



**Mining, Minerals and
Sustainable Development Project**



MANAGING THE IMPACTS OF THE AUSTRALIAN MINERALS INDUSTRY ON BIODIVERSITY

Final Report

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EXECUTIVE SUMMARY

Biodiversity can be described as ‘the variety of all life forms – the different plants, animals and microorganisms, the genes they contain and the ecosystems of which they form a part’. This report, which has been prepared by the Australian Centre for Mining Environmental Research (ACMER), as part of the Australian regional Mining, Minerals and Sustainable Development (MMSD) project, addresses (1) the impact of the minerals industry on biodiversity, (2) how the modern minerals industry manages its impact on biodiversity, (3) the potential for enhancement of industry practices to protect biodiversity, and (4) the opportunities for indigenous communities to assist the minerals industry in managing biodiversity.

Australia has 80 biogeographic regions containing a large number of endemic species, and is one of the most mega-diverse countries in the world. A number of threats to biodiversity by all forms of land use have been identified, namely habitat modification and fragmentation, overexploitation of species, impact of introduced species and genes, and the pollution of soil, water and the atmosphere.

Surveys have shown that the minerals industry affects less than 0.05% of the Australian terrestrial land surface, and it has not been responsible for the extinction of any known species (with possibly one exception). Rather, it is the agricultural and grazing industries that occupy the greatest amount of developed land area (greater than one-half), and these industries have caused the most adverse effects on biodiversity, with a total of 44 attributed extinctions.

Whereas the national impact on biodiversity by the industry has been low, past practices have been responsible for some severe local impacts on both terrestrial and aquatic biodiversity. These impacts, which have arisen from exploration, mining and mineral processing activities, have involved direct clearance of vegetation (and faunal habitat), on- and off-site impacts of acid mine drainage from waste rock dumps, tailings storage facilities and open pits, and poor rehabilitation practices.

The industry now recognises the potential for impact on both terrestrial and aquatic biodiversity and has developed measures for managing this impact through both in-house and commissioned research undertaken for environmental impact assessments for mining proposals and for rehabilitation of post-mine environments. As a result, the

industry may be credited with contributing a substantial amount of knowledge on Australia's biodiversity. Most of Australia's mineral reserves are located in remote locations, away from major population centres. Mineral reserves are concentrated on the basis of geology, rather than ecology or archaeology, and therefore are not necessarily in areas that would have received thorough biological studies without the presence of mining.

In certain fields of rehabilitation expertise, such as native ecosystem reconstruction, the minerals industry in Australia is seen as a leader in development of new technologies. With the continuing globalisation of the industry, these technologies may become useful in the other countries with similar climatic ranges.

Means by which the industry has the potential to enhance its protection of diversity include (1) developing a greater understanding of the ecology of reconstructed landscapes, (2) identifying, and obtaining agreement on, indicators of rehabilitation success, (3) improving the utilisation of native seed reserves, and (4) improving fire and weed management techniques.

The minerals industry is increasingly recognising the role that indigenous communities can play in the management of biodiversity. The knowledge of these indigenous communities of native flora is being utilised in (1) identifying the species important to these communities and thus the post-mine vegetation mix, and (2) developing contracts with communities to collect native seed for mine rehabilitation programs.

Through the development of environmentally sensitive practices and ongoing research and monitoring, the minerals industry has, for the most, demonstrated it to be a responsible land manager, which is aware of the temporary nature of its activities and its commitment to future land users. A number of case studies, both positive and negative, have been presented in this report to illustrate the improved awareness of biodiversity issues by the minerals industry.

1.0 INTRODUCTION

1.1 What is Biodiversity?

The term ‘biodiversity’ has come to encapsulate the vast varieties of life forms and their physical, chemical and biotic environments. There are numerous definitions that are associated with the term, of which one of the most accepted within Australia is the definition that was adopted in the 1996 Australia State of the Environment Report:

‘The variety of all life forms – the different plants, animals and microorganisms, the genes they contain and the ecosystems of which they form a part’.

