to predict what such differences may mean for decomposition processes. While some workers have utilised familiar groups to reflect functional trophic guilds (eg Tydeidae as nematophagous) in an attempt to apply some ecological significance to Family-level community descriptors, the approach has come under considerable criticism. There is increasing evidence that neither Family designation or mouthpart morphology (particularly in the case of micropredators and

fungivores) is not an appropriate indicators of trophic status (Walter *et al.*, 1988; Walter & Ikonen, 1989). Thus, there is insufficient knowledge at the time to utilise the guild approach and predict potential effects on mite community dynamics.

5.6 Distribution of 'species-suites'

An analysis of individual species distributions across sites revealed useful patterns, of distribution of species at a particular site or set of sites. This allows some inferences as to the ability of the specie(s) to colonise rehabilitation.

Firstly there were no species which could be described as uniquely colonisers of young-aged rehabilitation. Rather, the species-suites which were recorded at these sites were found in older rehabilitation and/or the forest control. These species displayed a tolerance to the varied environmental conditions which existed across sites. Such species are here designated as 'generalists' displaying relative insensitivity to environmental conditions (Aoki, 1979 as cited in Franchini & Rocket, 1996).

One such generalist species-suite was formed by the Oppiidae, Oribatulidae, and Scutobelbidae (Figures 4.4 - 4.7). The majority of the species in this suite were found in the litter. Species of the Oppiidae and Scutacaridae were most abundant in the younger sites, suggesting that they are insensitive to the harsh environmental conditions of the immature 2 and 5 year old sites. Thus, they may represent species associated with perturbed systems. Such a result is consistent with the findings of Greenslade and Majer (1993) who determined a greater number of introduced collembolan species in younger rehabilitation sites. Majer *et al.* (1984) investigation of ant recolonisation also found a number of species that were primarily colonisers of perturbed areas. Thus, this suite of early rehabilitation colonisers are potentially species associated with disturbance.

The second species-suite comprised of species found across all rehabilitated sites of 5 years and older and the forest site. In addition to the species-suite previously discussed, individuals of Brachychthoniidae, Cepheidae and Epilohmanniidae were recorded in this group. Small scale changes in forest litter characteristics have been suggested to increase species richness (Aoki, 1967). Therefore, the increase in species richness can be attributed to the improvements to the soil and litter habitats occurring as rehabilitation ages.

A third 'species suite' comprised those species restricted to the 10 year old and older rehabilitation sites and the forest control site. It may be inferred that these species require somewhat more stable microclimatic conditions, and an improved soil resource. Again the Oppiidae were amongst the species found, along with individuals from Halplozetidae, Rhagidiidae and Stigmaeidae. The species-suite may have management significance since it associates the 10 year old site (oldest site which was rehabilitated with techniques approximating current techniques) and the forest site. The species were found in comparable relative abundances across sites and were likely contributors to the ordination-classification outcomes of separation of the older from the younger sites (Figure 4.4 - 4.7). This species-suite is an indicator of the degree of matching between the rehabilitation and forest sites, and is indicative of the beginning of some community conformity with the undisturbed forest site. The strength of this association was greater in the litter, again suggesting that the litter microhabitat begins to approximate that of the forest with respect to acarine communities sooner than in the soil. This is consistent with the similar decomposer investigation by Greenslade & Majer (1993) that determined rehabilitation 10 years and older consisted of collembolan fauna most similar to that of the forest control.

The fourth species-suites represent individuals found at the 20 year old and forest control site. The method of rehabilitation for this site is far removed from current techniques, with vegetation characteristics substantially different to that of the forest control, thus interpretation of this result is inappropriate.

A fifth species-suite identified contained those restricted to forest sites (14 species). These may represent species characteristic of undisturbed forest systems. The importance of this site-specific suite was that the number of species recorded approximated species recorded at 2 and 5 year old sites, and was almost the half species recorded in the 10 year old and 20 year old sites (Section 4.2.6). The individuals included inferior cryptostigmatid mites of the Families Cosmochthoniidae and Sphaerochthoniidae. Prostigmatid mites found only at the forest site included a subset of predators of Bdellidae, Camerobiidae, Raphignathidae, and Xenocaligonellididae (section 4.2.6). The species were recorded at a range of frequencies. The lower frequency of some species is attributed to soil faunal distribution and the sampling intensity. The contagious distribution of soil mites means that rare species are likely to be 'missed' species (Usher, 1976). In addition, sampling over longer periods is likely to uncover greater number of species in the forest.

The range of site-specific species identified in the forest and the considerably higher species richness, suggests that the heterogeneity in microhabitat required by these species has not yet developed in the rehabilitation. The importance of resource substrates associated with mature forests, such as wood and rotting logs, to recolonisation by other invertebrates is well supported in the literature (Greenslade & Majer, 1993; Majer *et al.*, 1984; Moldenke, 1990b). Thus, the forest site-specific species may represent mites that are particularly sensitive to environmental conditions and/or require particular resource substrates not yet available in the rehabilitation ages investigated.

