After the Goldrush

The Success of Ecological Restoration Following Mining in the Box and Ironbark Forests, North Central Victoria

By

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Statement

This work contains no material that has been accepted for the award of any degree or diploma in any University and to the best of the author's knowledge, contains no copy or paraphrase of material previously published or written by other persons except when due reference is made in the text of this thesis.

signed............................

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Abstract

The new science of restoration ecology offers those who work towards ecological restoration an evaluative framework for measuring success. This research project considers the restoration work carried out on four mined sites in the Box and Ironbark Forest Ecosystem of North Central Victoria. To measure success, vegetation cover and height, along with thirteen environmental variables and three site characteristics, were recorded in four mine sites and compared to nearby forest controls. It was found that mined sites had fewer native species than the control sites, and soil fertility and litter cover were less. Five floristic communities were described from the mined areas and controls, two of which are restricted to mined areas. Global Non-parametric Multi Dimensional Scaling of the vegetation data and vector fitting of the environmental and site variables also showed that strong floristic differences exist between mined and control areas at most sites. As restoration attempts were similar at each site, ecosystem resilience was considered as the main contributing factor to the different degrees of success. It was found that mined areas with prolonged disturbance regimes shared less in common with their control. Weed cover was not found to be significantly different between the controls and mined areas. This study serves as baseline data for long term research and recommends that clear goals and objectives need to be implemented in determining successful mine site restoration in the Box and Ironbark Ecosystem.

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Chapter 1: Introduction

1.1 Statement of Problem and Overall Research Aim

> Our relationship with the ground is, culturally speaking, paradoxical: for we appreciate it only in so far as it bows to our will. Let the ground rise up to resist us, let it prove porous, spongy, rough, irregular - let it assert its native title, its right to maintain its traditional surfaces - and instantly our engineering instinct is to wipe it out; to lay our foundations on rationally apprehensible level ground. (Carter, 1996)

European utilization of Box-Ironbark forests has significantly altered this natural vegetation community. Over 75% of the original cover of the Box and Ironbark forests of Victoria has been cleared, whilst the remaining 25% has been modified. In both the past and present degrading land practices include harvesting of trees for wood and oil products, grazing by exotic animals and mining. Subsequently, a few Box-Ironbark species have become extinct, threatened or rare. Many exotic species have been successful at colonising this degraded forest type. Action is needed to halt or mitigate these negative impacts.

The restoration of this forest type is emerging as a conservation objective. Many groups such as government, the mining and farming industries, community groups, schools and private landholders have revegetated areas with native species for conservation purposes. Despite there being many examples of practical restoration efforts, to date, little empirical research to evaluate the success of these practices has been carried out. Indeed, recent scientific research into the ecology of the Box and Ironbark forests is limited in comparison to other forest ecosystems of Victoria. The lack of empirical research presents a serious gap in the knowledge required to determine the success of current techniques of restoration in Box and Ironbark forests.

Many gold mine sites in this ecosystem have been subject to restoration attempts. They provide an excellent case study in restoration. **This study aims to evaluate the success of restoration following gold mining in the Box and Ironbark forests of North Central Victoria.**

This study covers the success of the restoration process and the impact of mining on native flora, soil fertility, and the introduction of weed species. It forms a small, but nonetheless significant contribution to the growing interest and debate between scientists, governmental agencies, community groups and industry about the future conservation of the Box and Ironbark forests. It complements other research and conservation projects that are currently taking place. For government and conservation organisations concerned with mining on public land, this study may clarify some of the issues about the impact of mining. For the restoration workers, this study endeavors to provide constructive feedback on the success of their activities.

1.2 Research Approach

To achieve this aim, Chapter two introduces the reader to the background information relevant to this particular case study. A general review of the new science and practice of restoration ecology is given. Following this, Chapter three considers the natural and cultural factors of the Box and Ironbark forests. Chapter four sets out the study objectives and methods used to fulfill the research aim. Chapter five will present the results of this study, whilst Chapter six is a discussion of these results. Chapter 7 summarises and concludes the project, recommending future research possibilities. The reference list offers an extensive bibliography of restoration ecology and associated research, as well as literature on the Box and Ironbark forests.

1.3 Project Objectives

The specific objectives to achieve the overall aim are as follows:

- Determine the success of restoration following surface mining. Success is measured by total vegetative cover, species richness, and abiotic factors in mined sites compared to adjacent vegetation that was assumed to resemble the original vegetation of mined areas.

- Assess the responses to restoration of native and exotic species.

- Develop recommendations useful for restoration ecologists and community groups working in the Box-Ironbark Ecosystem.

1.4 Limitations of the Study

The Box-Ironbark ecosystem stretches across Victoria from Stawell in the west to Chiltern in the east. The study was confined to a small part of the entire forested area.

These forests known as Northern Goldfields Vegetation, are most common in forests around the Bendigo, Heathcote, Rushworth and Dunolly .

Most of the field work was conducted over the extremely hot 1996-1997 December - March period. Thus, many annuals and geophytes failed to be included in this study. A second site visit in October 1997 picked up some of these species, although more site visits would almost certainly have revealed more species.

This study falls far short of providing a detailed assessment of the success of mine site restoration. As the literature review will show, to measure restoration success is a difficult task which has often resulted in years of research into many attributes of ecosystem function and structure. This study failed to consider the impact that mining has had on fauna, especially birds and marsupials that rely on older trees for habitat, nor used invertebrates as indicators of restoration success. This study was unable to consider the success of vegetation change over the long term; however, could be used as baseline research for such a project.

Chapter 2: Literature Review

2.1 Introduction

Restoration ecology is a burgeoning field of science. The first part of this chapter aims to introduce the reader to some of the academic debates surrounding the definition of restoration ecology and measuring success. Some of the terms used by restoration ecologists are also explained herein. The latter part of this chapter is a review of other ecological restoration studies relevant to this project.

2.2 "Restoration" is the Word

Restoration belongs to a group of words beginning with the prefix "re". Other common examples include; *revegetation*, *regeneration*, *rehabilitation* and *reclamation.* These words are often used interchangably to describe the same thing - at other times they are used independently to describe different things. In ecology, they describe the return to a previous state by an ecosystem, usually following the cessation of anthropogenic disturbance. It is important to note the discussion surrounding the definitions of each of these terms.

David Storey (1990) claims that most authors refer to the 1974 definition of restoration, reclamation and rehabilitation by the United States National Academy of Science (NAS). Storey (1990) writes:

> According to the NAS the three terms are defined in the following manner: **restoration**, is the return of the site to the exact condition which prevailed prior to disturbance; **reclamation**, is the return of the site to a state where the species composition and density is comparable to the original community; and **rehabilitation**, is the return of the site to a stable state compatible with the surrounding aesthetic values, and in accord with a prior land-use plan.

From the above definitions, two themes are evident. Firstly, many authors see a clear distinction in the "re" words between those that describe a return to the original pre-existing indigenous vegetation and those that fail to do so (McDonald 1996). Thus, words such as revegetation, reclamation and rehabilitation do not necessarily describe a return to the original ecosystem - they may indeed imply an alternate state. For example, a ski slope may be cleared of its native vegetation and **revegetated** with exotic grasses. Secondly, most ecologists recognise that there is a continuum of "re" words. This continuum is '...dictated by the degradation degree and practicality...' of restoration (McDonald 1996). William Jordan III (1995) argues that of all the "re" words, restoration offers the clearest commitment to a goal; he writes '...it promises to return the system or landscape to some specified previous condition...'.

In another sense, it can be argued that this continuum is simply different forms of restoration (Hobbs and Norton 1996). Indeed, any work that enhances, or at least does not prevent the future restoration potential of a site may be considered a part of the restoration process (McDonald 1996).

Richard Hobbs and David Norton (1996) pointed out that restoration ecologists should be more concerned with ecology rather than nomenclature quibbling, but they did not dismiss the need to adequtaely define the terms being used. Aronson and Le Floc'h (1996a) stated the need for clarity on the matter:

> ...a clear statement of concepts and definitions is ... an essential step or process in the practice of any science, theoretical or applied, or any practical endeavor as ambitious as the reorganization and reorientation of landscapes.

The founding of the Society for Ecological Restoration (SER) in the early 1990s has provided a forum for definitions to be discussed. Recently, a definition has been adopted by SER (1996) and is provided below:

> Ecological restoration is the process of assisting the recovery and management of ecological integrity. Ecological integrity includes a critical range of variability in biodiversity, ecological processes and structures, regional and historical context, and sustainable cultural practices.

Much work is carried out to restore mined sites (Hobbs and Norton 1996; Chambers *et al.* 1994; Bell *et al.* 1990; Koch *et al.* 1996). In the case at hand, there is a perceived need to restore the characteristics of the mined site to a pre-disturbed state. Without this assistance, it is suspected that the vegetation community would be unable to recover in the near term and would lack important ecosystem attributes. The Box and Ironbark forests that are under investigation in this study are by definition undergoing "restoration".

In the particular case at hand, a few implicit aims are also distinguishable. The mining companies not only have the responsibility to ensure the ecological integrity of the disturbed site in the long-term, but also to ensure that the mining process has not impacted greatly upon the amenity and service of the forest to the local community. As the region is highly populated and the forests are used for a range of activities other than mining, the restoration of these small sites is important for the aesthetic, recreational, commercial and conservation qualities of the entire forest.

2.3 Evaluating Ecological Restoration Success

According to SER, a major focus of restoration ecology is the evaluation of the success of restoration activities, although in practice the number of projects seems to far outweigh the number of empirical evaluations. This is most likely a result of the fact that in '...restoration ecology today, there are far more practitioners than scientists' (Aronson *et al.* 1995).

In cases where success of a restoration project is measured, it is often gauged by comparing the site to one assumed similar to the pre-existing ecosystem, often called a control or reference site (Storey 1990; Aronson *et al.* 1995; Koch *et al.* 1996; Chambers *et al.* 1994; Hobbs and Norton 1996; Chapman and Underwood 1997). As John Cairns (1987) wrote:

> Research on the recovery or restoration of disturbed ecosystems to some stable condition assumes, for example, that we have a fairly comprehensive knowledge of the structure and function of the reference (natural) systems; the recovery or restoration becomes a test of the validity of that knowledge, and also raises new questions.

2.3.1 Are Control Sites a Valid Way of Measuring Success?

Exactly what governs the particular characteristics of an ecosystem, is a complex question for ecology - especially for restoration ecologists who attempt to restore the "natural" state of an ecosystem. No definitive answers are provided here. Rather, there is a review of the arguments that were considered when deciding the particular design of this project.

In recent times there has been some criticism made of the use of control sites to measure success. Pickett and Parker (1994) are particularly vocal on this matter. They argue that it is an "old pitfall" to perceive that nature has a climax state, and therefore in choosing a control site, the ecologist may mistakenly assume that there is one ecologically legitimate or ideal ecosystem. Pickett and Parker argue that the ecologist risks thwarting success by assuming that the ecosystem is unchanging. The academic ground onto which Pickett and Parker stray to support their point is that of community ecology. It is worth reviewing before moving on.

What has been termed the "climax community" involves the notion that disturbed ecosystems will work towards restoring themselves to a stable state. This view has arisen from the ideas of the ecologist Clements, who coined the phrase "climax community". According to Clements (in Recher *et al.* 1992), following disturbance, a vegetation community given sufficient time, and the same environmental factors, would reach a stable and self perpetuating state (at least until another disturbance). This view of plant communities has remained an important concept in plant ecology. The task of "speeding up succession" would be very easy for the restoration ecologist, if every community moved towards a final and stable state. Unfortunately, the process is not as simple as Clements thought.

As early as the 1940s, ecologists began to doubt the concept of "climax community". Around this time, Watt (in Recher *et al.* 1992) demonstrated that cyclic changes occurred in apparently "stable" grassland and bracken fern communities. In more recent times, chaos theory and computer modeling have challenged the way ecologists think about stable ecosystems (Leaky & Lewin 1996).

Now returning to the argument by Pickett and Parker that control sites are an old pitfall. They insist upon the "flux of nature" as a new paradigm in ecology, rather than the "balance of nature" paradigm (as discussed in reference to climax communities above). They argue that ecologists should be very careful in selecting which past ecosystem is to be restored. In their own words, they state that ecologists should consider an ecosystem's *process* and *context* before attempting to restore it. According to Pickett and Parker (1994), processes are the internal dynamics of an ecosystem. These include:

> [T]he movement and interaction among organisms, transformation of energy and material, and the successional trajectories, changes in patchiness, or responses to environmental change that a system exhibits.

Context, on the other hand, refers to the influences of the surrounding landscape on the particular area of study. Pickett and Parker (1994) offer a concept of *contingency*, as a way of understanding the importance of process and context to restoration ecologists:

> Although sound ecological generalizations and predictions arise from regularities in species characteristics, environmental properties, and the interaction of species with one another and with physical environments, the specific dynamics of any one ecosystem will be contingent on its history, the accidents of arrival of species at the site, and the nature of the system's connections to the surrounding landscape. ... Contingency means that restoration ecologists will have a variety of reference states to choose from. Contingency establishes a whole range of systems, not just one "climax" or predisturbance state.

The "flux of nature" paradigm and the selection of a control site need not be mutually exclusive. This is certainly the belief of Aronson *et al.* (1995) who replied to Pickett and Parker's remarks in the editorial of *Restoration Ecology*. They point out that:

> [F]or the purposes of project design and evaluation, it is desirable to establish at the outset some standard of comparison and evaluation, even if it is arbitrary and imperfect . ... While we certainly agree with Pickett and Parker's reminder that any ecological system is inevitably influenced by the "context" (or "matrix") provided by its surrounding landscape, and by the "contingencies" imposed by its "unique past, specific spatial setting, and current influences," this does not rule out the possibility of selecting a reference system. If no reference system or "control" is selected, how can the experiment be evaluated? ... [I]n the myriad real-world situations, where restoration and rehabilitation projects are taking shape today, their message might be more harmful than helpful, especially if taken literally by those who don't follow the professional ecological literature.

Hobbs and Norton (1996) support control sites to direct restoration work, but warn against focusing the project on unattainable goals, such as the recreation of a past ecosystem. I agree with Hobbs and Norton. It would be absurd to propose to restore the forest to its former hypothetical pristine state, or to a forest that was a product of past European or indigenous peoples land management practices. In mine site restoration, it is unrealistic to aim to restore all of the attributes and species of a forest. Failure is imminent if restoration ecologists aim to achieve such great expectations. A control site should thus be used as a "guide" for measuring restoration success rather than a goal to be achieved by the restoration effort (Hobbs and Norton 1996).

In this project, the use of a control site offered the least uncomplicated measure of success. Control sites were selected in the forest adjoining the revegetated site. In one case, the adjoining forest was only about 50 square meters, yet even this site was chosen as a control. As Aronson *et al.* (1995) comment:

> [T]here's no reason at all that a full-scale model need exist; all else failing, at least a few square meters or tens of square meters may usually be found as a vestige of former vegetation, and this can serve as a micromodel, reference, and inspiration all the same.

2.3.2 How To Select A Control Site and How Many Are Needed?

In stark contrast to Aronson and friend's use of a mircomodel, Chapman & Underwood (1997) warn that lack of spatial replication of control sites is pseudo-replication of the control ecosystem as described by Hulbert (1984). Faith *et al.* (1995) explain the perceived problem:

> [T]here is a small probability that some factor other than the putative impact coincidentally caused the two sites to diverge at just that time. Additional control sites could help to distinguish such a coincidence.

Underwood (1994;1996) argues that the use of more than one control will overcome this problem. Although Underwood and Chapman's recommendations may be useful for future research design, factors that contributed to a "one control" study design should be highlighted.

Firstly, other authors have disagreed with Underwood and Chapman's recommendation of multiple control sites. C. L. Humphrey *et al.* (1995) and Faith *et al.* (1995) have pointed out that multiple control sites may introduce variability from controls which are relatively remote from the main site of interest. In this study, finding controls in the immediate area that had a similar *contingency*, proved to be exceptionally difficult. It was thought to be much safer to select an across-the-fence control site. Only here could the researcher be confident that both sites had shared similar environmental characteristics before mining, whereas spatial controls may introduce the problem that Humphrey *et al.* (1995) and Faith *et al.* (1995) mention.

Kirkpatrick (1997) makes the point that multiple selection of controls may have major cost implications and is not always needed to gain an ecological understanding. As an example, he refers to the unreplicated grazing exclusion plot established in the 1950s on the Bogong High Plains (see Wahren, Papst, Williams 1994). Fifty years after the establishment of the plot, Kirkpatrick (1997) points out that the floristic and structural differences across the fenceline are so different from the rest of the landscape that 'it is hard to doubt that the exclusion of grazing was the major cause of these differences'. Likewise, in two other studies, Humphrey *et al.* (1995) and Faith *et al.* (1995) make the point that multiple controls were not required to attribute significant changes in an environment to mining. In this study, I am confident that significant differences between a control and impacted site can safely be attributed to disturbance by mining. It is worth noting that much of the discussion surrounding the use of multiple controls has been concerned with aquatic and marine ecosystems. Here the line of demarcation between an impacted and non-impacted ecosystem is perhaps much more enigmatic than their terrestrial counterpart.

I had limitations that prevented the use of multiple controls. These included, time, budget, and personal skills and knowledge. What Chapman and Underwood (1997) describe as '...widespread enthusiasm in environmental studies to compare one degraded with one control site...' is not without reason. Particularly in the case of student research, limitations inevitably dictate what is achievable.

2.3.3 Vital Ecosystem Attributes as Measurements of Success

Aronson *et al.* (1993) have identified 18 vital ecosystem attributes (VEA) '...that are correlated with and serve as indicators of ecosystem structure and function' (later applied to landscapes, see Arnoson and Le Floc'h 1996b). The CSIRO defines an indicator as 'a significant physical, chemical, biological, social or economic variable which can be measured in a defined way for management purposes' (Heinemann 1998). The use of VEA as measures of success has gained support from Hobbs and Norton (1996). The 18 VEA are mentioned briefly here, so that they can be considered in the discussion of the results of this study (Aronson *et al.* 1993):

I. Vital Ecosystem Attributes as Related to Ecosystem Structure
(1) perennial species richness,
(2) annual species richness,
(3) total plant cover,
(4) above ground phytomass,
(5) beta diversity,
(6) life form spectrum
(7) keystone species
(8) microbial biomass, and
(9) soil biota diversity...

II. Vital Ecosystem Attributes Related to Ecosystem Function
(1) biomass productivity,
(2) soil organic matter,
(3) maximum available soil water reserves,
(4) coefficient of rainfall efficiency,
(5) rain use efficiency,
(7) nitrogen use efficiency,
(8) microsymbiont effectiveness, and
(9) cycling indices.

2.4 Ecosystem Resilience

Ecosystem *resilience*, was described by W.E Westman (1978) as 'the ability of a natural ecosystem to restore its structure following acute or chronic disturbance...'. Westman also noted a quality which he called *inertia.* Inertia is the resistance to change that an ecosystem displays. According to Westman, resilience has four characteristics. The first one of these was *elasticity,* referring to the time involved for an ecosystem to recover, the second, *amplitude* is the degree of "brittleness" of an ecosystem - in simple terms, how far an ecosystem could be stressed before loosing its ability to recover (McDonald 1996). The third characteristic of Westman's resilience was *hysteresis,* which described how similar the path of recovery was to its alteration. Finally, *malleability* refers '...to the ease with which the system can become permanently altered' (Westman 1978). Fox and Fox (1986) added a fifth characteristic called *damping* - 'which is the degree and manner by which the path of restoration is altered by any forces' (McDonald 1996).

McDonald (1996) notes that *succession* and resilience are often used interchangeably by ecologists. Clarity on the matter is needed. Whereas succession refers to 'the progressive, directional development of that community up to and beyond the "point" of recovery', McDonald (1996) confines the use of the term resilience to the recovery of an ecosystem to a pre-existing state. Grubb and Hopkins (1986) distinguish between two types of resilience. *In-situ* resilience refers to an ecosystem's ability to recover using the biomass and seed store on-site, whereas *migratory* resilience refers to species being transported into the area.

The concept of *thresholds* of recoverability, irreversibility or amplitude are also discussed in the literature (Westman 1978; Hobbs and Norton 1996; McDonald 1996). When a threshold is crossed by an ecosystem, the removal of the stressing factor(s) will not be enough to enable the ecosystem to return to a state similar to the original. Increased anthropogenic intervention would be required to achieve this threshold re-crossing (Hobbs & Norton 1996). If this reverse crossing is not achieved the ecosystem reaches a new equilibrium, termed an *alternative state* by Hobbs and Norton.

2.5 Review of Restoration Case Studies

A number of studies have been carried out to measure the recovery of ecosystems after disturbance, many of which have dealt with surface mining.

In Idaho, North America, Chambers *et al.* (1994) compared a mined site in a native grassland to a nearby control 14 years after disturbance. In this study, species composition, vegetation structure, plant biomass and soil properties were used to measure the success of restoration attempts with a number of different mulch and seed treatments, in comparison to a nearby control. The results showed that the mined areas had high biomass but low species diversity compared to the controls. Soil properties also differed between the mined and control areas.

Closer to home, a large amount of research has been published in relation to the restoration attempts in bauxite mined areas in Western Australian *Eucalyptus marginata* forests. Improvements in top soil handling techniques at these sites has resulted in an increase of species being recorded in mined areas (McDonald 1996).