The broad nature of this and other definitions of biodiversity are the source of considerable scientific debate, as they have essentially become a synonym of ‘all life’, hence rendering the concept extremely difficult to operationalise (Doherty *et al.* 2000). Nevertheless, for the purpose of this report, the definition provided above will be used.

1.2 Biodiversity and Conservation in Australia

The Australian continent extends approximately 3,700 km from the south latitudes of 10° to 43° and contains a number of climatic zones from the tropical north, through the dry, arid interior to the southern temperate areas and alpine regions in the Australian Alps. A geologically stable land mass has resulted in highly weathered soils and few mountain ranges. The relatively flat landscape presents few opportunities for orographic rainfall, hence there is a scarcity of fresh water in inland Australia. Australia comprises slightly over 5% of the world’s land area, but its proportion of surface runoff is less than 1% (Smith 1998) with the average annual runoff for Australia being 52 mm. On this basis, Australia may be considered the driest inhabited continent in the world.

The majority of Australia is characterised by unpredictable rainfall and vast seasonal variations in evaporation rates, especially in the extensive arid and semi-arid regions. The arid landscapes are dotted with fresh, brackish and hypersaline lakes encrusted with salt crystals with many inundated for only a few weeks annually. The area of saline wetlands in Australia far exceeds that occupied by freshwater (Mummery and Hardy, 1994). In addition, high variability of flow has caused a large number of

intermittent streams and lakes. The ephemeral nature of a large number of inland waterbodies (including streams and rivers), in turn, has helped to shape the unique survival strategies of Australia's flora and fauna.

Australia has 80 biogeographic regions containing a large number of endemic species (species that can be found only in this country). As a result, the International Union for the Conservation of Nature (IUCN) lists Australia among the mega diverse countries in the world. The degree of knowledge about biodiversity varies with geographical regions, ecosystems and taxa (Lovejoy 1997). The following are all currently investigated under the broad domain of biodiversity: inventory (cataloguing) at the level of taxonomic groups, genetic origin, evolution and dispersion of species; economic, ecological and indicator values of taxa; bio-invasion of exotic species; stress, fragmentation, destruction, and rehabilitation of habitats and ecosystems.

A number of threats to biodiversity in Australia have been identified, namely, habitat modification and fragmentation, overexploitation of species, the impact of introduced species or genes, and pollution of soil, water and the atmosphere (BDAC 1992).

The 1996 State of the Environment Report highlights Australia's loss of biodiversity and lists a number of key threats to sustainability. The single largest threat to biodiversity is reported to be land clearing and related activities, the extent of which, both previous and current, varies greatly between states. Currently, Australia experiences an annual net loss of native vegetation with an estimated average to be 300,000 to 340,000 hectares per year (NHT Midterm Review 1999). Many of our native ecosystems are now fragmented and in danger of becoming irreversibly degraded as clearing is compounded by more insidious, widespread, incremental losses of native vegetation. The majority of land clearing activities has been undertaken for agricultural purposes. In the State of Queensland over the period 1991-1999, 95.3% of clearing was undertaken for agriculture with only 0.6% of land clearing attributable to mining over the same period (SLATS 2000).

Since the 1996 State of the Environment Report was released, a number of Commonwealth initiatives have been established to address the increasing areas of degraded lands and establish a system of protected areas to conserve environmentally and culturally sensitive environments.

Australia is a participant in a number of international agreements and has developed national and State legislation that require an attempt to conserve biodiversity and minimise the effects of activities on 'sensitive' environments. The definition of sensitive environments in this context may include: proposed and current national parks, nature reserves, conservation parks, State forests, timber reserves, rainforest areas, areas of declared rare flora and fauna, mangrove communities and wetlands (Department of Minerals and Energy WA 1998), areas with slow rates of recovery due to climatic variables (alpine and arid zones) and culturally significant areas.