In summary a number of species associations are apparent in the soil and litter. They include:

- a 'generalist' suite, that displays insensitivity to the varied environmental conditions and is found across all study sites;

- a complement of species occurring in 5 year and older rehabilitation, thus displaying reduced insensitivity to the environmental conditions as compared to the generalist group;
- species displaying intermediate tolerance of environmental conditions as they are found primarily in rehabilitation 10 years and older; and
- a group of site-specific species that are restricted to the forest site, suggesting sensitivity to environmental conditions

5.7 The Indicator Value of Species

The potential of Australian acarine species as indicators of habitat condition has received little attention to date. Hunt (1994) suggests in a review of Cryptostigmata that certain Families (11) may be useful in assessing biodiversity and as indicators due to particular sensitivities. Of the potential families he identified, those most relevant to this study are the Oppiidae, Oribatulidae, Galumnidae and Brachychthoniidae. On a global scale Aoki, 1979 (as cited in Franchini & Rockett, 1996) rated cryptostigmatid Families according to their sensitivities of environmental conditions. By his definition the greater the sensitivity of the species the less tolerance it displays of environmental conditions. Thus, sensitive species may be useful as indicators of environmental change. Families recorded by Aoki as insensitive include the Oppiidae, Oribatulidae, Haplozetidae and Galumnidae (Aoki, 1979). Individuals of the Ceratozetidae are suggested as displaying intermediate sensitivity. In the following section the distribution and occurrence of each of these Families will be discussed with regard to sensitivity and potential as an indicator. The potential of other Families found in this study to act as an indicator will also be discussed.

The Oppiidae were recorded extensively across all rehabilitated sites and in the forest control, and were the most speciose Family (8 species) (Figure 4.4 & 4.5). This is consistent with the literature. Unfortunately, individuals of this Family are very small and difficult to identify (Aoki, 1979; Hunt, 1994). The Oppiidae found in this

study displayed varying degrees of sensitivity to environmental conditions. Three species (1, 2 & 6) of the Family appeared relatively insensitive to environmental conditions, being recorded from all rehabilitation and the forest control in comparable abundances. These 'generalists' species would provide little indicator value of rehabilitation success.

The Oppiidae species 3, 4 , 5 and 7 were found in relatively similar abundances in older rehabilitation sites (10 and 20 years) and in the forest control. The species displayed a degree of increased sensitivity, and they may potentially indicate changes in habitat structure such as litter cover. The Oppiidae species 8, displayed even greater sensitivity, with distribution restricted to 20 year old rehabilitation and the forest site. Although, Aoki (1979) suggests this Family is insensitive, the distribution and frequency recorded by the Oppiidae in this study, suggests that particular species warrant further investigation as potential indicators of conditions.

The Oribatulidae displayed reduced abundances in comparison to the Oppiidae. Their relative abundances across rehabilitated sites were similar to that of the forest control site. The Family displayed increased sensitivity with less frequent occurrences in the younger rehabilitation. Thus, although Aoki (1979) suggested the Family is insensitive, the results of this study are more consistent with trends recorded by Franchini & Rockett (1996) where the Family displayed intermediate sensitivity to tillage disturbance. As a result further investigations of the of this Family may uncover potential species that can be attributed to the development stage of the habitat.

The Haplozetidae species recorded in this study displayed particular sensitivity, being found only in rehabilitation of 10 years and older and the forest control. The relative abundances of the species in rehabilitation sites and the forest control site were similar, particularly in the litter habitat. The limited distribution of this species indicates sensitivity of the species to canopy and litter cover, therefore the species may indicate the level of microhabitat development. Although not recognised by

Hunt (1994) as a potential indicator, the consistency with Franchini & Rockett (1996) and to a lesser extent Aoki (1979) work warrants further investigation of this species.

The Galumnidae, Ceratozetidae and Brachychothoniidae species suggested as potential indicators, were recorded in minimal abundances. The infrequency and limited relative abundance of these species recorded in this study prevents any inferences regarding indicator status.

The forest site-specific species previously discussed may prove useful as potential indicators. The Cosmochthoniidae, Gymnodamaeidae and Tegoribatidae were species recorded in considerable levels of abundance within the forest site. These Families have not been suggested as potential indicators to date, though their relative occurrence in the forest site may indicate particular sensitivity. The return of such species may indicate the level of habitat development.

The determination of invertebrate indicator species is important to Alcoa's rehabilitation goal, primarily to measure the success of rehabilitation and secondly as a tool for the development of completion criteria. The use of mite species as indicators of disturbance and to assess biodiversity is a growing area of research. The preliminary groups identified by this study as displaying degrees of sensitivity include the Oppiidae, Oribatulidae, Cosmochthoniidae, Gymnodamaeidae and Tegoribatidae. Such species appear to have particular requirements, and thus they may be useful as indicators of microhabitat conditions which are essential for the return of species complements that approach that of the un-mined forest.