A study of a returned topsoil site at a Western Australian bauxite mine found that 44 species were recorded, which compared to 47 being found in a nearby control area

(Glossop 1981). Interestingly, many of the species were different to those found in the control as species adapted to colonise after disturbance had responded well whilst others had not, mostly geophytes.

A later study by Bell *et al.* (1990) concerning the seed ecology of these mined areas found that seed grown from top soil respread over the mined area, differed considerably to the species found growing in the nearby control. The addition of hand broadcasted seeds, particularly of woody shrubs and trees (which store their seed in the canopy rather than the soil), improved the similarity between mined and control areas.

A recent study on topsoil seed reserves after disturbance by mining in bauxite mines in Western Australia highlighted the importance of the correct management of topsoil in order to maximise seed germination (Koch *et al.* 1996). A quick return of topsoil resulted in losses of 50% of the soil seed store, whilst stockpiling caused losses of 80-90%. It was shown that most seed from this eucalyptus forest will not germinate if submerged to depths greater than 5 cm. In this particular study it was found that in control plots, 9% of seeds resided in the litter layer, 26% came from the 0-2 cm stratum, 36% in the 2-5 cm stratum, compared to 28% in the 5-10 cm stratum of topsoil. Both the burial and thick spread of topsoils on re-application to mined areas was shown to reduce seed germination.

A further study (Ward *et al.* 1997) of the soil seed-bank in relation to bauxite mining in an unmined area, revealed that soil seed stores differed seasonally in unmined forest. Removal of soils in the dry season, rather than the wet season for mining is now believed to be an important method to maximise germination from topsoil in these areas. A similar study on the soil seed-bank of a 12 year old mined area, revealed that seed content was highest in Autumn, although 53% of seeds were exotic (Grant and Koch 1997). Both of these studies supported the earlier findings that most seed was found in the top 5 cm of soil. The use of smoke and heat treatment in these studies resulted in higher germination of some native species.

Further studies have been conducted on these bauxite mines in relation to litter fall and nutrient cycling. Ward *et al.* (1991) noted that litter decomposition is greater where topsoil had been returned to the mined area than when it had not. This is a result of the micro-organisms found in the top-soil which move into, and decompose the litter layer. Litter decomposition was also related to soil moisture, which is positively linked to vegetative cover and litter. Ward and Koch's (1996) recent study on biomass and nutrient distribution in a 15.5 year old forest showed positive results for the establishment of a forest ecosystem that is self sustaining in nitrogen. These studies also show the importance of legume species for early establishment of a leaf litter high in nitrogen.

In eastern Australia, Fox *et al.* (1996) conducted a lengthy study on the impact of multiple disturbances in forest, woodland, shrubland and swamp areas in the Tomago area, NSW. On 17 year old mined sites it was observed that, 5 years after revegetation, there was a decrease in vegetation cover as short lived shrubs died or trees grew taller. The exception was vegetation in the 0-20 cm range that had stayed at the same level.

Storey (1990) evaluated mine rehabilitation success at South Mount Cameron in northeastern Tasmania. Floristic composition was compared to a nearby natural community and the contribution of natural regeneration and species colonisation to the mined site was considered. Mined areas were found to be less species diverse than the controls, although colonistation from nearby vegetation was shown to be contributing to the restoration attempt.

2.6 Summary

The aim of this chapter has been to review literature relevant to this study. At the beginning of this chapter the word *restoration* was defined in terms of this project. This section discussed how different restorationist ecologists consider its usage. Some ecologists saw the word restoration as being limited to projects that aim to return an ecosystem to the condition which had prevailed before disturbance. Others argued that all attempts at repairing damaged ecosystems can be called a restoration project.

Next, the chapter considered the need to measure *success* in restoration work, and how this might be achieved. The criticism by some ecologists of the use of *controls* was considered. Consideration was given to the concepts of *flux of nature* and *climax community*. Taking into account the influences of *context* and *contingency* in an ecosystem, it was decided that a control was the best means of measuring success as it offers a clear method to evaluate an experiment.

Still on the topic of controls, the chapter considered literature concerning *pseudo-replication*. Although there are statistical advantages in having more than one control, there are also statistical disadvantages along with practical problems in finding and surveying more than one truly comparable control.

The next section considered the term *resilience*, and its five characteristics; *elasticity, amplitude, hysteresis, malleability* and *damping*. It was shown that resilience is the ability of an ecosystem to "spring back" after disturbance. The difference between *succession* and resilience was also discussed, showing that succession implies the development of an ecosystem irrespective of where recovery occurs along the trajectory of change. Two kinds of resilience were considered. *In-situ* resilience was the potential for an ecosystem to recover using components remaining on the site, whereas, *migratory* resilience refers to the ability for colonisation components outside the site. The concept of *thresholds* and *alternative states* was discussed. Threshold describes the "stretching" of an ecosystem beyond a point of recoverability, whereas an alternative state, is the new ecosystem that results. After this the concept of vital ecosystem attributes was introduced as measures of success.

The last section reviewed a number of case studies of mine site restoration, mainly studies concerning the bauxite mines of Western Australia. In particular, the literature on topsoil handling techniques was reviewed, along with research into litter fall and decomposition rates.

Chapter 3: Victoria's Box and Ironbark Ecosystem

3.1 Introduction

This chapter provides the reader with a precursory glance of the Box and Ironbark ecosystem of Victoria. The first section considers the environmental factors of the area that have helped shaped this ecosystem. The next section provides a general introduction to the flora of the area and an understanding of the resilience attributes of the ecosystem. The last section considers how human utilisation of the ecosystem has resulted in the ecological changes to the Box and Ironbark Forests.

3.2 The Ecosystem

3.2.1 Geology

Much of what is present day Victoria has been inundated by sea water. During the late Cambrian and Ordorvician periods, a thick sandstone bed (up to 3000 m) was formed. This bed rock is now wide spread throughout Victoria, and largely made up of sandstone, quartz, siltstone and black shale (Douglas 1993). Much of the Box and Ironbark Forests of Victoria are found on soils derived from this bed rock.

Following the Ordovician period Central Victoria's geology was without significant change until the Devonian period. The Devonian period of Victoria has been referred to as 'an igneous regime "par excellence" ' (Douglas 1993). During this period, extensive granite plutons arose between the present day coast and the inland, causing contact metamorphic rocks. During the Quartenary period there was intrusion of basaltic lavas and pyroclasyics (known as the "newer volcanics"). Tertiary gravels resulting from high energy water flows are also an important substrate in determining vegetation communities.

3.2.2 Topography

The land forms of the Box and Ironbark country consists of subtle rises and declines formed by folded sandstone and metamorphic slopes, and intercepted by drainage lines. Granitic plutons, such as the Mount Kooyoora, Mount Black and Mount Alexandra regions are surrounded by metamorphic contact orioles forming ranges.

To the south the Box and Ironbark country is bounded by increasing elevation and rainfall as the country rises up and over the Great Dividing Range. To the north, the Box and Ironbark region is bordered by the northern plains of Victoria. This country is much more fertile and grassy than the Box and Ironbark forests, and forms the southern boundary of the great Riverine Plain stretching far into New South Wales. Further west is the Mallee, a large area of flat and sandy country, whilst to the east the land rises up to the Victorian section of the Australian Alps.

The Box and Ironbark Ecosystem is not a naturally continuous area, rather it is separated by a number of Victoria's major rivers and their alluvial floodplains, including the Ovens, Broken, Campaspe, Loddon, Avoca and Wimmera Rivers. All flow in a northerly direction as part of the Murray-Darling Basin. The Goulburn River in particular forms a significant divide between the Northern Goldfields and the North - Eastern Box and Ironbark Communities.

3.2.3 Soils

Soils are complex and give rise to changes in vegetation. Those derived from the Ordovician sandstone and shale bedrock predominate (Paleozoic soils). They are typically yellow or reddish duplex soils, characterised by a very shallow profile. Soils in gully lines are normally deeper and more sandy compared to those found on slopes and higher ground. On higher ground, tilted bedrock is often found close to or penetrating the soil layer.

The A Horizon (the top layer of mineral soil) is often a sandy loam and very shallow (typically 5 –15 cm in forested areas), whilst the B Horizon is more often clayey with unconsolidated parent material and quartz gravel throughout. The B Horizon is often mottled, with bleached rust coloured streaks and blotches (Northcote 1975). These soils are predominately acidic. When devoid of organic matter they tend to crust, causing low water infiltration, run-off and subsequent erosion. They are naturally sodic.

In forested areas, the soil layers often includes an O Horizon (a layer of organic material). In older forests, two parts can be distinguished in the organic layer; the O_1 and O_2 Horizons, as described by Murphy (1994). The O_1 Horizon consists of undecomposed plant material. In mature Box and Ironbark Forests, this horizon mainly consists of leaves from Eucalyptus and Acacia spp., fine woody debris, and animal scats. The O_2 Horizon is partly decomposed and the matter is finer and unrecognisable. This layer contains much of the seed stock of the soil. Under native vegetation, the A_1 Horizon is often brownish through to grayish brown, reflecting accumulation of organic matter (Northcote 1975).

All the study sites for this project were found on soils as described above. Yet, not all Box and Ironbark vegetation is found on these soils. Similar plant communities grow on a variety of basalt, igneous, alluvial and aeolian soils found in the area. These soils are described elsewhere (Environment Conservation Council 1997; Land Conservation Council 1978; Lorimer & Rowan 1982).

3.2.4 Climate

The climate of Central Victoria can be described as Mediterranean. The Bureau of Meteorology's records show that January and February are the hottest months with average maximum temperatures of about 28-29°C in Bendigo (Bureau of Meteorology & Walsh 1993). In comparison, the winter months of June and July have average maximum temperatures of about 12-13°C. Temperatures can be extreme in both summer (dry season) and winter (wet season). Days over 40°C are not unusual in summer, whilst morning frosts and night time temperatures of minus 5°C can prevail in winter.

Rain in the region is almost entirely dependent upon the seasonal movement of low pressure systems (Bureau of Meteorology 1993). Most rain events are associated with cold frontal weather patterns that approach the State from the West and South. Frontal weather is often abated by high pressure systems centred north of Victoria, whilst weak frontal weather fails to cross the ranges to the south. Hence, areas south of the Great Divide experience much higher rainfall and humidity than the Box and Ironbark Ecosystem. During winter the low pressure systems migrate north, and are more likely to penetrate Central Victoria. Thus, Bendigo's wettest months are June (average of 61 mm), July (56 mm) and August (59 mm) and the driest months being December (33 mm), January (34 mm) and February (33 mm) (Bureau of Meteorology 1993). In winter, the Box and Ironbark forests usually receive periodic "soaking" rains. Summer rain is more likely to be associated with brief down-pours resulting from day time convection. Thunderstorms are a regular summer event.

Due to orographic and continental effects, there is an overall decrease in rainfall from south to north. Southern outlying communities of the Box and Ironbark Forests have mean annual rainfall of 600-700 mm, whilst in the north, communities survive on 400-500 mm (Muir *et al.* 1995). Bendigo has a mean annual rainfall of 554 mm.

The above annual averages fail to indicate that rainfall is highly variable from year to year. Drought conditions may be prevalent for a particular summer, and so might heavy rain. This seemingly chaotic weather pattern is a result of what is called the Southern Oscillation (Flannery 1994).

3.2.5 Floristic Communities

One thousand three hundred and thirty vascular plant taxa have been recorded in the Box and Ironbark Ecosystem of Victoria. Of this total, 70 are rare or threatened in Victoria, whilst 322 are considered environmental weeds (Muir *et al.* 1995).

As the name suggests the Box and Ironbark forests have a dominant canopy of *Eucalyptus spp.,* belonging to the Box or Ironbark groups (with the exception of Mallee and Riparian vegetation). An open understorey of shrubs is common, almost always including several Acacia spp., with a sparse ground cover of herbaceous plants (Calder *et al.* 1994).

Muir *et al.* (1995) identified 17 Ecological Vegetation Classes (EVCs) which contain 25 floristic communities. All these communities are described as having at least 1 sub-community. Detailed descriptions of each of these communities and their sub-communities are provided in Muir's report. Calder *et al.* (1994) has divided the Box and Ironbark communities into six broad "vegetation-landscape types"; Dry Forest, Mallee, Heathy Woodland, Herb-rich Woodland, Granitic Woodland and Wetland. Calder's vegetation types provide a broad overview.

By far the most common Eucalypts in the Bendigo district are *E. tricarpa* and *E. microcarpa.* Other common species are *E. leucoxylon*, *E polyanthemos*, *E. macrorhyncha* and *E. camaldulensis.* Other Eucalypts are also present.

3.2.5.1 Herb-Rich Woodlands

E. leucoxylon and *E. microcarpa* are commonly dominant on lower slopes, alluvial plains and moist areas. The understorey consists of a tall shrub stratum dominated by several species of Acacia and *Cassinia arcuata.* The ground layer is usually sparsely covered with a variety of plant species, mainly *Lomandra filiformis, Danthonia setacea, Astroloma humifusum, Pultenaea largiflorens* and *Dianella revoluta,* with shrub and grassy areas patchily distributed. *E. leucoxylon* and *E. microcarpa* forests may represent a plant community that was common on flat areas before European arrival (Muir *et al.* 1995).

3.2.5.2 Dry Forest

Upslope, *E. tricarpa* and *E. microcarpa* are the dominant trees, either mixed or in pure stands. *E. tricarpa* grows further upslope than *E. microcarpa* and may often crown knolls, ridges and spurs. The understorey and ground layer is often slightly more shrubby than *E. leucoxylon* and *E. microcarpa* dominated forests, with the addition of *Chionochloa pallida* and *Poa sieberiana*, among the grasses.

3.2.5.3 Heathy Woodland

On high ground with shallow stony soils, low fertility and low waterholding capacity, there often grows a forest dominated by *E. polyanthemos* and *E. macrorhyncha* (Muir *et al.* 1995). This forest is characterised by a dense heath stratum, sometimes dominated by a single heath, often *Brachyloma daphnoides*. Grassy patches of *Chionochloa pallida* and *Poa sieberiana* are also common. *Stipa mollis, Eriostemon verrucosus, Hakea sericea* and *Xanthorrhoea australis* are some of the common species which are found in heathy woodlands.

3.2.5.4 Wetlands

Not all forests in the area are as described above. Most notably, large riparian areas dissect the Box and Ironbark Ecosystem. On the floodplains, grassy *Eucalyptus camaldulensis* forest occurs. *E. camaldulensis* also grows along creek lines or at seasonally wet sites forming a grassy, often forb-rich woodland (Muir *et al.* 1995). These areas are often inter-mixed with *E. microcarpa* and *E. melliodora* on higher ground. A number of tall shrubs also grow here, including *Acacia retinodes*, *A. mearnsii* and *Melaleuca parvistaminea.* The ground cover consists of many native and introduced grasses. Muir *et al.* (1995) found that weeds comprise 34% of the flora of this community. This study suggested that this community is quite distinct from the riparian vegetation found along permanently flowing streams.

3.2.5.5 Mallee

Within the Box and Ironbark Forests, and tending towards the drier areas, Mallee vegetation occurs in patches. These low-open forests and woodlands have a dominant cover of the Mallee Eucalyptus species, *E. polybractea, E. viridis* and *E. behriana.* The ground cover in these Mallee patches is often very sparse, with small heaths. Mean floristic richness of these areas is slightly less than the Box and Ironbark forests (Muir *et al.* 1995). Very poor soils, with a stony profile are common, and a microcosm of lichens, mosses and algae is present, and serves to protect the soil in the absence of ground covering vegetation (Calder 1994). A similar vegetation community, called "Broombush" occurs where Mallee Eucalypts are reduced in size and tall shrubs, such as *Melaleuca uncinata* and *Melaleuca decussata* and *Acacia calamifolia,* codominate the canopy (Muir *et al.* 1995).

3.2.5.6 Granitic Woodland

Another widespread and distinct ecological vegetation class is that growing on granitic soils forming open woodlands. Dominant Eucalypts include: *E. macrorhyncha, E. goniocalyx, E. melliodora and E. blakelyi.* A herbaceous ground cover, including some shrubs is common. The ground cover includes *Stipa* spp., *Cheilanthes austrotenuifolia, Themeda triandra, Senecio quadridentatus* and *Gonocarpus elatus* and many exotic plants (Muir *et al.* 1995; Calder *et al.* 1994).

Many variations on the general themes outlined above do exist and the demarcation between each sub-community is not always clear. Specific details of the vegetation communities covered by this study are provided in Chapter 3.

3.2.6 Weeds

Unfortunately, environmental weeds are a major component (24%) of the flora of the area. The study by Muir *et al.* (1995) found that 24 species are particularly common throughout the Box and Ironbark Ecosystem, 18 of which are considered to present a serious threat to vegetation communities in Victoria (Carr *et al.* 1992). Most of these species were introduced to the area for agricultural purposes, whilst others have escaped from gardens. Weeds vary greatly in their dispersal and frequency throughout the Box and Ironbark Ecosystem. Species such as *Vulpia* spp., and *Briza* spp., are found almost anywhere throughout the ecosystem.

Cortaderia selloana (Pampas Grass) is locally invasive, often having escaped to bushland gullies from adjoining gardens, or spreading from unlawful rubbish dumping. Some native plants, most notably *Acacia baileyana,* have escaped from private or municipal gardens and display health and vigor when compared to locally indigenous flora. Other Australian native species, present a threat to their indigenous counterparts through their potential to hybridize.

Weeds are more common in areas that have been subject to recent or long-term disturbances (Muir *et al.* 1995). Such disturbances may result from mining or stock grazing. Muir *et al.* (1995) has observed that sites with higher soil fertility and water holding capacity are sometimes dominated by weed cover. Hence, annual weed species pose a greater threat to grassy plant communities rather than Heathy Forest, Dry Forest and Mallee communities. In the latter communities, most weeds that are short lived, and have high water/nutrient requirements are absent. However, other weeds such as *Genista* spp. (Broom) do succeed in such areas.

3.2.7 Significant Species

The study by Muir *et al.* (1995) is the most recent and detailed assessment of significant species occurring in the Box and Ironbark Ecosystem. Out of the 1330 taxa recorded, 70 taxa were listed as rare or threatened in Victoria, with 3 being endemic to the ecosystem. About 10% of these species belong to the Orchidaceae family, including the 3 endemic species mentioned above. A further six taxa are found primarily in the Box and Ironbark Ecosystem with one or two populations elsewhere. The Box and Ironbark Ecosystem also hosts a number of plants that may be common in other States, but reach their southern limit in Central Victoria. Other taxa were once common in Victoria but populations have significantly declined as a result of native vegetation clearing. Finally, Muir *et al.* (1995) suggests that some taxa may be recorded as rare due to undersampling, particularly recently described taxa.

3.3 Land Use

3.3.1 Koorie History

The Box and Ironbark Ecosystem would have provided the Koorie people with many resources, including meats (including fowl), fibers, tuberous plants such as orchids and Mernongs *(Microseris lanceolata)*, bark, honey, fire lighting tools (*Xanthorrhoea australis*) and quartz stones implements, to name a few. Several sacred sites are also known to exist in the area.

It is thought that Koorie people continuously burnt the forested areas of Central Victoria. Burning would have assisted forest nutrient cycling, allowed space for spring annuals and kept the forest "open" (Flannery 1994; Flood 1995; Zola & Gott 1992). Another management technique was connected to the "digging stick", an implement to dig up tubers. With these sticks, the Koorie women and children regularly turned the soil in search of tuberous plants to eat, thus aerating the soil and possibly assisting the dispersal of these plants (Zola & Gott 1992).

3.3.2 The (Not So) Golden Age

The discovery of gold in the Box and Ironbark Ecosystem in the early 1850s brought incredible wealth and prosperity to Victoria. The population of Victoria grew at an unprecedented rate rising from 77,000 to 540,000 in 10 years (Serle 1968). "When are you off" (referring to the Goldfields) was the common greeting amongst Melbournians (Serle 1968). Melbourne was almost deserted at certain times during the 1850s, and the La Trobe Government even considered a complete abandonment of government (save the police) due to the lack of personnel. Towns and encampments sprung up throughout the Box and Ironbark country.

This era brought extensive change to the native vegetation of the Box and Ironbark Ecosystem. Every creek line in the area was meticulously dug over in search for gold. Almost every tree in the Box and Ironbark Ecosystem was felled to meet the high demand for pit-props, building materials and firewood (Woodgate & Black 1988). This denuded landscape lay exposed to rain and wind. Erosion, especially in the creek and gully-lines was extreme and many deeply eroded gullies void of native vegetation are prevalent in the forested areas of today. William Howitt's observations of the Bendigo Creek illustrate this change (in Powell 1976):

> Little more than a year ago, the whole of this valley on the Bendigo Creek, seven miles long by one and a half wide, was an unbroken wood! It is now perfectly bare of trees, and the whole of it riddled with holes from ten to eighty feet deep – all one huge chaos of clay, gravel, stones and pipeclay, thrown up out of the bowels of the earth!

Much of the forested area today has a pot-holed topography of old diggings and mullock heaps. Mullock heaps have capped the original top soil with infertile B horizon clays, preventing the re-establishment of creek-line vegetation and favoring the disturbance favoring species, particularly *Cassinia arcuata*. This native ruderal, is notoriously known as "Chinese Scrub", apparently due to the observation that it infested diggings following the meticulous work of the Chinese. *Cassinia arcuata* was not the only plant to do well out of gold mining disturbance. Many environmental weeds that traveled to the area with the new immigrants were also able to take advantage of the disturbed landscape and secure a future in the ecosystem.