As signatories to the National Strategy for the Conservation of Australia's Biological Diversity (NSCABD), Commonwealth and State governments are committed to the establishment of a comprehensive and representative system of ecologically viable conservation areas. For conservation of biodiversity, the IUCN recommends protecting a minimum of 10 percent of natural areas worldwide. Currently, Australia has 60,273,030 ha of terrestrial lands on the mainland (including Tasmania) that are managed for nature conservation. This represents 7.84% of the Australian continent (including Tasmania).

1.3 Overview of the Minerals Industry in Australia

Australia has the world's largest reserves of several key mineral commodities (Australia's Identified Mineral Resources 2001) with the minerals industry contributing approximately \$40 billion annually to the Australian economy (Commonwealth Minister for Environment and Heritage 2000). The minerals industry in Australia is taken to include the process of removing the targeted resource from the ground (mining) plus the associated minerals processing activities. The industry directly employs more than 80,000 people in the minerals, oil and gas industries and contributes more than 300,000 indirect jobs in the manufacture of downstream products (Commonwealth Minister for Environment and Heritage 2000).

Historically, environmental protection was relegated behind economic development on the list of national priorities. With scant knowledge of environmental protection measures and the consequences of incorrect disposal of wastes, the majority of the early development projects focussed on production with little regard for biodiversity and ecology. The activities of the minerals industry reflected the views of the time and left a legacy of unrehabilitated waste dumps, polluted waterways and deforested

hillsides. The Australian government has spent significant sums of money in correcting the environmental damage that has resulted from historical activities, such as Rum Jungle and Captains Flat, which remain a burden to the mineral industry's attempts to improve its environmental image (Brooks 1997).

Today, Australia is at the leading edge of rehabilitation technologies, especially mine-site rehabilitation (Beattie 1995). In 1996-97, the minerals industry spent \$369m on environmental protection, primarily in waste water management and water protection as well as the protection of biodiversity and landscape ecosystems (Astolfi *et al.* 2000) yet the industry continues to have a negative environmental image in the community (Commonwealth Minister for Environment and Heritage 2000; Hancock and O'Neill 1996). The reality is that mining affects less than 0.05% of the terrestrial land surface (Bell 2001) and has significantly contributed to the knowledge and understanding of Australia's biodiversity.

With the exception of mining occurring on agricultural lands where the community wants the post-mined land use as improved pastures, the majority of mines place an emphasis on establishing native ecosystems after mining. As a result, there has been considerable effort placed on the development of technologies to ensure successful establishment and stability of these ecosystems often under adverse environmental conditions (Bell 2001). With many of our native ecosystems now fragmented and in danger of becoming severely degraded, unmined lands managed within mineral leases are frequently in a more pristine condition than the surrounding communities adjacent to the lease due to management of degradative factors.

Severe environmental pollution caused by mining operations within Australia, as evident by the denuded hillsides of Queenstown in Tasmania, and Australian offshore operations such as the Ok Tedi mine in Papua New Guinea and the Esmeralda Exploration cyanide spill in Romania, impact on the public image of the Australian minerals industry as a whole. With access to viable mineral deposits requiring approval of stakeholders and being dependent on the minerals industry indicating the potential for multiple land use, the continued activities of the Australian minerals industry will be increasingly determined by its environmental performance.

In 1996, the Minerals Council of Australia (MCA) launched the Australian Minerals Industry Code for Environmental Management (the Code). The primary purpose of

the Code was to provide a framework for continual improvement in environmental management and communication in each phase of mineral development, from initial exploration to closure and final rehabilitation (MCA 1999).

According to Hamblin (1998), the highly organised and commercial nature of the industry means that voluntary compliance by large mining operations is a viable option for gaining adoption of the Code by most sections of the industry. Participation in the Code is intended to facilitate the signatory's improvement of environmental performance and to communicate the performance to stakeholders and the community. The Code requires each signatory to produce annual environmental reports to verify implementation of the Code and to describe their commitment to excellence in environmental management. In 1999, the Code underwent a major review in consultation with key industry stakeholders. An updated 2000 Code was the outcome of this review process. Key improvements include greater emphasis on the importance of verification of Code performance and the introduction of a self-assessment protocol (the Code Implementation Survey) with the purpose of providing an industry-wide standard for gauging progress towards Code implementation.