6.0 Conclusions and Management Implications

The return of an abundant and diverse acarine community in rehabilitated sites is dependant upon the development of litter characteristics that approximate those of un-mined jarrah forest. In this study age since rehabilitation was determined as the primary determinant of acarine abundance.

The acarine fauna of rehabilitated sites displayed considerably lower abundance and diversity than that of the forest control site. This pattern was particularly apparent in the soil community. The abundance and diversity of acari was also at a minimum in litter of the youngest sites (2 and 5 year old), and reached maximal levels in 10 and 20 year old sites. Faunal abundance in the 10 and 20 year old site litter habitat was similar to that of the forest control and the species complements were beginning to approach that of the forest control. The implication of these findings are that soil conditions require considerably longer time to approximate those of the forest control. Further investigation of the physical and biological development of the soil are warranted. Such investigations may potentially identify rehabilitation techniques that improve the structure and chemical composition of the soil, benefiting both the floral and faunal communities.

An analysis of the community structure at the Ordinal level revealed a similar structure between the rehabilitated sites and the forest control site. However, examination of the taxa at Family level revealed clear differences in the community structure of rehabilitated sites as compared to the undisturbed forest control. The significance of this result is that interpretation of invertebrate community investigations, based on Ordinal level data may produce spurious assumptions.

The importance of lower level taxonomic assessments of invertebrate fauna was further supported by an analysis of species distribution across rehabilitated sites. This analysis identified distinct species complements associated with age since rehabilitation. The groups included generalist species considered insensitive to

environmental condition, an intermediate suite that required successional-like development of site characteristics, through to site-specific species that were restricted to the undisturbed forest site. The most likely factor determining such distributions is the development of litter cover and its associated amelioration of microclimatic conditions, with increasing maturity of the vegetation.

The large number of forest site-specific species, suggests that there are particular niches only associated with forest sites which require extensive time for development in rehabilitation sites. The potential to accelerate the development of such habitats in rehabilitation requires further investigation as the return of these species may have management implications. A precautionary approach is therefore appropriate as the number of species and their ecosystem roles remains unknown.

Our knowledge of invertebrate communities of the rehabilitated areas would benefit from a long-term study of invertebrate groups at the species level, along with environmental parameters known to influence the distribution, abundance and diversity of such species. A similar analysis of undisturbed jarrah forest would provide base-line community structure and potential indicators critical for the assessment of rehabilitation success.

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APPENDIX 1.0 Vegetation analysis of tree and shrub species recorded at each of the rehabilitated sites (years) and forest control.

Species	2	5	10	20	Forest
CASUARINACEAE					
Allocasuarina fraseriana	*	*	*		*
CYCADOPSIDA					
Macrozamia reidlei			*	*	*
DENNSTAEDTIACEAE					
Pteridium esculentum					*
DILLENIACEAE					
Hibbertia amplexicaulis				*	*
Hibbertia commutata					*
EPACRIDACEAE					
Astroloma ciliatum					*
Leucopogon capitellatus					*
Leucopogon oxycedrus			*		
Leucopogon propinguus			*		*
Leucopogon verticillatus					*
MIMOSACEAE					
Acacia atlas					
Acacia celastrifolia		*	*		
Acacia decurrens				*	
Acacia drummondii		*	*		*
Acacia extensa	*	*			
Acacia lateriticola	*	*			
Acacia pulchella	*	*			*
Acacia saligna		*			
Acacia urophylla	*	*			*
Acacia species 1			*		
MYRTACEAE					
Calothamnus sanguineus		*	*		
Coryrmbia calophylla	*	*	*		
Eucalytus marginata	*	*	*	*	*
Eucalyptus patens		*	*		
Eucalyptus resinifera				*	
Hypocalymma angustifolium		*	*		
PROTEACEAE					
Banksia grandis	*				*
Dryandra sessilis			*		*
Grevillea synapheae					
Persoonia longifolia			*		

APPENDIX 1.0 contiued....

	2	5	10	20	Forest
PALILIONACEAE					
Bossiaea aquifolium	*		*	*	
Bossiaea ornata	*		*		
Hardenbergia comptoniana		*			
PITTOSPORACE					
Sollya heterophylla			*		
Styphelia tenuiflora					*
PLUMBAGINACEAE					
Kennedia prostrata	*				
Mirbelia dilatata			*		
RHAMNACEAE					
Trymalium ledifolium	*				*
RUTACEAE					
Boronia fastigiata	*		*		*
Boronia scabra					*
STERCULIACEAE					
Lasiopetalum floribundum	*	*		*	*
XANTHORRHOEACEAE					
Xanthorrhoea preissii		*			*