The Box and Ironbark forests of today look entirely different to the forests depicted in drawings and writings of the early settlers. This Box and Ironbark ecosystem seems to have been open and grassy. Today the forests are almost entirely post 1850s regrowth.

The trees of today are often multi-stemmed, having grown from epicormic shoots, and most trees lack tree hollows that develop with age. Old vehicle tracks and encampments abound throughout the forests.

Following the gold rushes of the 1850s, much of the forest areas that offered any fertility were cleared and utilized for agricultural purposes, mainly sheep grazing. Many of the areas left as public land were the more infertile metamorphic hills and upper-slopes. Land clearance placed further burdens on the Box and Ironbark Ecosystem, particularly the loss of streamside plant communities and the fragmentation of remaining forested areas. The Land Acts of the 1870s saw marginal grazing land given to miners along the narrower valleys whilst more fertile land remained in the hands of the politically powerful squatters (Slattery 1998).

3.3.3 Modern Land Use And Abuse

The forest areas mined in the 1850s (which account for less than 15% of the original forest cover) have been subjected to intense resource utilization. Circumstantial and documented evidence suggests that the accumulated impact of these activities has caused the incremental loss of forest along with the simplification of ecosystem processes.

3.3.3.1 Forest Clearance

Forest clearance in the Box and Ironbark forest still occurs, and is characterised by incremental clearance of small areas of land. Usually, it is associated with suburban development and hobby farming, particularly around the larger cities, such as Bendigo. Hobby farming and vacant private land has also been associated with the natural regeneration of native species on agricultural land. Reforestation on freehold land in the Bendigo area between 1972-1987 was about 8.5% of land cleared in the same period (Woodgate & Black 1988).

3.3.3.2 Grazing

By the 1840s large areas of the Box and Ironbark area were being grazed by introduced animals, predominately sheep. Up until the late 1970s, one third of public land in the area was leased to farmers for grazing (Land Conservation Council 1978). In more recent times, many grazing leases have been phased-out, but grazing still continues in some areas, particularly on granite soils (Muir *et al.* 1995).

3.3.3.3 Mining and Fossicking

Mining for gold, clay, stone, gravel and sand takes place throughout much of the ecosystem. It is difficult to assess how much land is currently being mined, but most public land in the area is covered by exploration leases (Muir *et al.* 1995).

Gold mining is still prevalent in the area, but the techniques have changed significantly since the 1850s. The area has some of the largest open-cut mines in Victoria, namely at Fosterville, Baileston and Heathcote. All three of these mines use or have used the cyanide leaching method for extracting gold. Smaller operations such as the Waanyarra sites, use a technique called "doze and detect". This involves vegetation clearance, then deep ripping the sub soils before using metal detectors to find gold nuggets. Gold fossicking is a recreational and professional occupation for many local people. Many people travel to the area from around Australia for fossicking holidays.

3.3.3.4 Timber Extraction

Much of the remaining Box and Ironbark forest cover is available for wood harvesting. Around 75-90% of wood harvested from the Box and Ironbark Ecosystem is used for fire wood, the rest being used for fence posts, poles and sleepers (Sherwin 1996). A very small amount of timber is used for house building materials.

3.3.3.5 Eucalyptus Oil Harvesting

The oils extracted from the Mallee eucalypts, particularly the Blue Mallee *(E. polybractea)* have long been noted for their superior quality. Around 72% of the 19,000 ha of Mallee vegetation occurring on public land in the Ecosystem is currently available for oil harvesting (Sherwin 1996).

3.3.3.6 Other Activities

The Box and Ironbark Ecosystem is exposed to a number of other potentially degrading activities. These include high impact recreational activities such as the illegal shooting of wildlife, motorcycle riding, and other recreational activities, such as off-track bushwalking, orienteering, cycling and horseriding. Apiculture is also common throughout the Ecosystem, as many Box and Ironbark Eucalypts produce excellent honey.

3.4 Conservation Status

Prior to European arrival, the Box and Ironbark ecosystem covered an estimated 1,040,035 ha of land across central Victoria (Calder *et al.* 1994). In 1987, only 254,332 ha remained on both private and public land. Thus there has been a 75% reduction in the cover of Box and Ironbark Forests. The remaining forest has been extensively modified by the activities outlined above.

Forty nine thousand hectares of forest is currently designated as conservation reserves, 26,133 ha of which is protected in Victorian State Parks. One Box and Ironbark forest is represented in the Victorian National Park system. A large amount of forested area (167,300 ha) is currently State Forest and Uncommitted Crown Land. These areas are exposed to a number of intensive industries as outlined above.

The Box and Ironbark Ecosystem is currently being investigated by the Environment Conservation Council (1997), who will make recommendations to the State Government on the balanced use of this forest type. The Nationally Agreed Criteria for the establishment of a comprehensive, adequate and representative reserve system is to be taken into consideration by the Council in forming their recommendations (ECC 1997).

3.5 Summary

This chapter has provided the reader with an introduction to the Box and Ironbark ecosystem. It has been shown that this forest has provided rich resources that have been used by its inhabitants for many thousands of years. In the last 150 years the ecosystem has witnessed a dramatic reduction and modification through intensive human utilization. This has led to a forest type that is different when to that which was encountered by early European settlers.

The remaining forest cover is underrepresented in conservation reserves when compared to many other forest ecosystems in Victoria. Associated with a lack of conservation, the forest is exposed to many intensive uses which is resulting in further modification and vegetation loss. Remnant floristic communities tend to be those on public land. Public land tends to be confined to infertile metamorphic ridges and other high areas (hence dry forest floristic communities are the "typical" forest type of public land). This means that vegetation communities of low lying areas and fertile soils have been disproportionately cleared and modified (particularly wetlands and herb-rich woodlands).

Chapter 4: Methods

4.1 Introduction

The aim of this chapter is to outline the methods used to fulfill the overall aims of the study. A brief overview of the methods used by the company "Goldfields Revegetation" in restoring the mined sites is also presented here.

4.2 Ecological Restoration As Practiced By Goldfields Revegetation Nursery

Goldfields Revegetation Nursery is a small business operating from Bendigo, Victoria. It is owned and run by Marilyn Sprague. The business involves the running of a large Nursery that specialises in indigenous and Koorie plants of the Bendigo district. Its customers include; gardeners, farmers, government, and local industries. Since its conception, Goldfields Revegetation has worked closely with the mining industry, restoring the indigenous vegetation following gold mining projects in the Box and Ironbark forests.

Site specific species lists for hand broadcasted seeds were not available nor were exact methods. Methods used to revegetate disturbed bush sites by Goldfields Revegetation are as follows:

Prior to Site Disturbance

- A visit to the site to determine the species that will be used in revegetation.
- Collection of seed stock from the site, or from other local bush sites.
- Removal and storage of the top 10-15 cm of soil, organic matter and coarse woody debris.

Immediately Following Mining

- Deep ripping of subsoils across the contour line of the slope, to encourage deep root establishment and discourage water erosion.
- Respreading of topsoil, organic matter, and coarse woody debris over subsoils.
- Hand casting of seed stocks in the late winter/early spring period.
- Some tube stock planting at the Heathcote site.
- Follow-up weed eradication if deemed necessary.

4.3 Study Sites

Table 4.1: Site Characteristics

Site	*1*		*2*		*2B*		*3*		*4*	
Mined/Control	*M*	*C*	*M*	*C*	*M*	*C*	*M*	*C*	*M*	*C*
Age (years)*	8	100	2	100	5	100	5	100	2	100
Aspect	3	3	3	1	3	2	4	3	2	4
Slope**	1	3	1	3	3	3	1	1	3	3
Size (acres)***	2	1	10	10	5	5	25	5	20	15

** 1 = Gully Line, 2 = Hill Slope, 3 = Hill Crest
*** Approximate size in acres

4.3.1 Vegetation Overview

All of the areas studied were covered by Box-Ironbark Forest plant communities. These communities form part of a distinct ecological vegetation class. An ecological vegetation class (EVC) consists of one or more floristic communities that share common ecological processes, which are manifested by comparable life forms, genera and vegetation structure (Muir *et al.* 1995). This EVC encompasses four separate floristic communities, of which, most of the study sites can be said to belong to the Box-Ironbark Forest (Northern Goldfields) floristic community, which has three distinct sub-communities, as defined by Muir *et al.* (1995).

The Box and Ironbark forest EVC is an open-forest, with a tree canopy dominated by *Eucalyptus tricarpa* (Red Ironbark), *E. microcarpa* (Grey Box), and in some cases *Eucalyptus leucoxylon* (White Ironbark or Yellow Gum). *Acacia pycantha* (Golden Wattle) and *Cassinia arcuata* (Drooping Cassinia or Chinese Scrub) commonly form the top of an open understorey. Many smaller plants contribute to a shrub layer, and almost always include *Pultenea largiflorens* (Twiggy Bush-pea), and *Acacia acinacea* (Gold-dust Wattle). A sparse, heathy, although sometimes grassy ground cover includes such species as *Lomandra filiformis* (Black-anther Flax-lily), *Danthonia setecea* (Bristly Wallaby Grass), *Astroloma humisfusum* (Cranberry Heath) and *Bracteantha viscosa* (Shiny Everlasting).

4.3.2 Site Locations

4.3.2.1 Bendigo (Carshalton Site)

This site is located within the city of Bendigo. The site follows an ephemeral creek line. The revegetated area is best located from the entrance gates to the underground Carshalton Mine site. Looking north from the entrance gates the area is bounded by remnant native vegetation on State owned land. The current mine site is on its southern and eastern sides. Private housing and an industrial estate occur on its north and western sides. Roads and trails define the entire boundary of the site.

The site was formally wasteland. It had been used by local residents for dumping of rubbish and garden waste for some years. The revegetation project was conducted in 1989 by Goldfields Revegetation in collaboration with Flora Hill Primary School. The area revegetated is less than 1 acre. Both direct seeding and tube stock of native species were used to revegetate the site. It is believed that fertilizer was applied to the minedarea following revegetation (Sprague 1997).

A remnant area of bushland on a ridge line immediately across the road on the western boundary was chosen as the control. Although the control did not mirror the aspect and slope of the mined area, and therefore would be likely to have a slightly different species composition to the original vegetation, it was the only large area of native bush land in close proximity that could be considered "undisturbed". Other areas were vastly altered by the mining activities of the 1850s, vehicle tracks and rubbish dumping.

4.3.2.2 Waanyarra 1a (Tipperary Site)

The three Waanyarra sites are best accessed from the Tarnagulla/Dunolly Road and are found in State Forest near the remains of the Waanyarra township, 6 km south from Tarnagulla. Sites 2 (Tipperary Gully) and 2B (Secret Hill) are the same mine site but were separated for the purpose of this study due to their floristic differences. They are located on the southern side of Morton's Lane, about 300 meters east of the main Tarnagulla/Dunolly Road. The vehicle track leading into the mined area was chosen as the line of demarcation between site 2 and 2B .

All gullies in the area were extensively mined in the early 1900s and forest harvesting has been conducted in the area in recent times (Sprague 1992). In 1992, much of Tipperary Gully and the northeastern slope of Secret Hill was cleared of vegetation for the purpose of a doze and detect mining operation. Several mature trees were left standing in the mined area. Revegetation methods utilised direct seeding and the reapplication of the topsoil. Since revegetation, much of the Tipperary Gully Site has been recontoured to halt gully erosion along the drainage line (approximately 12 months prior to this study), which resulted in the removal of revegetation. A second revegetation treatment was applied to the site following this work.

The control site for the Tipperary Gully area was chosen to the east of the mined areas in the low lying area between Tipperary Gully and Wet Gully Track. It was important to find an area that was relatively undisturbed. Thus, the area between the revegetated site and the dam at the junction of Wet Gully Track and Morton's Lane was avoided because of prior diggings for gold and unmarked graves. A slightly elevated, but less disturbed area was chosen.

4.3.2.3 Waanyarra 2B (Secret Hill Site)

The adjoining Secret Hill site has some evidence of early diggings, but they are not as extensive as the Tipperary Gully line. This site lies on the north-eastern slope of Secret Hill. The control was chosen directly uphill of the revegetated area and did not extend south across the vehicle track that traverses directly across the knoll.

4.3.3.4 Waanyarra 3 (Laurie State Forest Sites)

Waanyarra 3, is a collection of sites located along two gully lines on the western side of the Tarnagulla/Dunolly Road in Laurie State Forest, about 3 kilometers from Tarnagulla. These sites were mined in 1992 using doze and detect methods. They are best accessed via Sarah Track, which departs the main road after the Laurie State Forest sign. These sites were collectively grouped because of their floristic homogeneity. The control site, was located in a subtle gully line, on both sides of Sarah Track, immediately east of the Sarah Track/Curley Track junction. The control site is bounded by Curley Track on its north-western side and the Tarnagulla/Dunolly Road, on its south-east. Direct seeding was utilised in revegetating the site.

4.3.2.4 Heathcote (Heathcote Site)

The Heathcote site is located about 2 kilometers from the Heathcote town centre. The site is located just short of the entry to the current rubbish tip. The area was State Forest until it was cleared for open cut mining in the early 1990s. The revegetation work has been carried out on the waste material of the open cut mine and planted facing the road side. Both tube stock and direct seeding were utilised in revegetating the site. Revegetation work had taken place 16 months prior to this study.

The control was located on the south eastern slope of the subtle knoll located across the road, directly opposite the mined areas. This site was chosen as it was close to the mined areas and was claimed to be similar to their original vegetation (Sprague 1997).

4.4 Measuring The Cover And Height Of Plants

4.4.1 Line-Intercept Method

This method was used to measure the percentage of plant cover in both the mined area and control. This was achieved by laying out a 50 m long tape measure across the site. In such cases where 50 m exceeded the total length or breath of the site two 25 m lengths of tape were laid out parallel to each other. The tape was either set at foot height in low or sparse vegetation, or at head height in more dense vegetation to assist with visibility. Usually five intercept lines (about three lines were needed to record all species present) were used in each area. They were always placed parallel to each other. The positions of the intercepts were selected randomly.

Occasionally plants intercepted the tape. In these cases the entire length of a plant that intercepted with the tape was recorded. Thus, if the plant crossed the tape twice, the total distance between the extremes of the two interceptions were recorded as the plant's cover. This method of "filling-in" areas between branches relies on the assumption that the space is dominated by the plant being measured (Mueller-Dombois & Ellenberg 1974). It also makes work in the field much less tedious. Cover was measured to the nearest centimeter. A total percentage of cover was calculated for each species.

Plants that occurred infrequently along the intercept line with a small cover value (less than 2 cm) were simply recorded as 0.001% of cover. Also, plants that did not occur along the intercept line but were within 1 m of the tape were also recorded as having a cover of 0.001% and were given a "missing" height value. Any plants found at the site which had not been recorded in the above manner, were given a cover value of 0.001% and a "missing" height value. In each of these cases the aim was to acknowledge their presence in the data collection, rather than accurately record their percentage cover or height.

A 1 m length of dowel was used to determine where plants intercepted with the tape if the crossing occurred above or below the tape itself. In some cases a 230 cm length of dowel proved useful for this purpose, although the entire study could have been successfully undertaken with the 1m long dowel.

4.4.2 Plant Heights

Plant heights were taken from the tallest individual for each plant species present along the intercept line. All species heights for an area were averaged. Plant heights were measured in one of three ways. In most cases a 1 m length of dowel was used. This proved effective in measuring plant heights up to 2.5 m. On taller plants, the measuring tape and a clinometer was used to enable triangulation. Species were grouped into ground cover, understorey or canopy, and each group averaged to achieve a stratum height.

4.5 Measuring Environmental Variables

Eleven environmental variables were recorded for each sample. These were; aspect, slope, rocks, litter, litter depth, top soil depth, soil chroma, hue and value, coarse woody debris and bare ground. Litter, rocks, coarse woody debris and bare ground were recorded as a percentage of cover in much the same way as described for recording vegetation, except only those variables that directly intercepted with the tape were recorded. As well:

- Aspect was measured using a compass.
- Slope was measured on a scale from 1 to 3, with 1 being a gully line, 2 being flat ground, and 3 being a hill side.
- Litter depth was measured using a ruler.
- Stones having a surface area greater than 2 cm were counted as rock cover.
- Coarse woody debris (surface area >2 cm) was counted separately to "ground cover". If several branches from the same debris crossed the intercept line, each was counted separately (no "filling-in").
- Ground that was free of any organic matter or rocks was counted as bare ground. Bare ground patches smaller than 5 cm were not counted.
- Ground cover consisted of leaves, small dead plants such as grasses, fine woody debris (<2 cm), small bare ground patches (<5 cm), stones (<2 cm) and non-descript organic matter.
- Measuring techniques for soil characteristics are described below.

4.5.1 Soil Collection And Analysis

Soils were collected along each intercept line at the 0, 25, 50 metre intervals. Care was taken to ensure that soil collected did not detract from the soil sample being representative of the intercept. Thus, bare ground along otherwise littered ground, or conversely, small areas of litter along otherwise bare ground were avoided. In such cases another point was chosen in close vicinity along the intercept.

In mined areas, it was often necessary to break the soil's sun baked crust and push it aside before taking a soil sample. This was to access the soil immediately below this crust which plants utilised. Similarly, in the control sites, the non-decomposed, and partly decomposed organic debris was moved aside to reveal the A Horizon. Only the A Horizon was taken for sampling, as it is the most useful horizon for plant growth and revegetation (Murphy 1994). Although other horizons may have been useful, their collection would have been time consuming.

In both the mined areas and controls, an auger was used to take a core sample of soil about 7-10cm in depth. A handful of soil at each point along the intercept line was taken and placed in a bag. By mixing the soils along the intercept an overall average was achieved. Non-decomposed organic material and stones were avoided. Soils were collected in brown paper bags, and air dried for several days in the shade before being stored. Soils were very dry when collected.

Analysis on soils began 5 months after the collection period. Soils were ground using a mortar and pestle and sieved through a 2 mm screen. Soil nitrogen testing was conducted using the Kjedahl method described in Rayment and Higginson (1992). Total phosphorus was tested using the acid digestion method as described in Olsen and Sommers (1976). Soil pH was tested using a standard field pH soil test kit. Soil Chroma, Hue and Value were assessed using a Standard Munsell Colour Chart (1991)

Texture was assessed using the Northcote's (1975) 17 field soil texture classes. Each class was given a numerical value for data analysis: 1= sand; 2= loamy sand; 3= clayey sand; 4= sandy loam; 5= light sandy clay loam; 6= loam; 7= silt loam; 8= sandy clay loam; 9= clay loam; 10= silty clay loam; 11= sandy clay; 12= silty clay; 13= light clay; 14= light medium clay; 15= medium clay; 16= medium heavy clay; 17= heavy clay.

4.6 Data Handling & Analysis

Data were analysed using TWINSPAN (Two-Way INdicator SPecies ANalysis). This is a technique used to classify and ordinate complex data sets. It closely resembles Mueller-Dombrois and Ellenberg's (1974) "hand" method of classification, differing in its independent classification of species (Hill 1979).

Global Non Parametric Multi-dimensional Scaling was used to show the spatial differences between sites. Multi-dimensional scaling (MDS) has been utilised extensively in assessing environmental impacts (Clarke 1993). Its benefits and limitations have been discussed in detail elsewhere (see Clarke 1993; Hero *et al.*, 1998; Underwood; 1996). Both MDS and TWINSPAN were undertaken from within the DECODA framework and used the Czekanowski (Bray-Curtis) similarity co-efficient and all other default options. Both TWINSPAN and MDS were run on presence/absence data for all plant taxa.

Using MDS, the relationship between abiotic variables and biotic data can be assessed by 'superimposing the value of each biotic variable separately onto the biotic ordination' (Clarke 1993). Vectors for the environmental variables were fitted to the MDS graph, and the correlation values were calculated. Their significance was tested using the Monte-Carlo analysis with 99 random permutations.

The total number of taxa, along with the proportions of native and exotic species were recorded for the two treatments at each site. For every species recorded at each site a percentage of cover was recorded in the control and mined areas. This was calculated and tabulated in an EXCEL spreadsheet environment. The same was done for environmental variables.

Chapter 5: Results

5.1 Vegetation Survey

5.1.1 Overview of Flora

A total of 112 vascular species and grouped taxa were recorded along the transects at the 4 localities. No species recorded in this study are listed as endangered, rare or vulnerable nationally or in Victoria. *Allocasuarina luehmannii* is considered as "depleted" in Victoria (Muir *et al.* 1995). *Acacia ausfeldii* is confined to the Box and Ironbark Forests of North Central Victoria, whilst *Danthonia procera* was listed as a rare, interesting and restricted species in the North Central Area by Beauglehole (1982). Eighteen exotic species were recorded, thus forming 20.6% the taxa. A full list of species and grouped taxa are provided in Appendix 1.

5.1.2 Description of the Vegetation Communities

The sorted table produced by the TWINSPAN presence/absence analysis indicated 5 distinct floristic communities and one sub-community.

- 1. Tall *Cassinia arcuata - Acacia pycnantha - Melaleuca decussata* shrubland.
- 2. Juvenile Revegetation.
- 3. Dry Heathy *Eucalyptus tricarpa* Woodland.
- 4. Open Shrubby *Eucalyptus leucoxylon - E. microcarpa* Forest.
  4.1 sub-community.
- 5. Grassy *Eucalyptus polyanthemos - E. macrorhyncha* Forest.