As of October 2001, 41 companies within Australia have adopted the Code of Environmental Management representing approximately 90% of production within the Australian minerals industry.

2.0 IMPACT OF THE MINERALS INDUSTRY ON BIODIVERSITY

All recognise the value of mineral wealth, but the concept of biological wealth has been slower to be accepted (Beattie 1992). The activities of the minerals industry could potentially pose some major threats to biodiversity. Mining removes all of the biota within the active area and therefore halts the associated ecosystem functions and processes. The industry, however, has come a long way since its historical activities, and systems are now in place to ensure that steps are taken to restore biodiversity wherever possible. For example, prior to mining in Western Australia, the Departments of Minerals and Energy, and Conservation and Land Management review the resource potential and biodiversity values of pastoral leases including those where exploration and mining leases are taken out (Smurthwaite *et al.* 2000).

Following mining, the Department of Minerals and Energy and the Department of Environmental Protection ensure suitable closure techniques have been implemented.

The minerals industry is not the only one with impacts on biodiversity, and certainly it is not the industry affecting the largest area. The State of Western Australia occupies one third of the country and is the State where the minerals industry is most active.

Figure 2.1 indicates that the industry occupies the least area of any of the major land uses in Western Australia, in fact occupying less than 1 percent of the land area. The area available for exploration and mining has been reduced due to their exclusion from National Parks and conservation reserves where they are no longer permitted (Trudinger and Pool 2000). By contrast, the agricultural industry, and particularly pastoral land use, affects a vast area in Western Australia, having its own impacts on the biodiversity of the land. Mining's major impacts result from clearing, excavating and waste disposal. These practices can cause erosion and soil damage, air pollution, contamination, have adverse affects on the groundwater such as salinisation and acidification, cause loss of flora, fauna and habitat and introduce disease and pests (Knight 1998).

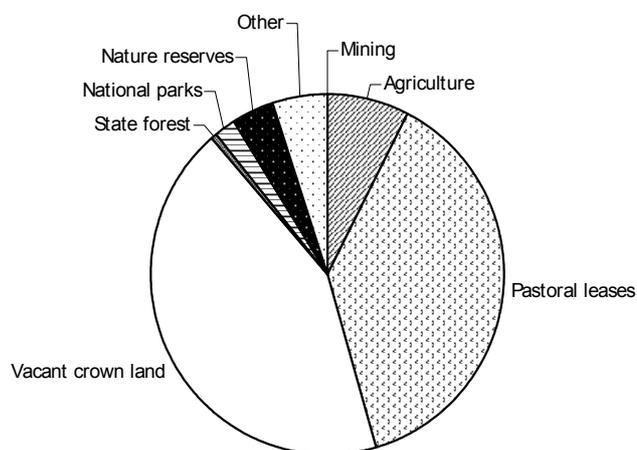


Figure 2.1. The percentage of land use in Western Australia (after Guy *et al.* 1995 and Grant 1992).

All major industries can have considerable impact on the biodiversity of Australia, particularly in the fragile arid zones, where ecosystems are already operating close to

their physiological limits (Smith 1992). Contrary to popular belief, the minerals industry is not Australia's major environmental challenge (Batini 1997), and in fact the industry is one of the leaders in ensuring that its impact on biodiversity is minimal (Anderson 2000).

There are several reviews of the impact of the minerals industry on the Australian environment (e.g. Webb 1990; Woodside and O'Neill 1995; Farrell and Kratzing 1996; and White 1997). However, with the possible exception of Woodside and O'Neill (1995), none of these reviews provide a comprehensive account of the impact of the industry on biodiversity. The following attempts to look at the positive and negative effects of the industry in relation to biodiversity.

2.1 Establishing an Ecological Context

Saunders *et al.* (1996) provide a useful review of the various processes that are threatening Australia's biodiversity. Their review clearly shows that agricultural and grazing land uses have had a far greater impact on Australia's biodiversity than the minerals industry. For instance, with regard to pressures on plant biodiversity, agriculture has been identified as the major cause of 44 presumed species extinctions as opposed to only the one attributed to the minerals industry. The pattern is similar for our faunal diversity.

Utilising ants as a measure of biodiversity integrity, Majer and Beeston (1996) calculated the relative impact of various land uses in Western Australia. In their study, agricultural clearing has had by far the greatest impact on biodiversity integrity, closely followed by rangeland grazing. The lower losses of biodiversity integrity as a result of urbanisation, roads and mining puts into context the lower impact of these relatively restricted land uses.

Agricultural and grazing land uses occupy more than half of Australia's land area. When compared to the area that is occupied by the minerals industry, it is not surprising that agricultural and grazing land uses have had a far greater impact on Australia's biodiversity. However, it is important to recognise that while the area of land affected by the minerals industry is relatively small, the magnitude of the impact can be locally significant. Mining activities often have a very rapid and devastating impact on biodiversity through the removal of vegetation and the alteration of soil profiles, topography and hydrological regimes. On the other hand, agricultural and

grazing impacts are less immediate and are often cumulative. It is plausible that Australia's previous mining legacy is the cause of only the one species thought to have become extinct, due to the relatively small area impacted by the activities rather than sound biodiversity management and rehabilitation techniques which did not exist prior to the 1970s.

2.1.1 *Spatial analysis of biodiversity and mining disturbances*

Due to the lack of information on mining disturbances and their impact on biodiversity, particularly at the national or industry-wide scale, a rapid assessment of the spatial analysis of biodiversity and the activity of the minerals industry was undertaken for this review using basic Geographic Information System (GIS) procedures and two readily available and relevant spatial datasets:

1. the Interim Biogeographic Regionalisation for Australia (IBRA) dataset that divides the continent into 80 biogeographic regions, which can be thought of as major environmental units (Thackway and Cresswell 1995); and,
2. the spatial representation of the mineral deposits database OZMIN developed by G. Ewers and B. Kilgour of the Australian Geological Survey Organisation (AGSO).

The results of this rapid assessment can be seen in Figure 2.2. Remembering that the individual operations have been enlarged for the purpose of this exercise, Figure 2.2 indicates that the minerals industry has impacted on the large majority (66) of the 80 different biogeographical regions identified by Thackway and Cresswell (1995). This is not surprising given the widely scattered nature of Australia's mineral resources.

Fourteen biogeographic regions were found to have no significant historical or current mining activity (Figure 2.3), and thus it can be assumed that the minerals industry has had little, if any, impact on the biodiversity that these biogeographic regions comprise. Six of these 14, however, contain significant mineral deposits, which may be the target for future mining activity. The Murray-Darling Depression biogeographic region is one of these six and is already experiencing considerable