5.1.2.1 Vegetation Community 1: *Tall Cassinia arcuata - Acacia pycnantha - Melaleuca decussata* shrubland

Table 5.1: Character Species of Community 1

CHARACTER SPECIES (Species With Average Percentage Cover Greater than 0.1%)		CHARACTER SPECIES	
Melaleuca decussata	34.22	*Eucalyptus polyanthemos*	0.76
Cassinia arcuata	8.04	*Pultenaea largiflorens*	0.59
Acacia pycnantha	6.11	**Plantago coronopus*	0.49
**Plantago lanceolata*	4.83	*Acacia acinacea*	0.31
Acacia aspera	1.86	* *Avena fatua*	0.26

*Juncus acutus	1.19	Eucalyptus camaldulensis	0.26
Acacia genistifolia	1.19	*Phalaris spp.	0.21
Danthonia setacea	1.03	Gonocarpus tetragynus	0.16
* Cortaderia selloana	0.87		

* Introduced taxa

This community occurred within the city of Bendigo (Site 1 mined area). The topography was mildly sloping and a subtle creek line ran through the area. Lower areas of the site showed evidence of periodic soaking.

This community is characterised by a tall and open *Acacia pycnantha/Cassinia arcuata* shrub layer on drier slopes, with *Melaleuca decussata* dominating in wetter areas. Many smaller shrubs also occur, namely *Acacia acinacea, A. genistifolia, A. aspera* and *Pultenaea largiflorens. Cortaderia selloana* (Pampas Grass) is also a characteristic species of this community. The high availability of water at the site has resulted in a herbaceous ground cover. *Danthonia setacea*, and exotic taxa including; *Plantago* spp. and *Avena fatua* are common. In drier areas, bare ground is intermixed with grassy sites. Floristic richness is 31 species. Six exotic species were recorded (18.6% of species). This community does not resemble any of the floristic communities described in Muir *et al.* (1995).

5.1.2.2 Vegetation Community 2: Juvenile Revegetation

Table 5.2: Character Species of Community 2

CHARACTER SPECIES (Species With Average Percentage Cover Greater Than 0.1%)		CHARACTER SPECIES	
Acacia pycnantha	2.55	*Gonocarpus tetragynus*	0.43
Eucalyptus macrorhyncha	0.98	*Chionochloa pallida*	0.27
Einadia hastata	0.89	*Cassinia arcuata*	0.26
**Solanum elaegnifolium*	0.76	*Acacia ausfeldii*	0.15
Eucalyptus microcarpa	0.72	*Senecio sp.*	0.12
Bracteantha viscosa	0.65		

* Introduced taxa

This community was recorded as growing on mine tailings near the township of Heathcote (Site 4 mined area). *Eucalyptus macrorhyncha* is the most common tree species. *Eucalyptus microcarpa* is also present. *Acacia pycnantha* and *Cassinia arcuata* are the most common shrub species. Many grasses and forbs are also evident. Floristic richness is 35 species, 5 being exotic (14.7% of species). This community has no similarity to communities described in Muir *et al.* (1995) although many of the species recorded occur in indigenous plant communities of the Heathcote area.

5.1.2.3 Community 3: Dry Heathy *Eucalyptus tricarpa* Woodland

Table 5.3: Character Species of Community 3

CHARACTER SPECIES (Species With Average Percentage Cover Greater Than 0.1%)		CHARACTER SPECIES	
Eucalyptus tricarpa	24.6	*Acacia paradoxa*	2.02
Bursaria spinosa	23.59	*Cassytha melantha*	1.48
Calytrix tetragona	14.82	*Cassinia arcuata*	1.46
Gonocarpus tetragynus	12.98	*Stipa mollis*	0.86
Lomandra multiflora	6.14	*Eriostemon verrucosus*	0.7
Melaleuca decussata	4.48	*Poa sieberiana*	0.66
Eucalyptus microcarpa	4.4	*Danthonia eriantha*	0.56
Acacia aspera	4.24	*Acacia gunnii*	0.2
Lomandra filiformis	3.07		

This community occurs within the city of Bendigo (Site 1 Control), uphill of the Tall *Cassinia arcuata - Acacia pycnantha - Melaleuca decussata* shrubland. It resembles the Box-Ironbark Forest (Northern Goldfields) Community 4, as described in Muir *et al.* (1995). The open and stunted trees of *E. tricarpa* dominate, with *E. microcarpa* occurring less frequently. A dense heathy understorey is dominated by *Bursaria spinosa* and *Calytrix tetragona*, with *Acacia aspera*, *Acacia paradoxa*, *Melaleuca decussata*, *Eriostemon verrucosus* and *Cassinia arcuata* being also common. A prominent ground stratum includes species such as *Gonocarpus tetragynus*, *Cassytha melantha*, *Lomandra filiformis*, *Poa sieberiana* and *Stipa mollis*. *Aira cupaniana* and *Briza maxima* are common exotics. Recorded floristic richness is 25 species, 2 exotics (8% of species).

5.1.2.4 Community 4: Open Shrubby *Eucalyptus leucoxylon - E. microcarpa* Forest

Table 5.4: Character Species of Community 4

CHARACTER SPECIES (Species With Average Percentage Cover Greater Than 0.1%)		CHARACTER SPECIES	
Eucalyptus leucoxylon	18.27	*Juncus remotiflorus*	0.62
Eucalyptus microcarpa	9.55	*Leptomeria aphylla*	0.52
Acacia montana	7.83	*Acacia genistifolia*	0.48
Cassinia arcuata	5.51	*Dianella revoluta*	0.36
Acacia pycnantha	3.08	*Danthonia setacea*	0.24
Bracteantha viscosa	2.39	*Acacia aspera*	0.24
Melaleuca wilsonii	2.10	*Acacia acinacea*	0.16
Astroloma conostephioides	2.00	*Hakea sericea*	0.15
Acacia calamifolia	1.57	*Allocasuarina muelleriana*	0.13
Pultenaea largiflorens	1.45	*Astroloma humifusum*	0.11
Lomandra filiformis	0.68		

This community occurs at Waanyarra (Sites 2, 2B and 3 mined area and control). It was recorded growing along creek lines and on the gentle slopes. *Eucalyptus leucoxylon* forms a tall canopy with *E. microcarpa* occurring more often on higher ground. A tall and very sparse shrub layer of *Acacia montana, Cassinia arcuata* and *Acacia pycnantha* is evident. *Astroloma conostephioides, Acacia calamifolia, Pultenaea largiflorens, Leptomeria aphylla* and *Acacia genistifolia* are also common shrubs. The ground layer is a sparse array of grasses, namely (*Danthonia* spp, *Stipa* spp.), *Bracteantha viscosa, Dianella revoluta, Astroloma humifusum* and *Lomandra filiformis*. *Juncus remotiflorus* grows throughout the community in small depressions. Young plants of *Allocasuarina muelleriana* are found in mined areas, and *Melaleuca wilsonii* occurs along gully lines in some of the mined areas. The mined areas have a similar floristic composition to unmined areas but lack some species, namely *Astroloma conostephioides, Lomandra filiformis* and *Dianella revoluta.*

Sub-community 4.1 occurs on the Secret Hill site (2B mined area and control). This area is slightly more grassy than community 4. *E. microcarpa* formed the dominant canopy in Control areas. The presences of *Brunonia australis, Themeda triandra, Allocasuarina leuhmanni* and *Hakea sericea* separate the sub-community from the community. Orchids were also common in this sub-community.

Recorded floristic richness for this community (including the sub-community) was 80 species, of which 9 were exotics (7.2% of species). This community has close similarities to the Box and Ironbark Ecological Vegetation Class, with evidence of the Western and Northern Goldfields floristic communities as described by Muir *et al.* (1995). Sub-community 4.1 on the other hand, most likely belongs to the Heathy Woodland Ecological Vegetation Class described by Muir (1995).

5.1.2.5 Community 5: Grassy *Eucalyptus polyanthemos - E. macrorhyncha* Forest

Table 5.5: Character Species of Community 5

CHARACTER SPECIES (Species With Average Percentage Cover Greater Than 0.1%)			
Eucalyptus polyanthemos	40.37	*Eucalyptus microcarpa*	1.17
Chionochloa pallida	15.37	*Acacia acinacea*	0.95
Eucalyptus macrorhyncha	4.00	*Dianella revoluta*	0.92
Acacia pycnantha	2.68	*Lomandra multiflora*	0.38
Cassinia arcuata	2.04	*Melaleuca decussata*	0.24
Ptilotus spathulatus	1.39	*Gonocarpus tetragynus*	0.20

This community was sampled near the town of Heathcote (Site 4 Control), growing on sloping terrain. *Eucalyptus polyanthemos* and *E. macrorhyncha* form an almost continuous canopy, with a few scattered shrubs of *A. pycnantha* and *C. arcuata* growing about 2.5 meters tall. An open-tussock ground cover of *Chionochloa pallida* and *Poa sieberiana* is common. *Dianella revoluta*, *Lomandra filiformis* and *Acacia acinacea* are also common in the lower stratum. *Astroloma pinifolium* and *Pimelea linifolia* were interesting finds at this site. Recorded floristic richness is 33 species, with 2 exotics (6.1% of species). This community shares similarities with the Heathy Dry Forest (Northern Goldfields) Community 5, described in Muir *et al.* (1995).

Table 5.6: Summary of Twinspan Vegetation Communities by Site and Treatment

Site	1		2		2B		3	3A	3B	3BC	3	4	
Treatment	Mined	Control	Mined	Control	Mined	Control	Mined	Mined	Mined	Mined	Control	Mined	Control
Community	1	3	4	4	4.1	4.1	4	4	4	4	4	2	2

5.2 Comparison between Control and Mined Area at Each Site: How Similar Are They?

5.2.1 <u>Taxa Recorded on Mined Areas and Controls at each Site (Mean Averages of Height and Cover)</u>

5.2.1.1 Site 1

Forty five species were recorded at Site 1. Fourteen native species were restricted to the control, 8 were restricted to the mined area. Thirteen taxa are exotic, 32 are native. Of the 13 exotic taxa, 1 is found in both the control and the mined areas, the other 12 are restricted to the mined area.

Table 5.7: Cover and Height Values for Species At Site 1

Species Name	Mined Cover	Height	Control Cover	Height
Acacia acinacea	0.314	0.504	-	-
Acacia aspera	1.86	0.618	4.24	1.15
Acacia genistifolia	1.188	0.964	-	-
Acacia gunnii	-	-	0.2	0.3
Acacia paradoxa	-	-	2.02	0.98
Acacia pycnantha	6.114	2.656	0.01	1.4
Acacia retinodes	0.004	*	-	-
**Aira cupaniana*	0.006	0.072	0.08	0.01
Astroloma humifusum	0.044	0.012	-	-
**Avena fatua*	0.264	0.204	-	-
Bracteantha viscosa	-	-	0.06	0.61
**Briza maxima*	0.002	0.016	0.01	0.1
Bursaria spinosa	-	-	23.59	1.1
Calytrix tetragona	-	-	14.82	1.45
Cassinia arcuata	8.04	1.992	1.46	1.85
Cassytha melantha	-	-	1.48	1.4
**Centaurium tenuiflorum*	0.026	0.084	-	-
**Cortaderia selloana*	0.872	0.644	-	-
**Cynodon dactylon*	0.002	0.02	-	-

Table 5.7 Continued... Species Name	Mined Cover	Height	Control Cover	Height
Danthonia duttoniana	0.002	0.02	-	-
Danthonia eriantha	0.028	0.026	0.56	0.75
Danthonia setacea	1.032	0.206	-	-
Daviesia ulicifolia	0.028	0.14	-	-
Eriostemon verrucosus	-	-	0.7	0.66
Eucalyptus camaldulensis	0.26	0.45	-	-
Eucalyptus leucoxylon	-	-	0.01	0
Eucalyptus microcarpa	-	-	4.4	4.8
Eucalyptus polyanthemos	0.76	0.28	0.01	3.6
Eucalyptus tricarpa	0.002	*	24.6	13.6
Gonocarpus tetragynus	0.16	0.048	12.98	0.2
**Hypochoeris radicata*	0.082	0.026	-	-
* *Juncus acutus*	1.192	0.29	-	-
Lomandra filiformis	-	-	3.07	0.48
Lomandra multiflora	-	-	6.14	0.19
Melaleuca decussata	34.22	1.96	4.48	2.4
**Paspalum dilatatum*	0.002	0.02	-	-
*Phalaris ssp.	0.21	0.14	-	-
**Plantago coronopus*	0.492	0.006	-	-
**Plantago lanceolata*	4.832	0.116	-	-
Poa sieberiana	-	-	0.66	0.5
Pultenaea largiflorens	0.586	0.21	-	-
Stipa mollis	0.006	0.06	0.86	1.2
Thelymitra ssp.	-	-	0.01	*
**Vulpia genius*	0.004	0.04	-	-
Wurmbea dioica	-	-	0.01	0.15

* denotes an exotic species or grouped taxa - denotes a missing value

5.2.1.2 Site 2

Forty five species occur at Site 2. Twenty three native species were restricted to the control, four were restricted to the mined area. Six taxa are exotic, 39 are native. Of the 6 exotic taxa, 4 are found in both the control and the mined areas, the other 2 are restricted to the control.

Table 5.8: Cover and Height Values for Species At Site 2

Species Name	Mined Cover	Height	Control Cover	Height
Acacia acinacea	-	-	0.002	*
Acacia calamifolia	0.426	0.249	-	-
Acacia genistifolia	0.054	0.119	0.444	0.192
Acacia montana	3.423	0.454	4.736	1.976
Acacia pycnantha	1.114	0.422	1.902	0.998
**Aira cupaniana*	0.089	0.047	0.010	0.100
Astroloma conostephioides	-	-	3.034	0.746
Astroloma humifusum	-	-	0.146	0.088
**Avena fatua*	0.001	0.011	0.402	0.060
Brachyloma daphnoides	-	-	0.388	0.130
Bracteantha viscosa	0.070	0.120	0.180	0.330
**Briza maxima*	0.001	0.011	0.010	0.082

Table 5.8 Continued...	Mined		Control	
Species Name	Cover	Height	Cover	Height
Caladenia caerulea	-	-	0.002	0.020
Caladenia carnea	-	-	0.004	0.040
Cassinia arcuata	0.882	0.566	8.736	2.318
Danthonia caespitosa	-	-	0.002	0.020
Danthonia duttoniana	-	-	0.002	0.030
Danthonia eriantha	-	-	0.016	0.096
Danthonia pilosa	-	-	0.002	0.020
Danthonia racemosa	-	-	0.002	0.020
Danthonia setacea	0.003	0.033	0.070	0.100
Dianella revoluta	-	-	0.272	0.294
Dichelachne micrantha	0.001	0.011	0.006	0.060
Dillwynia sericea	-	-	0.002	*
Eucalyptus leucoxylon	0.662	0.163	11.700	18.410
Eucalyptus microcarpa	0.297	0.078	30.080	16.130
Eucalyptus tricarpa	-	-	0.006	8.460
Grevillea alpina	-	-	0.002	0.020
Hibbertia exutiacies	-	-	0.028	0.012
Juncus remotiflorus	0.013	0.067	0.242	0.234
Juncus subsecundus	0.001	0.011	-	-
Leptomeria aphylla	-	-	2.080	0.958
*Lolium spp.	-	-	0.002	0.020
Lomandra filiformis	-	-	0.856	0.114
Lomandra multiflora	-	-	0.002	0.020
Melaleuca wilsonii	0.881	0.254	-	-
Microseris lanceolata	-	-	0.002	0.020
Poa sieberiana	-	-	0.010	0.100
Pultenaea largiflorens	0.030	0.030	5.716	0.508
Senecio spp.	-	-	0.002	*
Stipa mollis	0.004	0.044	0.012	0.160
Stipa scabra group	0.038	0.016	-	-
Thysanotus patersonii	-	-	0.004	0.040
**Trifolium genius*	-	-	0.002	0.020
**Vulpia genius*	0.002	0.022	0.408	0.070

* denotes an exotic species or grouped taxa * denotes a missing value

5.2.1.3 Site 2B

Sixty two species occur at Site 2B. Thirteen native species were restricted to the control, 9 were restricted to the mined area. Five taxa are exotic, 57 are native. Of the 5 exotic taxa, 2 are found in both the control and the mined areas. Two exotic taxa are restricted to the control, 1 is found only in the mined area.

Table 5.9: Cover and Height Values for Species At Site 2B

	Mined		Control	
Species Name	Cover	Height	Cover	Height
Acacia acinacea	0.200	0.113	-	-
Acacia aspera	0.220	0.143	0.838	0.233
Acacia calamifolia	3.053	1.333	4.800	3.788
Acacia genistifolia	0.155	0.325	0.473	0.630
Acacia montana	1.823	0.728	0.008	*
Acacia pycnantha	2.210	1.320	3.138	3.325

Table 5.9 Continued... Species Name	Mined Cover	Height	Control Cover	Height
**Aira cupaniana*	0.008	0.075	0.008	0.075
Allocasuarina leuhmannii	-	-	0.003	1.013
Arthropodium strictum	0.008	0.075	0.008	0.050
Astroloma conostephioides	-	-	8.820	0.993
Astroloma humifusum	0.035	0.005	0.775	0.108
Brachyloma daphnoides	-	-	0.005	*
Bracteantha viscosa	1.958	0.673	0.825	0.525
**Briza maxima*	0.008	0.075	0.008	0.075
Brunonia australis	0.010	0.100	0.338	0.050
Bursaria spinosa	0.008	0.025	-	-
Caladenia carnea	-	-	0.005	0.050
Calytrix tetragona	0.198	0.138	0.003	*
Cassinia arcuata	9.590	1.570	0.103	0.360
Cheilanthes austrotenuifolia	-	-	0.003	0.025
Chionochloa pallida	-	-	0.200	0.070
**Cotula bipinnata*	-	-	0.003	0.025
Danthonia caespitosa	0.003	0.025	-	-
Danthonia eriantha	0.005	0.050	0.033	0.105
Danthonia setacea	0.083	0.113	0.205	0.088
Daviesia leptophylla	0.003	*	-	-
Dianella revoluta	0.005	*	0.365	0.138
Drosera peltata	0.003	0.025	0.003	0.025
Elymus scabrus	-	-	0.003	0.025
Eucalyptus leucoxylon	0.730	0.775	15.050	15.438
Eucalyptus microcarpa	3.113	1.018	10.850	10.750
Eucalyptus tricarpa	0.485	0.188	-	-
Glossodia major	-	-	0.008	0.075
Gonocarpus elatus	-	-	0.003	0.025
Gonocarpus tetragynus	0.003	0.020	0.068	0.063
Hakea sericea	0.678	0.548	0.535	0.508
Hibbertia exutiacies	-	-	0.453	0.078
Juncus remotiflorus	0.465	0.338	0.075	0.200
Lepidosperma laterale	0.003	*	-	-
Leptomeria aphylla	0.078	0.138	1.350	0.310
Leptorhynchos squamatus	-	-	0.001	0.025
Lomandra filiformis	0.040	0.005	1.783	0.173
Lomandra multiflora	0.003	*	0.003	*
Melaleuca wilsonii	0.403	0.263	-	-
Microseris lanceolata	0.005	0.050	0.010	0.100
Olearia teretifolia	0.003	*	0.435	0.115
Ozothamnus obcordatus	0.033	0.103	0.003	*
Pelargonium rodneyanum	0.003	0.025	0.003	0.025
Pimelea linifolia	0.005	*	0.005	*
Poa sieberiana	0.115	0.143	0.100	0.100
Ptilotus spathulatus	0.010	*	0.003	*
Pultenaea largiflorens	0.183	0.100	0.148	0.113
Senecio spp.	-	-	0.005	0.025
Stipa mollis	0.005	0.063	0.063	0.105
Stipa rudis	-	-	0.003	0.025
Stipa scabra group	0.008	0.075	-	-
Thelymitra ssp.	0.005	0.050	0.003	0.025
Themeda triandra	0.005	0.050	0.050	0.013
Thysanotus patersonii	0.010	0.100	0.010	0.100
**Tribulus terrestris*	0.003	0.025	-	-
**Vulpia genius*	-	-	0.003	0.025
Wurmbea dioica	0.003	*	-	-

* denotes an exotic species or grouped taxa   * denotes a missing value

5.2.1.4 Site 3

Forty five species occur at Site 3. Thirteen native species were restricted to the control, 9 were restricted to the mined area. Three taxa are exotic, 42 are native. Of the 3 exotic taxa, 1 exotic is restricted to the control, 1 is found only in the mined area and 1 occurs in both the mined and control areas.