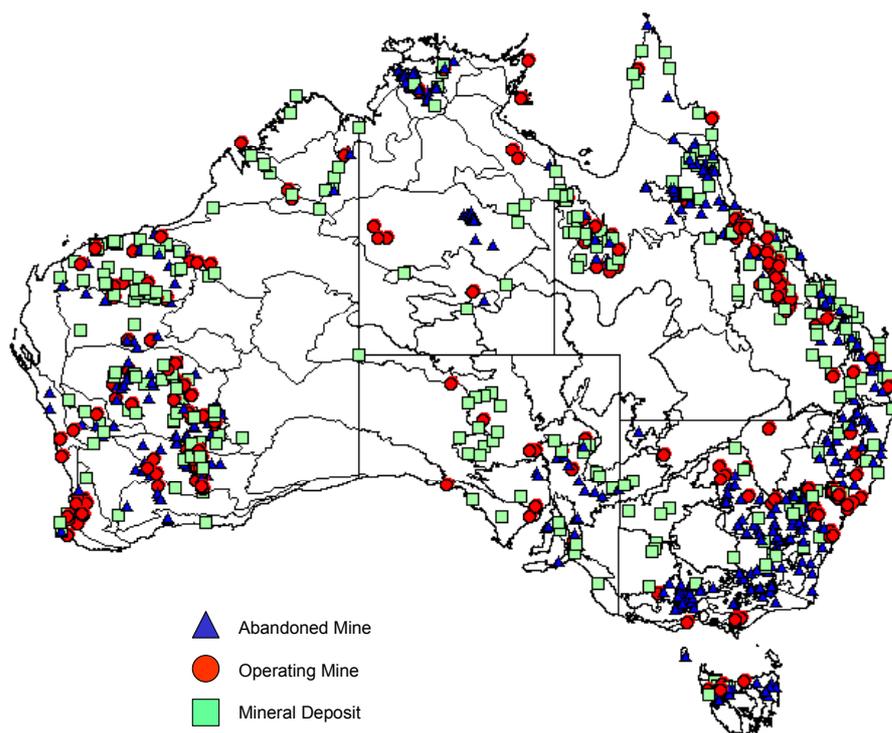


Figure 2.2. Spatial representation of IBRA and the mineral deposits database OZMIN.

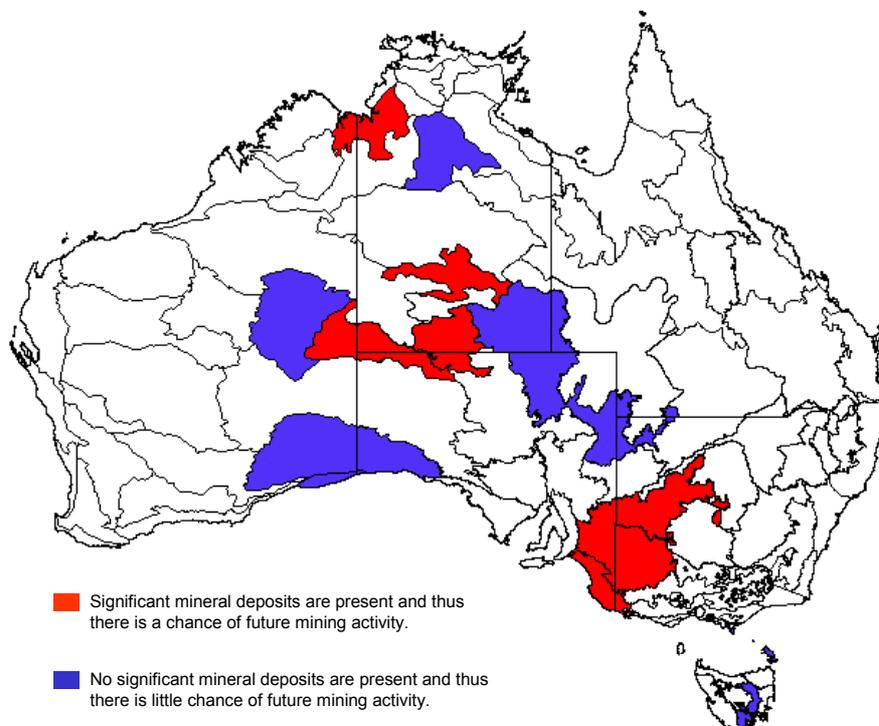


Figure 2.3. Biogeographic regions with no significant historical or current mining operations.

exploration activity and interest as a more accessible source of mineral sands than traditional coastal resources.

2.1.2 *Influence on threatened biogeographic regions*

Loss of biodiversity is often a result of multiple, interacting pressures (EPA QLD 1999). For this reason, it is important that the minerals industry is aware of those regions that have experienced substantial impacts on their biodiversity from other land uses. The IBRA dataset contains a qualitative and subjective assessment of the condition of each biogeographic region.