Table 5.10: Cover and Height Values for Species At Site 3

Species Name	Mined Cover	Height	Control Cover	Height
Acacia acinacea	0.009	0.044	1.190	0.375
Acacia aspera	0.273	0.184	-	-
Acacia calamifolia	1.454	0.641	-	-
Acacia genistifolia	0.799	0.538	-	-
Acacia montana	13.791	1.204	5.345	1.713
Acacia pycnantha	4.806	1.992	0.165	0.488
**Aira cupaniana*	0.001	0.005	0.003	0.025
Allocasuarina muelleriana	0.296	0.430	-	-
Arthropodium strictum	-	-	0.008	0.075
Astroloma conostephioides	-	-	6.103	0.700
Astroloma humifusum	-	-	0.003	0.025
Bracteantha viscosa	-	-	0.068	0.193
Caladenia carnea	-	-	0.003	0.025
Cassinia arcuata	5.243	1.580	9.280	1.888
Danthonia eriantha	-	-	0.105	0.138
Danthonia procera	-	-	0.005	0.050
Danthonia setacea	0.433	0.103	0.108	0.150
Daviesia leptophylla	0.001	*	-	-
Dianella revoluta	-	-	2.558	0.358
Dichelachne micrantha	-	-	0.003	0.025
Dillwynia sericea	0.014	0.011	0.540	0.513
Elymus scabrus	-	-	0.003	0.025
Eucalyptus leucoxylon	27.202	5.090	27.500	25.375
Eucalyptus melliodora	-	-	0.003	3.650
Eucalyptus microcarpa	8.269	2.332	8.500	18.025
Eucalyptus tricarpa	0.001	*	-	-
Hakea sericea	-	-	0.125	0.205
Hibbertia exutiacies	0.001	*	0.008	*
Hibbertia sericea	-	-	0.095	0.015
**Inula graveolens*	0.001	0.008	-	-
Juncus holoschoenus	0.012	0.038	-	-
Juncus remotiflorus	1.167	0.279	0.120	0.200
Leptomeria aphylla	0.095	0.124	0.783	0.408
Lomandra filiformis	0.005	0.023	3.453	0.200
Lomandra multiflora	-	-	0.270	0.065
Melaleuca wilsonii	4.400	0.574	-	-
Microseris lanceolata	-	-	0.010	0.100
Pelargonium rodneyanum	-	-	0.003	0.025
Poa labillardieri	0.001	0.008	-	-
Poa sieberiana	0.017	0.008	0.123	0.113
Ptilotus spathulatus	-	-	0.003	*
Pultenaea largiflorens	0.911	0.071	3.340	0.663
Stipa mollis	0.071	0.081	0.008	0.075

Table 5.10 Continued... Species Name	Mined Cover	Height	Control Cover	Height
Stipa scabra	-	-	0.003	0.025
**Tribulus terrestris*	0.001	0.008	-	-

* denotes an exotic species or grouped taxa * denotes a missing value

5.2.1.5 Site 4

Fifty species occur at Site 4. Seven taxa are exotic, 43 are native. Of the 7 exotic taxa, 1 is found in both the control and the mined areas. One exotic taxon is restricted to the control and 5 txa are found only in the mined area.

Table 5.11: Cover and Height Values for Species At Site 4

Species Name	Mined Cover	Height	Control Cover	Height
Acacia acinacea	0.005	*	0.947	0.492
Acacia ausfeldii	0.153	0.138	-	-
Acacia genistifolia	0.003	*	-	-
Acacia mearnsii	0.050	0.810	-	-
Acacia pycnantha	2.545	0.628	2.683	3.442
Arthropodium strictum	-	-	0.002	0.017
Astroloma humifusum	-	-	0.002	0.017
Astroloma pinifolium	-	-	0.002	0.148
Brachyscome multifida	0.003	0.025	-	-
Bracteantha viscosa	0.648	0.143	0.002	*
Caladenia caerulea	-	-	0.002	0.017
Caladenia carnea	-	-	0.005	0.050
Calytrix tetragona	-	-	0.003	0.033
Cassinia arcuata	0.258	0.365	2.040	1.408
**Centaurium tenuiflorum*	0.005	0.050	-	-
Cheiranthera cyanea	-	-	0.068	0.033
Chionochloa pallida	0.270	0.140	15.367	0.492
**Cynodon dactylon*	0.003	0.025	0.002	0.017
Danthonia caespitosa	0.003	0.025	-	-
Danthonia duttoniana	0.003	0.025	-	-
Danthonia eriantha	-	-	0.005	0.050
Danthonia setacea	0.048	0.045	0.007	0.005
Daviesia leptophylla	0.003	*	0.003	*
Dianella revoluta	-	-	0.923	0.330
Dichelachne micrantha	-	-	0.003	0.033
Dillwynia sericea	-	-	0.002	*
Drosera peltata	-	-	0.003	0.033
Einadia hastata	0.893	0.093	-	-
Einadia nutans	0.020	0.060	-	-
Eucalyptus macrorhyncha	0.978	0.313	4.002	10.967
Eucalyptus microcarpa	0.723	0.510	1.167	2.167
Eucalyptus polyanthemos	-	-	40.367	9.992
Exocarpos cupressiformis	-	-	0.002	*
Gonocarpus tetragynus	0.425	0.075	0.203	0.047
Goodenia blackiana	0.010	0.100	0.003	0.033

Table 5.11 Continued... Species Name	Mined Cover	Height	Control Cover	Height
Hardenbergia violacea	0.755	0.038	-	-
**Hypochoeris radicata*	0.005	0.050	-	-
Lomandra filiformis	0.003	*	0.377	0.053
Lomandra multiflora	0.003	0.025	0.243	0.058
Ozothamnus obcordatus	0.010	0.108	-	-
**Paspalum dilatatum*	-	-	0.002	0.017
**Phalaris ssp.*	0.003	0.025	-	-
Poa sieberiana	0.088	0.100	1.390	0.117
**Polygonum aviculare L.*	0.003	0.025	-	-
Pultenaea largiflorens	0.115	0.088	-	-
Senecio sp.	0.025	0.063	0.002	*
**Solanum elaegnifolium*	0.003	0.025	-	-
Stipa mollis	0.003	0.025	0.002	0.017
Thysanotus patersonii	-	-	0.008	0.083
Veronica plebeia	0.003	0.025	-	-

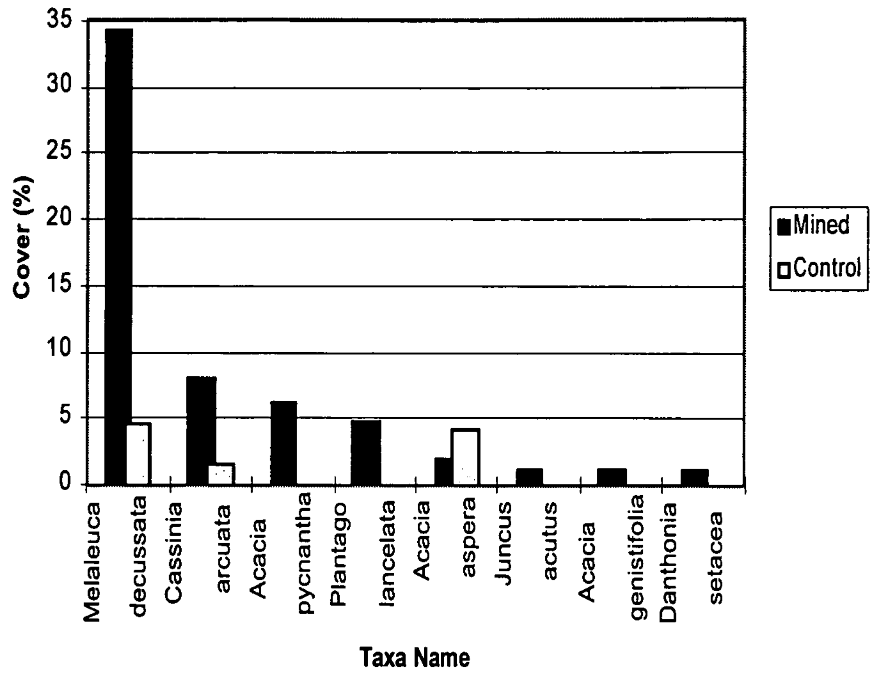
* denotes an exotic species or grouped taxa * denotes a missing value

5.2.2 Species with a Cover Value Greater than 1 Percent: Control/Mined Comparisons at Each Site

5.2.2.1 Site 1: Mined Area

In the mined area at site 1 (Figure 5.1), *Melaleuca decussata* has the highest cover of any species at 34.22%. This species forms a dense thicket along the creekline. It was present in the control, but has a cover of only 4.48%. *Cassinia arcuata* (8.04%) and *Acacia pycnantha* (6.11%) are also well represented in the mined site but had relatively little cover in the control site, with 1.46% and 0.01% respectively. The exotic species *Plantago lanceolata* (4.83%) is a common ground species in the mined area but is absent from the control. *Acacia aspera* is the only species with a cover of greater than 1% found in the mined area (1.86%) whose cover was greater in the control (4.24%). The exotic species, *Juncus acutus* (1.19%), along with the natives *Acacia genistifolia* (1.19%) and *Danthonia setacea* (1.03%) had low cover values and were absent in the control.

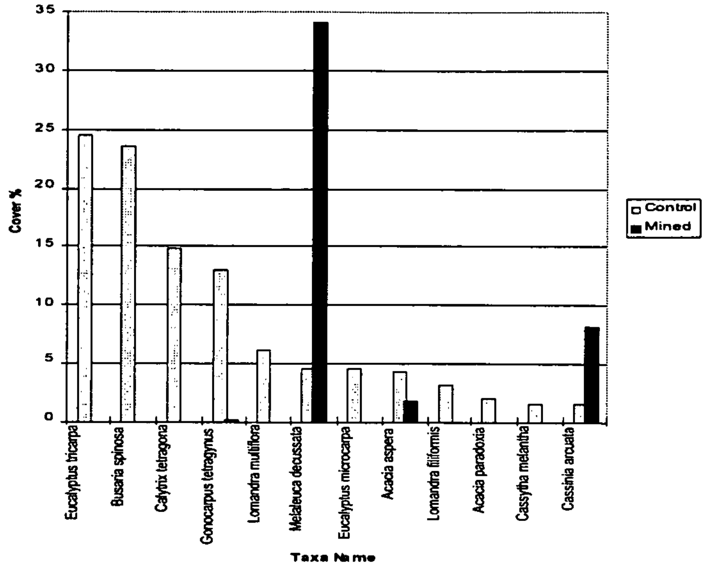
Figure 5.1: Site 1. Taxa which had a cover value greater than 1% in the mined area, and their cover in the control



5.2.2.2 Site 1: Control

In the control at site 1 (Figure 5.2), *Eucalyptus tricarpa* is the most dominant plant species with a cover of 24.6%. This species is much more abundant in the control than the mined area at 0.002%. Shrub species *Bursaria spinosa* (23.59%), *Calytrix tetragona* (14.82%), *Melaleuca decussata* (4.48%), *Acacia aspera* (4.24%), *Acacia paradoxa* (2.02%) and *Cassinia arcuata* (1.42%) formed a heathy understorey. Interestingly, the three shrubs most common in the mined area (collectively 48.37% cover) had a very low collective cover value in the control (5.95%). Similarly, the two most common shrubs in the control were absent from the mined area. The control also has a high ground stratum cover value of herbaceous taxa; *Gonocarpus tetragynus* (12.98%), *Lomandra multiflora* (6.14%), *Lomandra filiformis* (3.07%), and *Cassytha melantha* (1.48%), all of these species being absent from the mined site, except *G. tetragynus* (0.16%) which is found in the mined area, albeit much less abundant.

Figure 5.2: Site 1. Taxa which had a cover value greater than 1% in the control, and their cover in the mined area



5.2.2.3 Site 2: Mined Area

Site 2 mined area (Figure 5.3) has very low cover values, only 2 species having a cover value greater than 1%, with an additional 5 species having a cover value greater than 0.01%. *Acacia montana* (3.42%) has the highest percentage of cover, relatively similar to that species' cover value in the control (4.74%). *Acacia pycnantha* (1.11%) and *Cassinia arcuata* (0.88%) are also showing early signs of recovery. *Melaleuca wilsonii* (0.88%) and *Acacia calamifolia* (0.43%) are also showing early colonization capabilities, although they are absent from the control. *Eucalyptus leucoxylon* (0.66%) and *E. microcarpa* (0.3%) are also present, and have a dominant cover value of 41.78% in the control.

Figure 5.3: Site 2. Taxa which had a cover value greater than 1% in the mined area, and their cover in the control

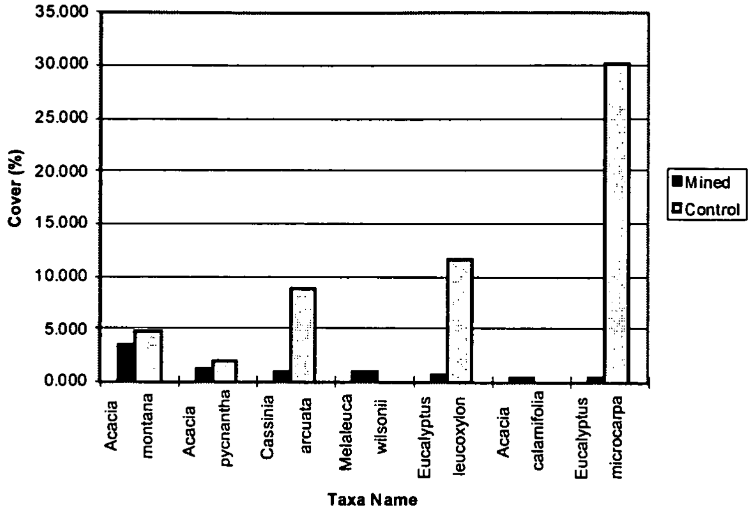
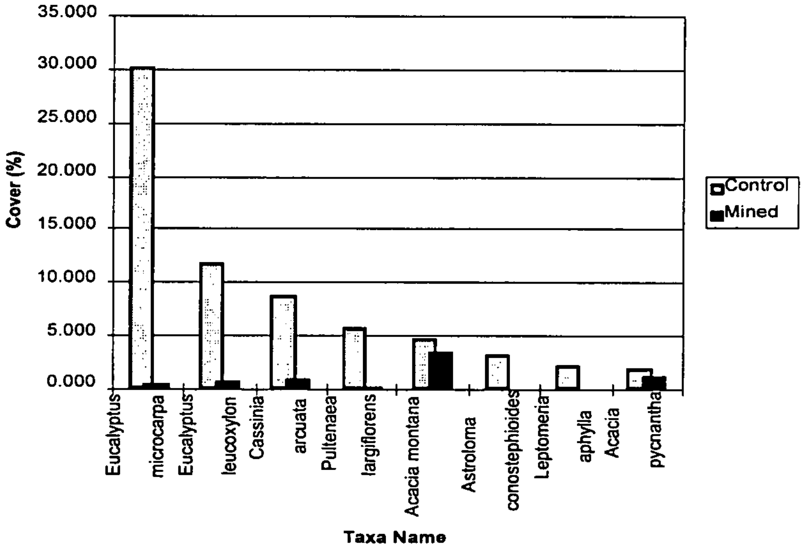


Figure 5.4: Site 2. Taxa which had a cover value greater than 1% in the control, and their cover in the mined area



5.2.2.4 Site 2: Control

The control of Site 2 (Figure 5.4), shows *E. microcarpa* (30.08%) and *E. leucoxylon* (11.7%) as the most dominant species. *Cassinia arcuata* (8.74%) is also prominent, reflecting the generally disturbed nature of the site. *Pultenaea largiflorens* (5.71%), *Astroloma conostephioides* (3.03%) and *Leptomeria aphylla* (2.08%) have significant cover values in the control but are absent from the mined area. *Acacia montana* (4.74%) and *Acacia pycnantha* (1.9%) have similar values to the mined area.

5.2.2.5 Site 2B: Mined Area

Site 2B (Figure 5.5) is dominated by a cover of *Cassinia arcuata* (9.6%), which is much less abundant in the control (0.1%). *Eucalyptus microcarpa* (3.11%), *Acacia calamifolia* (3.05%) and *Acacia pycnantha* (2.21%) share similar cover values, with the two *Acacia* species close to the cover values found in the control (4.8% and 3.1% respectively). *Bracteantha viscosa* (2%) is also common in the mined area and exceeds 0.83% cover in the control. *Acacia montana* is present in the mined area (1.82%), and also exceeds the 0.008% of cover found in the control.

Figure 5.5: Site 2B. Taxa which had a cover value greater than 1% in the mined area, and their cover in the control.

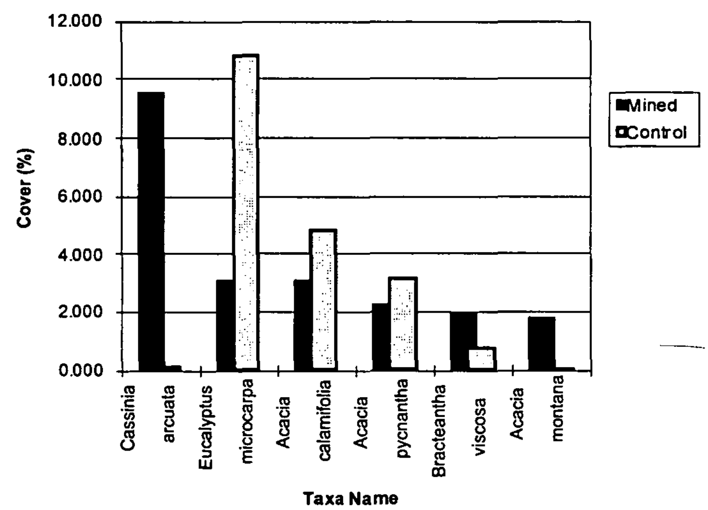
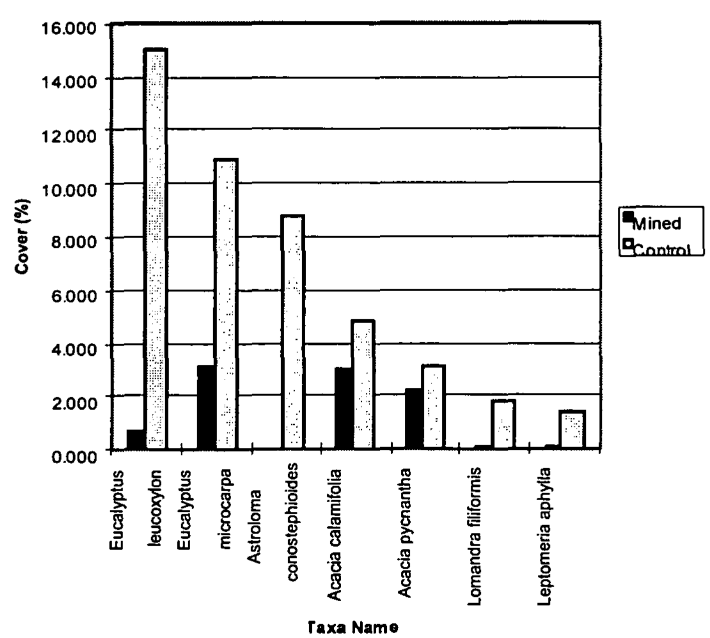


Figure 5.6: Site 2B. Taxa which had a cover value greater than 1% in the control, and their cover in the mined area



5.2.2.6 Site 2B: Control

Eucalyptus leucoxylon (15.1%) with *E. microcarpa* (10.9%) form a canopy cover, with *Astroloma conostephioides* (8.82%) contributing strongly to a shrub layer (Figure 5.6). This species is absent from the mined area. *Acacia calamifolia* (3.1%) and *Acacia pycnantha* (2.0%) are common understorey species which are also prominent in the mined area. *Leptomeria aphylla* (1.4%) and *Lomandra filiformis* (1.8%) are also common, but with low cover values in the mined areas (0.08% and 0.04% respectively).

5.2.2.7 Site 3: Mined Area

The mined area of site 3 (Figure 5.7) has a dominant cover of *Eucalyptus leucoxylon* (27.20%), which is very similar to the control (27.5%). *Eucalyptus microcarpa* also contributes to the canopy cover (8.27%) which is similar to the control (8.5%). *Acacia montana* (13.8%), *Acacia pycnantha* (4.8%) and *Cassinia arcuata* (5.2%) are found throughout , whilst *Melaleuca wilsonii* (4.4%) grows along creek lines and in damp areas and *Acacia calamifolia* (1.5%) is also common. *Acacia calamifolia* and *M. wilsonii* is absent from the control. *Juncus remotiflorus* is also common in the mined area (1.17%), having a higher cover value than in the control (0.12%).

Figure 5.7: Site 3. Taxa which has a cover value greater than 1% in the mined area, and their cover in the control

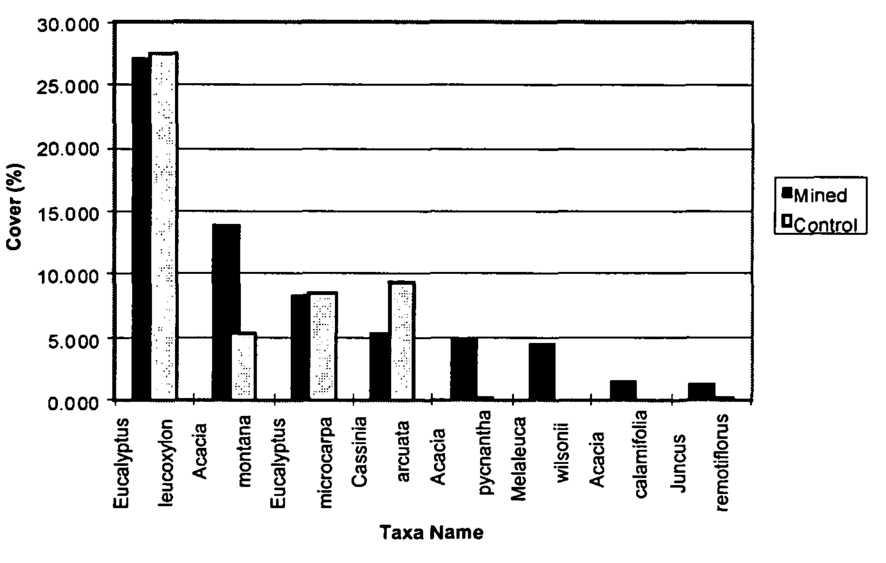
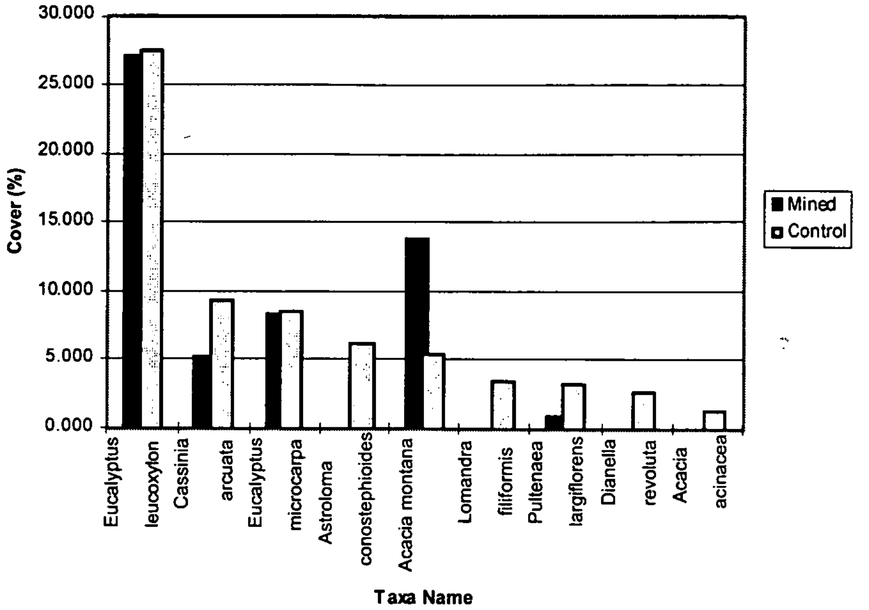


Figure 5.8: Site 3. Taxa which has a cover value greater than 1% in the control, and their cover in the mined area



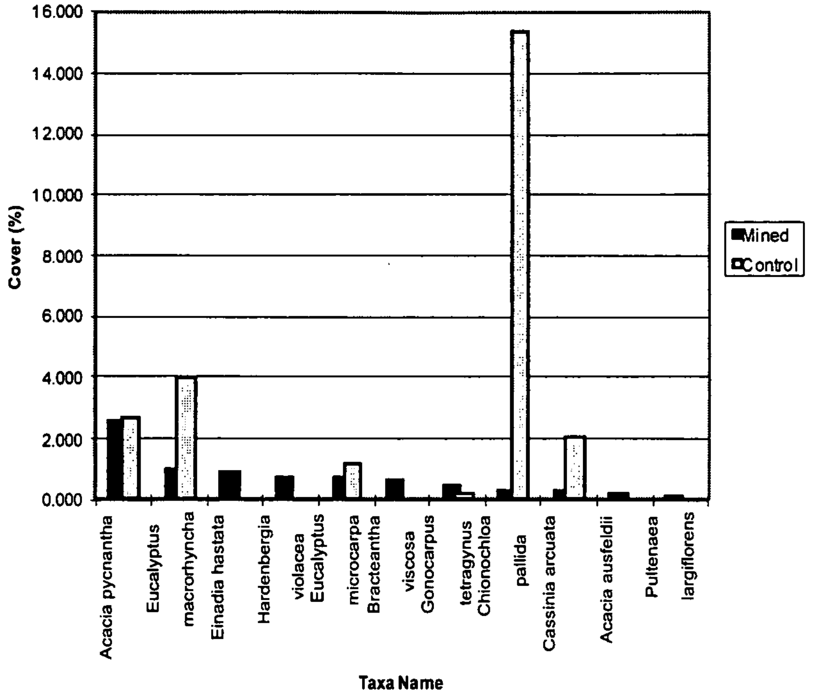
5.2.2.8 Site 3: Control

In the control for site 3 (Figure 5.8), *Eucalyptus leucoxylon* (27.5%) and *Eucalyptus microcarpa* (8.5%) form a dominant tree canopy layer. *Acacia montana* (5.35%) and *Cassinia arcuata* (9.29%) are common shrubs which are also present in the mined area as discussed above. *Astroloma conostephioides* (6.1%) is common in the control and absent from the mined area. *Pultenaea largiflorens* (3.3%) and *Acacia acinacea* (1.2%) are prominent in the control, but less so in the mined area. Likewise, *Lomandra filiformis* (3.5%) has a much higher cover value in the control compared to 0.01% in the mined area. *Dianella revoluta* (2.6%) is common in the control but absent from the mined area.

5.2.2.9 Site 4: Mined Area

The mined area at site 4 (Figure 5.9), has very low values of cover. *Acacia pycnantha* (2.6%) has the most cover, similar to its control cover value. *Eucalyptus macrorhyncha* (0.99%), *Einadia hastata* (0.89%), *Hardenbergia violacea* (0.76%), *Eucalyptus microcarpa* (0.72%), *Bracteantha viscosa* (0.65%), *Gonocarpus tetragynus* (0.43%), *Chionochloa pallida* (0.27%), *Cassinia arcuata* (0.26%), *Acacia ausfeldii* (0.15%) and *Pultenaea largiflorens* (0.12%) all have cover values less than 1.0%. *E. hastata* and *H. violacea* are absent from the control, whilst *B. viscosa* has a very low cover value of 0.002%.

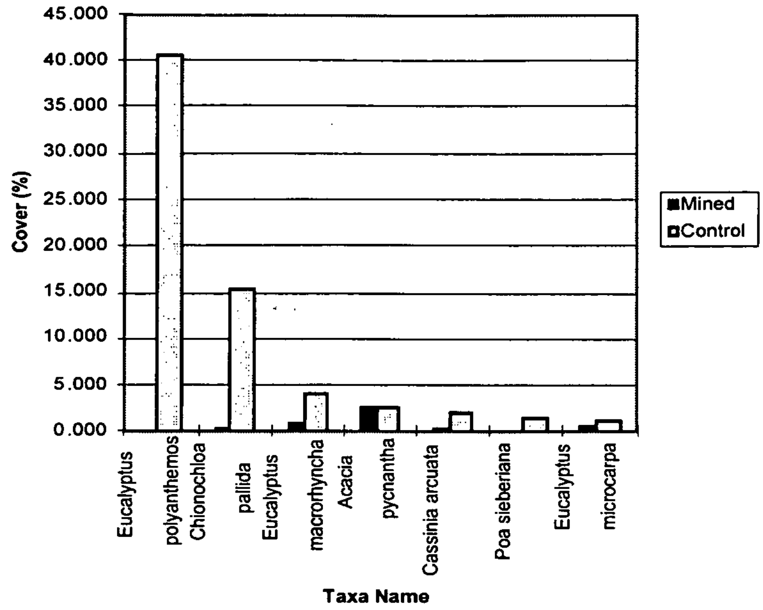
Figure 5.9: Site 4. Taxa which has a cover value greater than 0.1% in the mined area, and their cover in the control



5.2.2.10 Site 4: Control

Site 4, control (Figure 5.10) is dominated by a cover of *Eucalyptus polyanthemos* (40.37%), with a grassy ground layer of *Chionochloa pallida* (15.37%). *E. polyanthemos* was recorded as absent in the mined area, whilst *C. pallida* has a low cover value (0.27%). *Eucalyptus macrorhyncha* (4.0%) is also evident, with a much lower value in the mined area. *Acacia pycnantha* is as discussed above, whilst *Cassinia arcuata* (2.0%), *Poa sieberiana* (1.4%) and *Eucalyptus microcarpa* (1.2%) have low cover values. *Cassinia arcuata* has a much lower value in the mined area than the control.

Figure 5.10: Site 4. Taxa which has a cover value greater than 1% in the control, and their cover in the mined area



5.2.3 <u>Average Height and Cover of Stratum: Mined/Control Comparisons</u>

5.2.3.1 Site 1

Site 1 (Figures 5.11, 5.12), mined area shows a maturation of shrub species approximately meeting the average values of height (1.11m) and cover (5.32%) as in the control (1.13m and 6.20%). Ground cover species are far more prevalent in the mined area (2.16% as opposed to the control at 0.47%). The canopy cover of the control (7.26%) is in strong contrast to the lack of canopy cover in the mined area (0.37%), due mainly to the fact that canopy species were not sown in the mined area. However, those few canopy species recorded in the mined area were generally smaller than the understorey species, perhaps suggesting recent colonisation.

Figure 5.11: Stratum Height (cm) Site 1

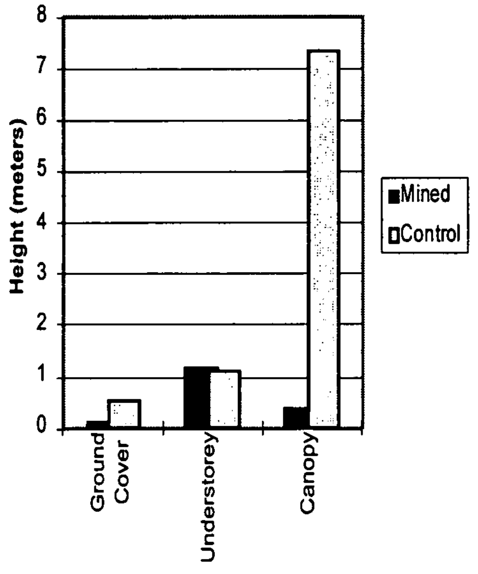


Figure 5.12: Stratum Cover (%) Site 1

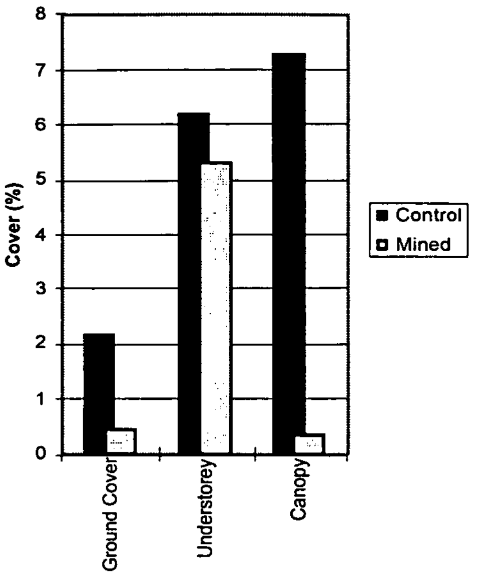


Figure 5.13: Stratum Height (cm) Site 2

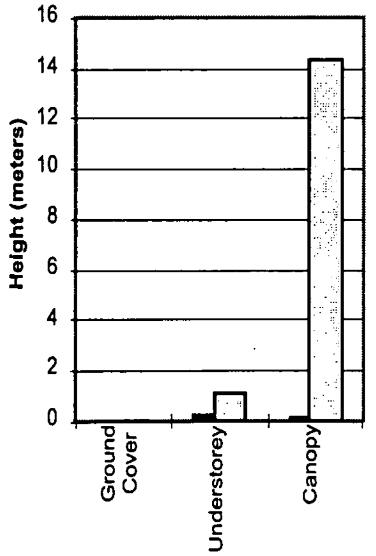
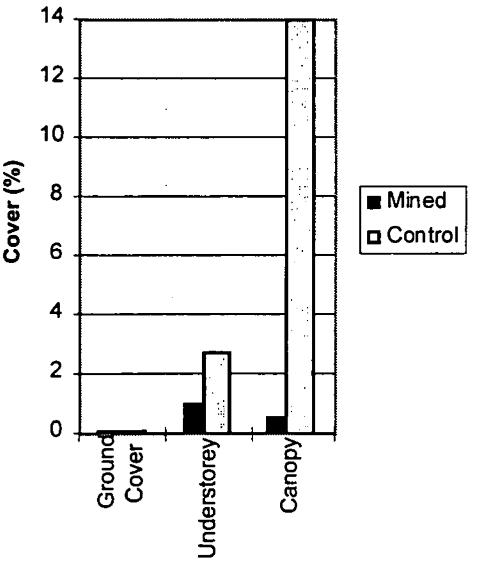


Figure 5.14: Stratum Cover (%) Site 2



5.2.3.2 Site 2

Site 2 (Figures 5.13, 5.14), mined area shows a low value of all stratum groups of species. There is some indication that understorey species are colonising the site faster than canopy species, as both average height (1.13 cm compared to 0.37 cm for canopy species) and cover (0.97% as opposed to 0.48% for canopy species) are greater. Ground stratum species provide less cover (0.02%) and are less tall (0.11 cm) than their control counterparts (0.10% and 0.51 cm), whilst canopy species have an average cover (13.93%) and height (7.33 m) value in the control, far in excess of their mined area counterparts (0.48% and 0.37 m respectively).

5.2.3.3 Site 2B

Site 2B (Figures 5.15, 5.16) mined area average cover values for understorey taxa are nearing those found in the control (1.1% as opposed to 1.3% in the control). Average height for understorey taxa is less in the mined area than the controls (0.41 m opposed to 1.11 m). Canopy taxa values are considerably less in the mined area than in the control for both height (0.66 m as opposed to 9.07 m) and cover (1.4% as opposed to 13.0%). Ground cover (0.1 as opposed to 0.16%) and height (0.16 m as opposed to 0.1 m in the control) is relatively similar to the control. Heights between understorey and canopy species in the mined area are relatively similar.

5.2.3.4 Site 3

Site 3 (Figures 5.17, 5.18) mined area, shows the development of ground cover (0.2% as opposed to 0.33%), understorey (2.7% for both areas) and canopy cover (8.9% compared to 12.0%) values to levels comparable to the control. Although canopy cover levels are lower than the control, this is partially a result of the sampling method and it can be expected that the canopy cover will increase as the average height of species (currently 2.6m) increases to that of the control (that of 21.7m). The failure of the averages to reflect the actual height of the canopy in the control is due to the recent recruitment of a number of *Allocasuarina muelleriana* saplings. Yet, even without this consideration, the development of three distinct strata as found in the control is evident in the site 3 mined area.

Figure 5.15: Stratum Height (cm) Site 2B

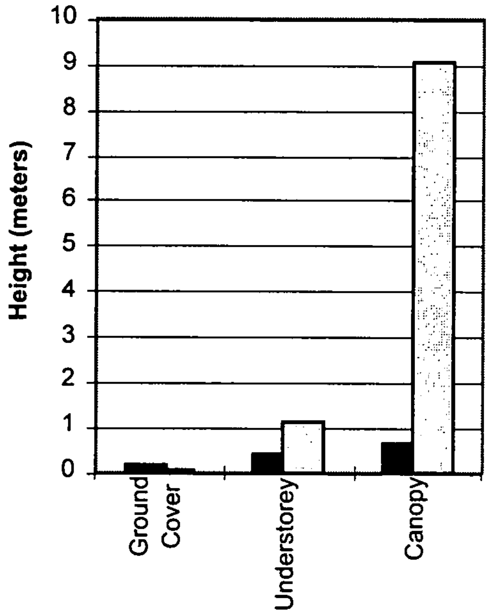


Figure 5.16: Stratum Cover (%) Site 2B

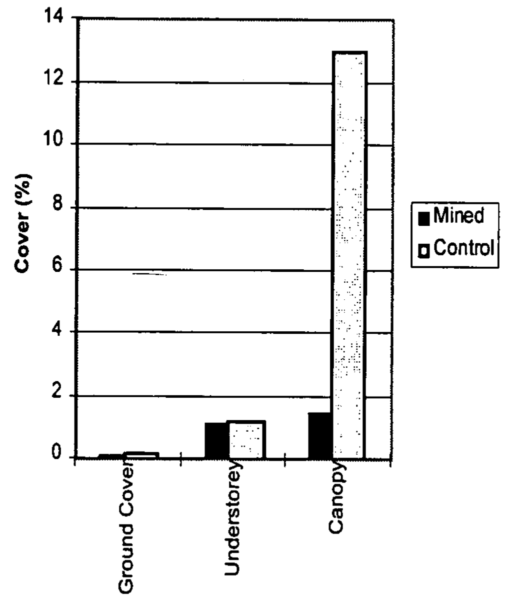


Figure 5.17: Stratum Height (cm) Site 3

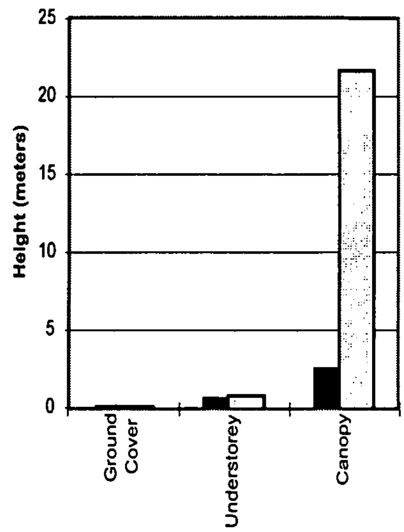


Figure 5.18: Stratum Cover (%) Site 3

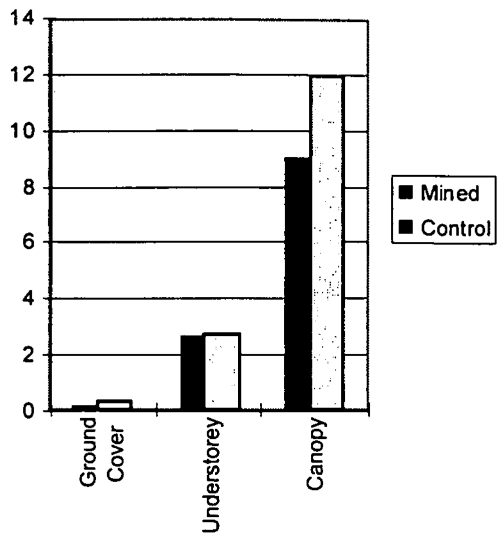


Figure 5.19: Stratum Height (cm) Site 4

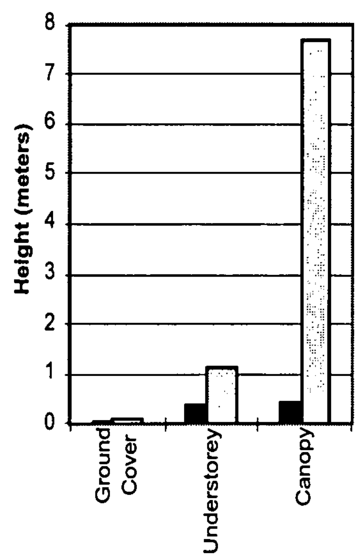
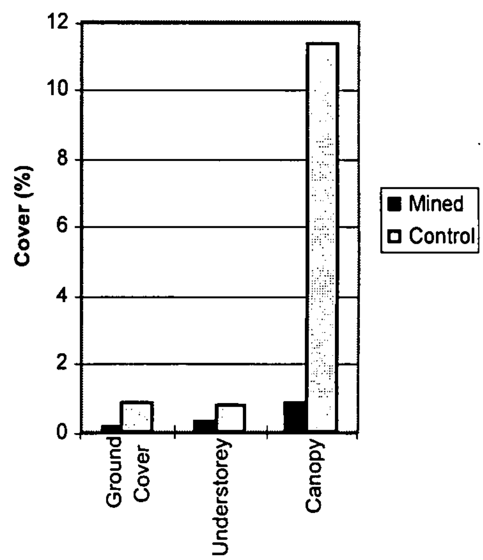


Figure 5.20: Stratum Cover (%) Site 4



5.2.3.5 Site 4

Site 4 (Figures 5.19, 5.20), average ground cover is 0.14% mined area compared to 0.85% in the control, understorey cover is 0.35% in the mined area compared to 0.81% in the control and canopy cover is 0.85% in the mined area compared to 11.38% to the control. Overall cover in the mined area is far below that of the control. As the site is very young, it would be expected that understorey values and ground cover values will quickly match those of the control, whereas canopy values will take a few more years.

5.3 Environmental Variables That Influence Community Composition

Table 5.12: Mean Values of Sample Environmental Variables by Site and Treatment

Site	*1*		*2*		*2B*		*3*		*4*		*Average*	
Mined/Control	*M*	*C*	*M*	*C*	*M*	*C*	*M*	*C*	*M*	*C*	*M*	*C*
A1 Depth (cm)	4.0	4.0	0.0	10.0	0.0	7.0	0.0	10.3	0.0	5.0	0.8	7.3
Bare Ground	65.8	3.2	91.6	3.8	82.1	1.4	64.8	2.4	95.6	1.4	80.0	2.4
Wood	0.0	0.0	0.7	5.1	1.1	4.3	0.9	0.8	0.1	0.7	0.6	2.2
Rock	6.7	1.5	0.7	0.4	3.6	0.2	0.3	0.0	3.6	0.0	3.0	0.4
Litter	43.5	99.5	7.7	75.3	13.9	93.8	33.8	96.9	0.4	96.0	19.9	92.3
H0 depth (cm)	0.0	4.0	0.0	3.8	0.0	1.9	2.3	4.5	0.0	1.2	0.5	3.1
Nitrogen	0.1	0.3	0.0	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2
Phosphorus	37.8	6.0	1.0	2.3	2.3	2.9	0.9	2.2	3.5	3.3	9.1	3.3
Soil Hue	8.0	6.0	7.0	6.0	6.0	5.0	5.8	6.0	6.0	6.0	6.6	5.8
Soil Value	6.0	5.0	6.0	5.0	6.0	5.0	6.0	5.0	6.0	5.0	6.0	5.0
Soil Chroma	3.0	4.0	4.0	4.0	4.0	3.0	4.0	3.0	4.0	3.0	3.8	3.4
Soil Texture	7.0	7.0	3.0	6.0	7.0	6.0	8.3	6.0	8.0	9.0	6.7	6.8
PH	8.6	7.5	6.9	5.6	5.9	5.8	6.7	6.8	5.8	5.5	6.8	6.2

5.4 Vector Fitting

Of the 16 environmental variables used in this study, 12 are significant in defining community composition. The most significant is pH with a maximum correlation value of 8.344 and a very high probability score. Slope, A1 depth, rock, litter, nitrogen, colour hue, value and chroma, phosphorus, and texture are all significantly correlated with community composition. Aspect is not significant. Wood is not significant due to the low values of coarse woody debris recorded for both the control and mined area.

Table 5.13: Maximum Correlation Values (Max.R) and Probability Scores for Vector Fits

Sample Variable	Max. R	Probability Score
A1 Depth	0.4176	0.000***
Wood	0.2792	0.160
Rock	0.4492	0.000***
Litter	0.6751	0.000***
H01&2 Depth	0.4218	0.010**
Nitrogen	0.5042	0.000***
Hue	0.5832	0.000***
Value	0.6354	0.000***
Chroma	0.4007	0.030*
Phosphorus	0.5605	0.000***
Texture	0.5358	0.000***
pH	0.8344	0.000***

Note: probability scores <0.05 are significant; * = probability score is significant, ** = highly significant, and *** = extremely significant.

By comparing Figure 5.21 and Figure 5.22 the significance between environmental variables and community composition is apparent. Treatment is a significant variable, with many other environmental variables being related to a site being a mined area or control. Sites with greater A1 depth, age and litter are controls. On the other hand, sites with greater bare ground, lightness in soil colour (chroma, value and hue) and alkalinity (mined areas are quite neutral, whereas the control sites are slightly more acidic) belong to the mined area.

Phosphorus and exposed rock cover are a significant environmental variable at Site 1, with Site 2B mined area being more rocky than its control. Soil texture is also significant with sites on the left of the graph, generally being more loamy than sites on the right side. High nitrogen also had a strong influence on a couple of samples in the top right quadrant, whilst Site 1 mined area samples generally had lower nitrogen than other sites.

Figure 5.22 shows the TWINSPAN vegetation communities in the GNMDS graph format. Interpreted in conjunction with the Vector fittings, some environmental variables that drive community composition are evident. A clear line of demarcation lies between the control (shaded symbols) and the mined areas (non-shaded symbols). The samples from Site 4 mined area occurring on the control side of this line show that this community is more closely related to its control than the other mined areas. Also the samples taken from site 2B mined areas are closely intermingled with the controls of site 2B showing the they have more in common with the controls than the other mined areas of the site. Interestingly, site 1 control and mined area are vastly separated, showing that site 1 control, has a lot more in common with the other controls (particularly the up-slope controls of site 2B and 4).

Another spatial separation on the graph shows sites found in the east of the study area (left side of the graph) and those of the west (right of the graph). Clearly, the locality of the sites relates to their position on the graph. This suggests different environments and vegetation comunities.

Figure 5.21: Vector fitting diagrams showing significant environmental variables for all sites

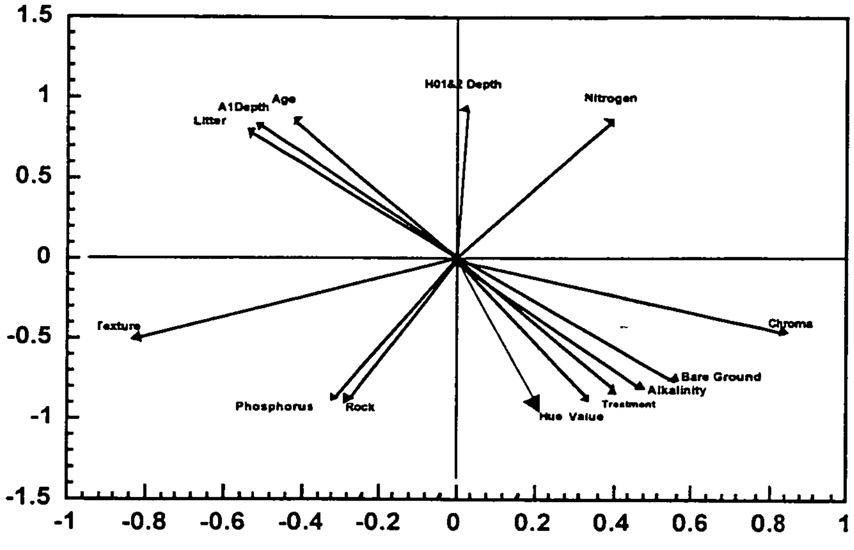
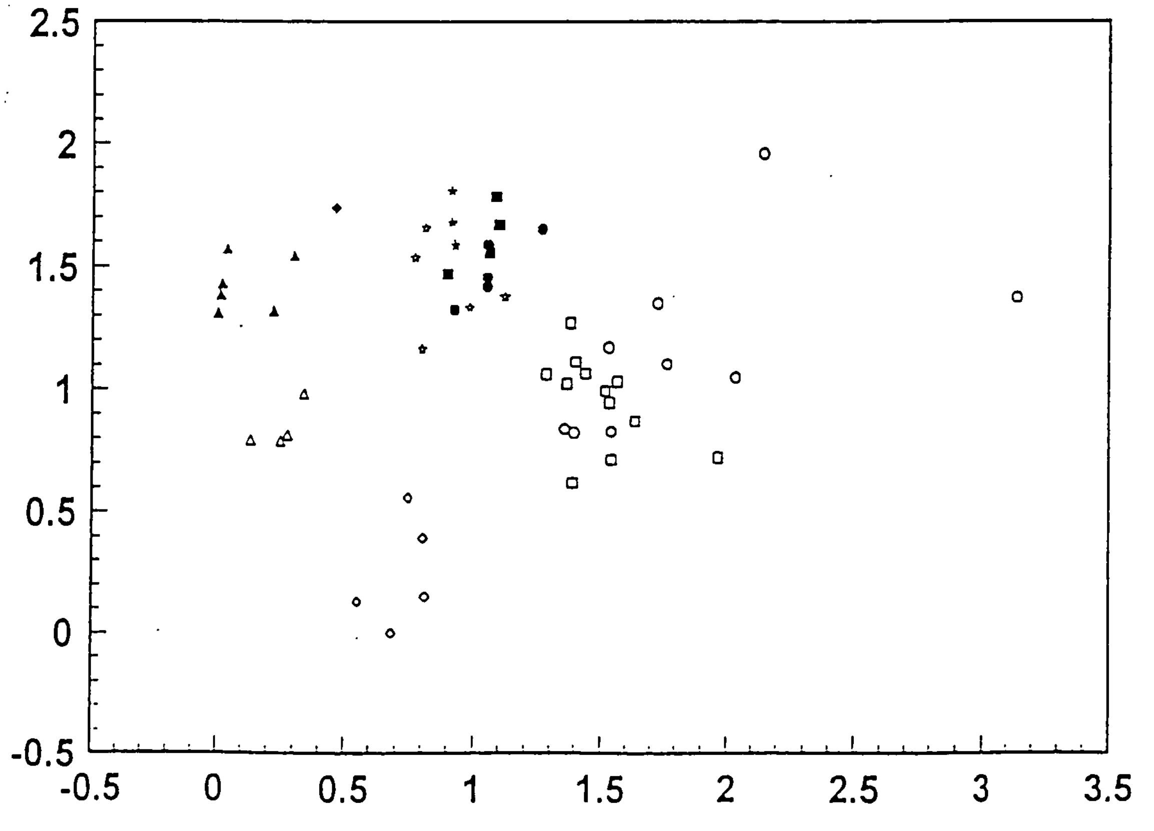


Figure 5.22: GNMDS Graph Illustrating The Spatial Difference Between Communities

Key: Triangle = Site 4, Star = Site 2B, Circle = Site 2, Square = Site 3, Diamond = Site 1. Shaded symbols = controls, non shaded symbols = mined areas.



Chapter 6: Discussion

6.1 Introduction

This chapter is divided into three sections. The first, and main part of this chapter considers the re-establishment of ecosystem structure and function in the mined areas studied. Ecosystem resilience is also discussed. The second part argues for the implementation of adequate monitoring techniques in mine site restoration of Box and Ironbark Forests. The final section is more prescriptive, making recommendations for restoration projects operating in the Box and Ironbark Forests.

6.2 The Success of Ecological Restoration

6.2.1 The Restoration of Ecosystem "Structure"

This study considered many of the 18 Vital Ecosystem Attributes (VEA) as identified by Aronson *et al.* (1993). Although this study has been limited to some of the easier VEAS to measure, their interelatedness allows for comment on ones that were not measured (Aronson *et al.* 1993).

The early establishment of *Eucalyptus* and *Acacia* species is evident in all mined areas, except Site 1 where no Eucalyptus species were sown. Most sites display fast growth in low competition conditions at an early age. Sites 2 and 4, due to very recent treatment, show this pulse in early growth with many understorey species, such as the *Acacia* spp., and *Cassinia arcuata* and in some cases *Melaleuca* spp., as early colonisers of succession. The results of this study suggest that in early years these species grow more quickly than canopy species, and dominate cover.

This pattern of strong recovery in height and cover of the understorey layer is consistent with the findings of other studies in similar forest environments. For instance, the long term study by Fox *et al.* (1996). This study found that on mined sites, where understorey height values grew rapidly in the first five years, and then changed little in the following 12 years following disturbance. The early establishment of *Acacia* species has also been noted in restoration studies in sclerophyll ecosystems in Tasmania (Storey 1990), and in Western Australia (Koch *et al.* 1996).

Interestingly, *Cassinia arcuata* is not directly seeded but rather seems to be present in the soil seed bank or able to migrate quickly from adjoining forest. Without direct seeding, recolonisation of Eucalyptus species would be a much slower process. While dispersal is aided by wind, Eucalyptus seeds seem to be unable to travel long distances by air currents (McDonald 1996). The centre of any mined area visted was never more than 150 m from mature trees. Eucalyptus seeds possess no eliasomes to aid seed dispersal by ants but ants may still play a part in seed dispersal. An eliasome is a small appendage on a seed which is favoured as a food source by ants. It entices ants to transport the seed from its original resting place, eat the eliasome and dispose the seed in a new location. Seed dispersal by ants is called *myrmecochory*. The seed of *Acacia pycnantha* does have an eliasome along with many other forest understorey species. Although the importance of myrmecochory for seed dispersal has been doubted by some (Auld 1987; Drake 1981), other studies have showed that ants successfully aided the dispersion of native plants (Smith 1989; Ireland and Andrew 1995; Mossop 1989). A recent study suggests that myrmecochory may be less effective on mine sites and warrants further investigation (Anderson & Morrison 1998).

In older mined areas, understorey species have matured, allowing any longer-lived and slower-growing Eucalyptus and other canopy species to grow above their understorey neighbours and start to dominate cover. This is evident in the average height and cover values recorded for the mined areas at Site 2B and 3. From this pattern it is possible to discern a directional succession in which the Eucalyptus species will attain final dominance (Heddle 1986). Thus, as far as ecosystem structure is concerned, the restored sites (excepting Site 1) are likely to strongly resemble the original forest in the future. This process has been greatly speeded by the restoration effort due to direct seeding of key species, as has been seen from site 1, where no Eucalyptus species were sown. Within 5 years of restoration at sites 3 and 2B, signs of a return to something like the original structure seems evident.

The mined area of Site 1, on the other hand, will have to rely on canopy species' natural dispersion, as none were sown. A low average cover and height value for canopy species recorded is reflective of a few individual Eucalyptus plants having recently established themselves in the mined area.

Although the pattern seems to suggest one of a succession from an *Acacia*/*Cassinia* shrubland to a Eucalyptus forest, a notable exception is to be found in some mined areas of Site 3 and 1, where a *Melaleuca* shrubland dominates. At Site 1, this shrubland follows the creekline, whereas at Site 3 *Melaleuca* thickets are scattered. A visit to Site 3 following rain revealed that this vegetation growth is related to water inundation. Although it can be expected that the general development of a Box and Ironbark Forest on the mined site will ensure the establishment of similar species in these thickets, their occurrence is an interesting. They share strong similarities to the "Broombush" communities found in the drier areas to the north of the study area.

6.2.2 The Restoration of Ecosystem "Richness"

The above discussion on canopy cover is dominated by two genera, namely the *Acacia* and *Eucalyptus*. This is indicative of the fact that most of the species in the Box and Ironbark Ecosystem occur at the ground or low shrub (<1 m) level. The number of indigenous taxa recorded at each site's mined area and control clearly suggests that mining in the Box and Ironbark Ecosystem has reduced indigenous species richness despite the mitigatory effect of restoration. Mining has been found to reduce overall species richness in scleophyll ecosystems elsewhere (Bell *et al.* 1990; Storey 1990).

When both indigenous and exotic species are considered, species richness was greater in the control than its associated mined area, except at Site 1. In Site 1, even though more species were recorded in the mined area, around 40% were exotic, whilst only 1 exotic species (*Briza maxima*) was found in the control area. Also, undersampling in the Site 1 control would explain fewer species being recorded there. In contrast with Site 1, Site 2B is the most species rich site (62 species in total), of which only 5 are exotic. The mined area has a high degree of similarity with its control.

As the forest structure matures in the mined area, there is a general fall in the cover (relative to that of the canopy) of understorey species that dominated during primary succession. This is due in part to the suppression by a *Eucalyptus* canopy. The increase in organic content of the soils may favour the reintroduction and establishment of a number of species which are absent from the mined site during early periods of regeneration (*Astroloma conestephoides*, *Astroloma humifusum*, *Brachyloma daphnoides* to name three).

It is hard to infer how long such species will require to colonise the mined areas without any anthropogenic assistance. Some areas extensively mined in the 1850s do contain these species. However, mining in the 1850s used completely different technologies and techniques. The disturbance would have been very spatially patchy and of differing intensity when compared to the uniform impact of a clearly defined area by the mining practices of today. On this point alone, it is impossible to conclude that ecosystem recovery will follow the same trajectory as the disturbance of the 1850s.

Species with cryptic dormancy-release codes, such as some of the Epacridaceae family are evident in older stands of forest but absent from the mined areas. For example, *Astroloma conostephioides* shows no recovery in mined areas, whilst it is quite abundant in the control. *Astroloma humifusum* shows very little recovery as yet in the mined areas whilst being rather common in all controls except at Site 1.

Many geophytes have shown little or no potential for early colonisation, despite their inevitable reintroduction within the application of top soil. Glossop (1981) also noted the absence of several *Lomandra* spp., following bauxite mining and the respreading of top soil in the in south west Western Australia. *Dianella revoluta* was absent from most of the mined areas whilst being fairly common in the control. Orchids were not observed in the mined areas. In Western Australia, species of the Orchidaceae appeared in the 5-10 year period following mining (Bell *et al.* 1993). It appears that in the Western Australian studies that their germination may be influenced by the development of 'appropriate vesicular arbuscular or ectotrophic mycorrhizal fungi' (Bell *et al.* 1993). Saprophytic orchids (those dependent on decaying organic matter) and those orchids that seem not to regenerate from seed seem to be most at risk from soil disturbances.

Although many species were reduced in number or eliminated by mining, some locally indigenous flora have benefited from introduction by the restorationist. Notable examples include the introduction of *Melaleuca wilsonii* at Site 2, 2B and 3, *Allocasuarina muelleriana* at Site 3, and a number of species at Site 4. The introduction of *Eucalyptus camaldulensis* at Site 1, mined area, is almost certainly an accident (Sprague 1997). On the other hand, some indigenous species were present in the mined area whilst not being recorded in the control area, although they were not included in the seed mix. *Astroloma humifusum* and *Danthonia setacea* at Site 1, are two examples. It can be assumed that these species did occur in the control but failed to be recorded as the area was under sampled. A specimen of *Danthonia duttoniana* was found at Site 1, mined area. Other species which occured in the control areas, flourished after mining. These were mostly members of the Mimoaceae and Asteraceae families.

6.2.3 The Litter Layer and the Restoration of Ecosystem "Function"

Although species richness is one indicator of ecosystem function, abiotic factors which were sampled in this study infer the development of functions such as nutrient cycling, hydrological cycles and soil development.

The results of this study show that older mined sites have a greater litter cover than more recently mined areas, although even the older mined areas fail to match the litter cover of their control. Furthermore, the litter in the control areas consists of a layer of undecomposed organic debris overlaying a clearly defined layer of decomposed organic debris. In mined areas this decomposed layer is absent or weak, with the undecomposed layer directly overlaying a mineral soil.

The development of a litter layer is important for several reasons. Firstly, litter cover is important for soil protection and hydrological flows. On bare ground, rain drops increase soil compaction which in turn is related to soil erosion (Rosewell *et al.* 1994). Some rill and sheet erosion is evident on all mined sites, with post mining alluvium being deposited in down-slope gullies or in saucer-shaped depressions within the mined area. In areas with highly developed litter layers and little bare ground, surface runoff is greatly decreased (even eliminated). Instead, water is able to be held within the soil for longer periods of time and be utilised by plants. Rain water also brings nutrients to the soil and moves nutrients down the soil profile, which again is an important function in an ecosystem. In summary, litter layer development promotes water and nutrient storage in the ecosystem, whilst mitigating erosion.

Secondly, the development of a litter layer is important for the return of micro and mesofauna who live therein. These animals, particularly the micro-organisms constitute an essential link in the ecosystem nutrient cycling through the decomposition of organic matter and the subsequent release of nitrogen. Mesofauna on the other hand, are important for seed dispersal, plant protection from predators, plant pollination and as a food source for other fauna in the ecosystem.

Data collected from sites concerning top soil conditions following mining are in keeping with the above observations. Mineral soils in the mined areas are often slightly lighter in colour, have consistently less nitrogen, and generally less phosphorus (excepting Site 1, where extremely high readings of phosphorus could be attributed to the application of fertilizers) than control areas. The pH data suggest that control areas are slightly more acidic, or less alkaline in some cases than the mined areas. Soil texture is quite similar between mined and control areas. The results suggest that mining has reduced the fertility of the soil, although this is to be expected from the loss of organic matter and the mixing of top soil with less fertile sub-soils during the mining process. According to one hypothesis of Aronson *et al.*, (1993), a decrease in an ecosystem's ability to efficiently use water and nitrogen is a sign of ecosystem degradation.

Studies conducted in Western Australian bauxite mines suggest that nitrogen levels are sustainable over the longer term in mined areas, due to the early establishment of *Acacia* species which greatly enhance the nitrogen cycling through the quick development of a litter layer high in nitrogen (Ward *et al.* 1991; Ward & Koch 1996). Given the high cover values of *Acacia* species at all mined areas, a similar outcome might be expected in the Box and Ironbark Ecosystem.

6.2.4 Examples of Ecosystem "Resilience"

Considerable attention was given to the ecological concepts behind ecosystem resilience in the literature review (Chapter 2). From this conceptual framework, an explanation for some of the recovery patterns of the different sites can be provided here.

Even though the sites studied were all treated with similar restoration methods, the results are clearly quite variable. For instance, why does the mined area in Site 1, have a much higher weed cover and diversity to all other sites and why is there such a strong difference in the success of Site 2B mined area compared to its ecologically similar site 2 and 3 mined counterparts?

As has been maintained throughout this work, the current Box and Ironbark ecosystem is both a result of natural factors and human induced pressures, many of which have resulted from the 1850s gold rush, which directly or inadvertently lead to the degradation of the Box and Ironbark ecosystem.

Using the terms of Westman (1978) to discuss resilience of Site 1 mined area; the limits from which this ecosystem will return (amplitude) to a stable state with a low degree of malleability have been exceeded. In such a case the elasticity following disturbance has been slow due to previous degradation, and in fact has been further halted by the damping effect of further stress (like rubbish dumping and weed invasion). These stresses have pushed the area over an ecosystem threshold, as defined by Hobbs and Norton (1996). An alternative state has resulted which favours the introduction of exotic species. The application of phosphorus at some time in the site's history has greatly assisted the change from a native to an exotic ecosystem. Thus, although the restoration effort has managed to restore some aspects of the original ecosystem, it has not managed to pass back across the many thresholds to an ecosystem that is largely indigenous. This case, lends particular support to two hypotheses of Aronson *et al.* (1993):

- Beyond one or more thresholds of irreversibility, ecosystem degradation is irreversible without structual interventions combined with revised management techniques.

- Without large-scale intervention, restoration will proceed only as far as the next highest threshold in the process of vegetation change or succession.

Site 2 and 3 were also degraded sites before mining, but had kept their indigenous integrity (unlike Site 1). Having not passed an ecosystem threshold these sites are displaying an ability to return to a state that shares similarities to the original, however malleable. It also has to be noted that the stress that has caused ecosystem degradation in these sites differs considerably from Site 1. Two significant stress periods (1850s and 1990s gold mining) would have been conducted over fairly short periods when compared to the damping faced by Site 1. This suggests that the elasticity of these ecosystems following disturbance is fairly high, because there is a considerable degree of inertia in the recovering ecosystem. In more simple terms, if the sites have faced a history of short bursts of intense impact, followed by long periods of little impact, than it would follow that the mined areas are able to recover quickly to a similar ecosystem that was present before the impact. This can be explained through examples, such as the presence of a viable seed bank of indigenous flora, the ability for the nutrient system to recover quickly, and the fast establishment of a ground cover to protect soils. Again, these thoughts compare favourably with one hypothesis posed by Aronson *et al.* (1993):

- The more thresholds passed, the more time and energy will be required for an ecosystem's restoration or rehabilitation.

Site 2B on the other hand, was apparently in a much less disturbed state than Site 2 and 3 which are in gully lines where the impacts of the 1850s gold rush was focused (Sprague 1997). Perhaps the lack of stress has meant that the area has been able to maintain a relatively high species richness and soil fertility both in the mined and control site. The mined area at Site 4 is still quite young and has yet to display ecosystem attributes worthy of note. These thoughts concur with another hypothesis posed by Aronson *et al.* (1993):

- The rate of recovery in restoration or rehabilitation pathways is inversely related to the structual and functional complexity of the ecosystem of reference.

This discussion of resilience, has to this point only considered the in-situ resilience of each site (excepting Eucalypts). It would also be beneficial to briefly comment on how migratory resilience is also an important influence for restoration success. In many cases, the restorationist relies on the reintroduction of many elements of an ecosystem via these means. Indeed, the input of micro and mesofauna which is instrumental in restoring ecosystem function (as discussed in the preceding section) rely on there being intact ecosystems from which these animals can migrate.

If species are not reintroduced the long term enhancement of floristic diversity is dependent upon there being areas from which plants can migrate. As an example, McDonald (1996) notes that members of the Epacridaceae family may be dispersed by birds, and may therefore show a far higher degree of migratory resilience. Indeed, Storey's (1990) work showed that some species are able to colonise a mined area from fringe vegetation.

In summary, the longer that the reinstatement of important ecosystem functions and species is delayed, the more malleable the community will be. In all the sites studied in this project, the history of the area has largely influenced the restoration outcome. Where the stress on an ecosystem has continued for many years, and the restoration process is hampered by continued stress, restoration has been more difficult. Mine site restoration generally is able to utilise an ecosystem's resilience whereas restoration of other areas (the rice fields of the Riverina, for example) would be considerably more difficult. Not only is the insitu resilience of an ecosystem important, but also the ability for migratory resilience. Bush land surrounding mined sites is an important asset for restoration success.

6.2.5 Does Restoration Favour Resilient Species?

An ecosystem in primary succession (that is, plants colonising bare ground such as a mine site) is open to new species and species fluctuations. Such species might include rare plants or fluctuations of species suppressed in the older forest structure, or alternatively the introduction of new exotic plants and the loss of otherwise common plants.

Many indigenous species are well adapted to disturbance. In this ecosystem such species include members of the Acacia and Eucalyptus genera and the Asteraceae family. The loss of less resilient species, such as geophytes, is of concern to the restorationist if the goals of the project are to restore a similar species diversity compared to the control. The choice of species for restoration work often tend to favour species that grow quickly in post-mining conditions and whose seeds are easy to collect. The result is a general weighing towards resilient species, with less resilient species having to rely on unassisted regeneration methods.

The careful reintroduction of less-resilient species along with the usual assisted-regeneration techniques may help to rectify this matter (McDonald 1996). Yet, such labour intensive work is expensive, and not always appreciated by those who pay. Also, the seed ecology of many species is not fully understood and time needs to be spent researching nursery techniques and developing "seed banks" for some species before they can be reintroduced.

6.2.6 Does Ecosystem Disturbance Allow for the Introduction of Exotic Species?

Through consideration of the results of the presence/absence of species in mined compared to controls, one can conclude that mining does allow for the introduction of new species, most of which are exotic. However, it should be noted that although the potential is available for exotic introductions, it depends largely upon the migratory ability of the exotic species. This in turn, depends upon the indigenous integrity of the ecosystem surrounding the mined area. Site 1 and 4, which are both close to towns have weeds that are garden and rural species such as *Cortaderia selloana, Phalaris sp.*, and *Paspalum dilatatum*. Some of these weeds pose serious threats to the success of the restoration project. The other sites, on the other hand, have weeds which are generally also found in the surrounding bushland, such as *Briza maxima*, *Vulpia* sp., and *Aira cupaniana* .

6.3 The Need for Restoration Goals and Objectives

It is extremely important that before any restoration work begins, project goal(s) and criteria of success are defined (Chapman and Underwood 1997; Underwood 1996; Cairns 1993). Early and on-going monitoring to evaluate success should be implemented to guide follow-up restoration work (such as on-going weed control and species introduction). Without these measures there is nothing to inform the restorationist if a desired end-point has been reached. Subsequently, restoration work might end prematurely; as the job is considered complete when in fact it is not - or alternatively, restoration work may continue unnecessarily at an additional cost to the restorationist (Underwood 1996).

6.3.1 Current Practices of Evaluating restoration Succeess in the Box and Ironbark Ecosystem: More Suitable Measures are Needed!

Current evaluation work being carried out following mining is inadequate for directing restoration and deciding if success has been achieved. Hitherto, the only empirical studies to measure success have been carried out by the Victorian Government's department responsible for land management. Neither the mining companies nor the restorationist has carried out any empirical evaluation, although the restorationist does make non-scientific evaluations from frequent site visits.

The Victorian Department for Natural Resources and the Environment (NRE, formally DCNR) has set out general requirements for the "rehabilitation" [sic] of mining sites in the Bendigo Forest Management Area (DCNR 1994). Unfortunately, these requirements lack appropriate measures for the success of restoration work. The department carries out a survey 12 months after sowing of native flora (1kg of overstorey, 1kg understorey species per hectare) and judges success by (1) a "stocking rate" and (2) presence of a receptive seed bed, and (3) retained trees. A restoration effort is considered to be successful if (1) at least one seedling (with a minimum of four leaves) is present within 2268 mm of the radius of a plot centre in over 70% of samples, and (2) the results are above a minimum expectable level in a similar survey for receptive seed bed and retained trees.

Although such a survey may demonstrate that an indigenous community is returning to the site, and thus indicate some degree of success (McDonald 1996), it does not necessarily indicate this, and leaves much unanswered. For instance, the restoration work is considered successful without considering exotic species invasion, indigenous species diversity and abundance (amongst other criteria). In practice, the restored site may be considered successful if only one native species has grown back in abundance (perhaps it was not even in the seed mix but an indigenous ruderal), or a number of exotics have colonised the area. Chapman and Underwood (1997) warn that this kind of survey may not be indicative of success (and that a reference community is of great assitance):

> Often statistical tests are performed to determine whether measurements (for example, of cover of salt marsh plants) are greater than those before restoration started. If values are greater, this is taken to mean that recovery has occurred. In fact, all this has shown is that values have increased.

In conclusion, restoration projects needs to be more than a one-off treatment. On-going monitoring, ecological research and maintenance will increase restoration success. Well defined goals and objectives need to be stated at the outset of the project so that it is clear to all stakeholders exactly what the restoration project aims to achieve. The value of environmental monitoring is to inform the restorationist if those goals have been achieved.

6.4 Recommendations for Future Restoration of Mined Areas in the Box and Ironbark Ecosystem

- Identify achievable goals and objectives for restoration projects before work begins. These should clearly relate to the restoration project aims.
- Evaluate success of all new projects through vegetation surveys. Consider the implementation of other indicators of success, such as invertebrate sampling.
- Develop techniques for the reintroduction of less resilient species.
- Research ways of promoting the fast development of ground cover.

Chapter 7: Conclusion and Future Research

7.1 Conclusion

The overall aim of this study was to evaluate the success of restoration following gold mining in the Box and Ironbark Forests of Northern Victora. The development of appropriate measures of "success" in restoration work in this forest type has never before been attempted, although many restoration projects have been undertaken.

The literature review began by considering "restoration" as an appropriate term to describe work carried out on mine sites, and discussed briefly why mining companies undertake restoration work. Having done this, the review then focused upon using undamaged reference communities as a control area to measure success, and some of the arguments against the use of a control. Through the proceeding chapters, it was shown that the use of a control is a valid measure of success, and produces meaningful information for the restoration ecologist. By comparing the mined area to a control, it was able to be shown that:

- mining reduces species richness despite the mitigatory action of restoration work;
- favours species that are more resilient;
- impacts considerably upon geophytes and the Epacridaceae genera;
- reduces soil fertility, particularly nitrogen;
- offers the potential for weed invasions; and,
- creates bare ground areas.

The second part of the literature review considered the concept of ecosystem *resilience*. In the discussion, the results of this study were interpreted in terms of this concept and the following suppositions were made:

- ecosystem resilience is a major factor influencing restoration success;
- short but intense impacts, such as gold mining, have resulted in the ecosystem returning to a state that is similar the indigenous communities;
- continued damping of resilience increases the malleability of an ecosystem, and increases the likelihood of a alternate state being achieved;
- migratory resilience as well as in-situ resilience of indigenous ecosystems is an important asset for the restorationist, yet the migratory resilience of exotic ecosystems can hamper restoration.

There exists much potential for the development of restoration techniques to improve upon current results. Some of these were briefly explored, and it was proposed that developing methods for the restoration of less resilient species is very important. Without anthropogenic assistance, these species may take years, or perhaps never return to mined areas. Even with assistance, the success of the reintroduction of these species is not known. Another much needed area of development and research was shown to be the quick and careful return of the top soil and litter cover. Less mixing of soil horizons and the quick return of coarse woody debris and litter may reduce erosion and increase microorganism activity and soil fertility.

The identification of goals and objectives in restoration projects, along with designing and implementing a monitoring program can be relatively simple and very useful additions to any restoration project. Yet, in the cases researched by this project, where restoration is required as a matter of course, what is to be achieved should definitely be stated from the outset. The government department responsible for the management of that land should also be very clear on what they expect from a restoration project. It is the opinion of the researcher that the current goals and monitoring methods used by the government department responsible are inadequate, for the following reason. Only a "stocking rate" is used as a measure of success, which fails to inform what level of similarity (species composition, soil fertility, structure) exists between a restored site and its former state.

To achieve improvements in restoration techniques, considerably more research would be required this research would be an expensive exercise. Yet, the improvements would be well worth the effort as mining companies have found in Western Australia. Their research work has not only greatly assisted the restoration projects there, but also provided a wealth of information that can be applied to projects operating in sclerophyll forests Australia-wide.

However, the challenge that confronts the ultimate success of restoration ecology, is not just to develop appropriate techniques and knowledge specific to the Box and Ironbark Ecosystem. Rather, the main challenge is for ecologists to convince planners, mining companies and the general community that the preservation and restoration of the Box and Ironbark Forests is a worthwhile pursuit. In a society where conservation is directed towards areas that are considered to be the most "natural", gaining interest in small and degraded areas of productive public land can indeed be difficult.

7.1.2 Future Research Directions

7.1.2.1 Before-After-Control-Impact-Pairs (BACIP) Design for Future Ecological Monitoring

The ideal control site for future studies could be the actual impacted site prior to mining, as has been used in aquatic studies (Humphrey *et al.* 1995; Faith *et al.* 1995). Such an opportunity was not an option in this case as the study began post-mining. Yet, the advantages would be that the restoration of the area would be directed by the former ecosystem. Introducing a BACIP approach would be most useful for research outcomes and evaluation of success. One criticism would be that only a static control for comparison would exist, thus not accounting for long term changes in the forest ecosystem. This could be overcome by having mutiple control sites, one of which was the site prior to mining, or a set of parameters, determined by the variation in the community as a whole, limiting acceptable differences (most differences would relate to successional floristics and structure which could be accomodated in a notional reference model).

7.1.2.2 Establishing Cover

Faster ways of establishing cover in mined areas may reduce erosion and improve fertility. The collection and re-application of litter and top soils seperately (currently they are collected and re-applied simultaneously) along with the development of techniques to more carefully remove top soils (so they do not get mixed with sub-soils) may have positive results for restoration. The belated application of a litter layer after the immergence of *Acacia* and *Eucalyptus* genera, may allow for the reintroduction of less resilient species, either via the soil seed bank or anthropogenically. Also, *Danthonia setecea* was noted as being one grass species that particularly grew well in mined areas. Perhaps, this species could be grown as a mulching crop to provide a quicker ground cover.

7.1.2.3 Research into ecological indicators of success

Restoration monitoring can be more informative if it considers other life forms and ecosystem functions. Seed bank experiments have been used as measures of success in mine site restoration in the Darling Ranges, Western Australia (Bell *et al.* 1990; Koch *et al.* 1996). Information resulting from seed bank studies may help indicate ecosystem resilience, and offer the potential for new restoration techniques. In addition to seed bank studies, Majer *et al.* (1984) has considered ants as a measure of success in the above mine sites, whilst Anderson and Sparling (1997) and Jansen (1997) have also done some work on ants as indicators of successful restoration. Often studies have been carried out in conjunction with vegetation studies (Fox *et al.* 1982; Jackson & Fox 1996). Similar studies would be complementary to on-going vegetation monitoring of mined areas in the Box and Ironbark Forests.

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Appendix 1: List of Species

Acacia acinacea
Acacia aspera
Acacia ausfeldii
Acacia calamifolia
Acacia genistifolia
Acacia gunnii
Acacia mearnsii
Acacia montana
Acacia paradoxa
Acacia pycnantha
Acacia retinodes
Aira cupaniana
Allocasuarina leuhmannii
Allocasuarina muelleriana
Arthropodium strictum
Astroloma conostephioides
Astroloma humifusum
Astroloma pinifolium
Avena fatua
Brachyloma daphnoides
Brachyscome multifida
Bracteantha viscosa
Briza maxima
Brunonia australis
Bursaria spinosa
Caladenia caerulea
Caladenia carnea
Calotis hispidula
Calytrix tetragona
Cassinia arcuata
Cassytha melantha
Centaurium tenuiflorum
Cheilanthes austrotenuifolia
Cheiranthera cyanea
Chionochloa pallida
Cortaderia selloana
Cotula bipinnata
Cynodon dactylon
Danthonia caespitosa
Danthonia duttoniana
Danthonia eriantha
Danthonia pilosa
Danthonia procera
Danthonia racemosa var. racemosa
Danthonia setacea
Daviesia leptophylla
Daviesia ulicifolia
Dianella revoluta
Dichelachne micrantha
Dillwynia sericea
Drosea peltata
Einadia hastata
Einadia nutans
Elymus scabrus
Eriostemon verrucosus
Eucalyptus camaldulensis
Eucalyptus leucoxylon
Eucalyptus macrorhyncha
Eucalyptus melliodora
Eucalyptus microcarpa
Eucalyptus polyanthemos
Eucalyptus tricarpa
Exocarpos cupressiformis
Glossodia major
Gonocarpus elatus
Gonocarpus tetragynus
Goodenia blackiana
Grevillea alpina
Hakea sericea
Hardenbergia violacea
Hibbertia exutiacies
Hibbertia sericea
Hypochoeris radicata
Inula graveolens
Juncus acutus
Juncus holoschoenus
Juncus remotiflorus
Juncus subsecundus
Lepidosperma laterale
Leptomeria aphylla
Leptorhynchos squamatus
Lolium spp.
Lomandra filiformis
Lomandra multiflora
Melaleuca decussata
Melaleuca wilsonii
Microseris lanceolata
Olearia teretifolia
Ozothamnus obcordatus
Paspalum dilatatum
Pelargonium rodneyanum
Phalaris spp.
Pimelea linifolia
Plantago coronopus
Plantago lanceolata
Poa labillardieri
Poa sieberiana
Polygonum aviculare
Ptilotus spathulatus
Pultenaea largiflorens
Senecio spp..
Solarium elaegnifolium
Stipa mollis
Stipa rudis
Stipa scabra group
Thelymitra spp.
Themeda triandra
Thysanotus patersonii
Trifolium spp.
Veronica plebeia
Vulpia spp.
Wurmbea dioica

Appendix 2: TWINSPAN Table for Vegetation Analysis

Species   Sample No

```
4444455555 22222222111234444413333334 2333 11111 1
512345678912403612734568789001243671345909926882401573

---1-1---------------------------1--------------------   1111
-11-1----------------------------1------------------1-   1111
11111----------1--------------------------------------   11101
1111--------------------------------------------------   111001
---1--------------------------------------------------   111000
---11-------------------------------------------------   111000
---1--------------------------------------------------   111000
--1---------------------------------------------------   111000
-1111-------------------------------------------------   111000
-1-1--------------------------------------------------   111000
1---1111-1111--1----11-1------------------------------   110111
----1---1-----1---------------------------------------   110110
---1---------1----------------------------------------   110110
---1--1-----------------------------------------------   110110
-1-11-11----------------------------------------------   110110
--11--1-1---------------------------------------------   110110
---------11-------------------------------------------   110101
---------1--------------------------------------------   110101
-1-------1-11111--------------------------------------   110101
------1111-1111---------------------------------------   110101
---------------1--------------------------------------   110101
------111111111------1--------------------------------   110101
---------------1--------------------------------------   110101
---------------1--------------------------------------   110101
---------------1--------------------------------------   110101
-------1----------------------------------------------   110100
-----111111-------------------------------------------   110100
-----11-----------------------------------------------   110100
--------1---------------------------------------------   110100
-----1-11---------------------------------------------   110100
-----1111---------------------------------------------   110100
-----1111---------------------------------------------   110100
-------1-----11--1----------1-------1-----------------   1100
-----1-11-----1-------11-1----------------------------   1100
-----1111-------1---1-1-------------------------------   1100
111111111111111111111111-1111---1--111111-1111-11-1--1   101
-111--11--11111----1----1----1-11----11---------------   1001
-----11111111111111111111111111111--------------------   10001
-----1---11----1-1---1-----1-111----------------------   10001
-------------111-1-11-1-------------------------------   10001
---------11-1--------1-1---1----11--------------------   10001
---------------1-1------------------------------------   10000
---------1--1---1-1-----------------------------------   10000
--------------1---------1-----------------------------   10000
-----1-------------1-------------1--------------------   0111
---------11111--11111111-1-1--------------------------   0111
---------------111--1---------------------------------   0111
1--------------1-1-11----111---------------1----------   01101
---------111111--11-111-111--11111--------------------   01101
1---------1--111-111-1111111-11111--------------------   01101
-----1---1111111111-11111-11-11111---1----------------   01100
-------------11----------111---1------------------1---   01100
1--1--------------1------1-------1----------------11--   0101
1111111111111111111111--111-1111111111111-1111-1111111   0101
11-11--1--------1-1-111---1-------11111-1----1--1-----   0101
11--111-1-------1--11-111111-1111--1-11----1-------1-1   01001
1111-1-11-1-----111111111111111-11-111111-1111-11-1---   01001
-----11111-----1111111111111-11-11-------------11--111   01001
111------------11111-11-1111-1---1---------1---11-11--   01001
11-1-----------1-111111--------------11---------------   01000
-1----1------1-1---11111-1-11-1111111111-1-1----1---11   0011
-----1-11----1-111111-111111111111-1111111-11-------11   0011
--------------1------------11111---11-----------------   0011
------------------------------------1-1---1-----------   001011
----------------------------------1-11111-------------   001011
-------------------11-------------1111111-11----1-11-1   001010
-------------------11--1111111-1-111111-1-11-1---11111   001001
-----------------111111111111111111111111-1111-1-11111   001001
----------------1111111-11-1111111-111111111-1-1111111   001001
-----------------1---------------------------1--------   001000
----------------11111111-----------1-1111-----1111-1-1   001000
-------------------11-1-1111111-------1---11----------   000111
-----------------------------11-----------------------   000110
---------------------------------1--------------------   000110
------------------111111-1---1111---------------------   000110
------------------------------1-----------------------   000110
------------------1--11----111-11---------------------   000110
```

```
-------------------------1----------------------------   000110
--------------------------------1---------------------   000110
-----------------------1--------1---------------------   000110
------------------1--1111111-1111---------------------   000110
----------------1--1-1-1------------------------------   000101
---------------------111------------------------------   000101
----------------111-----------------------------------   000101
-------------------11--1------------------------------   000101
----------------11-111----------1---------------------   000101
-----------------1---1---------1----------------------   000101
----------------1-1-----------------------------------   000101
------------------1-----------------------------------   000101
--------------------1---------------------------------   000101
-----------------1-11-1------1------------------------   000101
---------------------1--------------------------------   000101
------------------1-----------------------------------   000101
----------------11111--1------------------------------   000101
------------------1---1---1---------------------------   000101
------------------1-----------------------------------   000101
----------------11--1-----------1--------------1------   000100
1--------------11111-11-1111-----1------------------1-   0000
1----------1------1-11111111---1----------------------   0000
------------1----11111-1------111---------------------   0000

000000000000000011111111111111111111111111111111111111
000001111111111100000000000000000011111111111111111111
011110000111111100000000111111111100000000000011111111
          00000010001111100000000100000000001100000011
          000011    00111000011111 0000000111  000111
                             00001 0111111
```