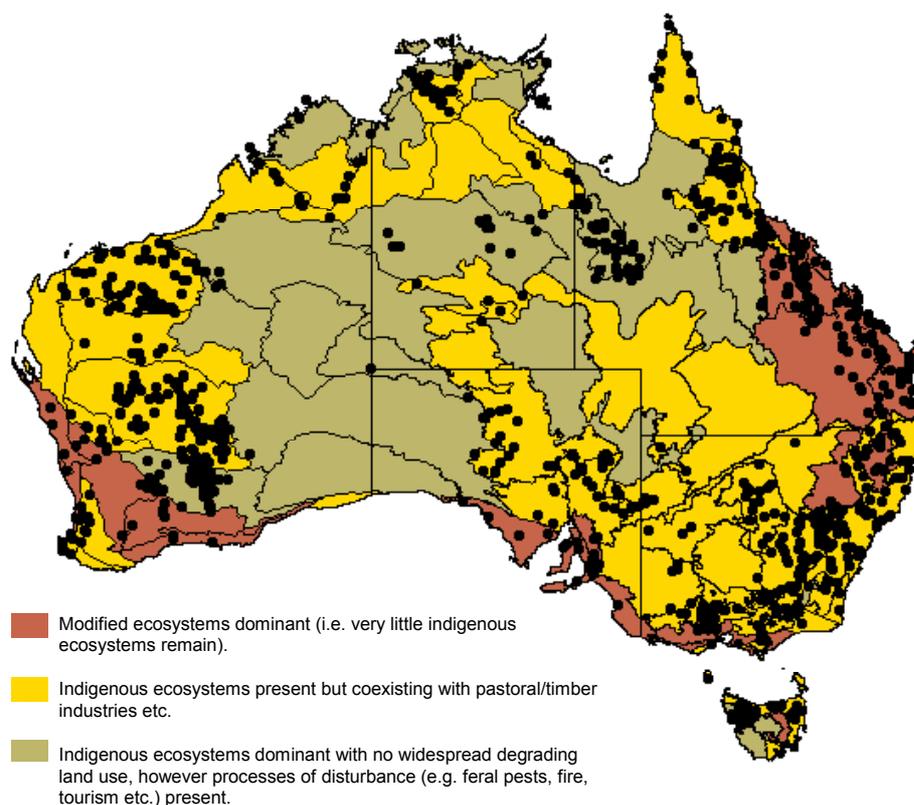


Figure 2.4. Condition of IBRA Regions and distribution of OZMIN data.

The results suggest that the most significant activity of the minerals industry in those biogeographic regions dominated by modified ecosystems (i.e. very little indigenous ecosystems remain) was in Queensland (Figure 2.4), in particular, Brigalow Belt

South, Brigalow Belt North, and South East Queensland biogeographic regions, which all have more than 60 percent of their vegetation cleared and many serious threats to biodiversity.

At the other end of the spectrum, the minerals industry has significant activity in two regions – Coolgardie and Mt Isa Inlier – where indigenous ecosystems are still dominant, and there are no widespread degrading land uses. The industry needs to guard against complacency in respect to assessing and managing impacts in these areas, because, despite the expanse of indigenous ecosystems, development can provide a conduit to other more insidious threatening processes, such as increased predation by feral animals and competitive interactions caused by introduced weeds.

2.1.3 *Influence on poorly conserved biogeographic regions*

Another indication of whether the minerals industry is potentially impacting on biodiversity is the degree to which the industry's activities are focussed in biogeographic regions where there is considerable bias in the existing system of protected areas.

As noted by Thackway and Cressell (1995), much of our existing system of protected areas (e.g. national parks and nature reserves) is biased toward certain environmental elements – high relief, low soil fertility, and steep rainfall gradients. Areas that are highly regarded for agriculture or other resource consumptive land uses are typically under-represented in Australia's existing system of protected areas.

Some biogeographic regions, in which the minerals industry is currently active, are poorly conserved (Figure 2.5). For instance, the Pilbara and Murchison biogeographic regions both have a high index of bias, whereby entire sub-regions, or many of the extensive ecosystems that characterise the region, are not represented in the existing system of protected areas. The minerals industry needs to acknowledge this bias in protected areas and ensure that its activities do not impact on the representativeness, comprehensiveness and adequacy of biodiversity conservation in the regions where it is operating.

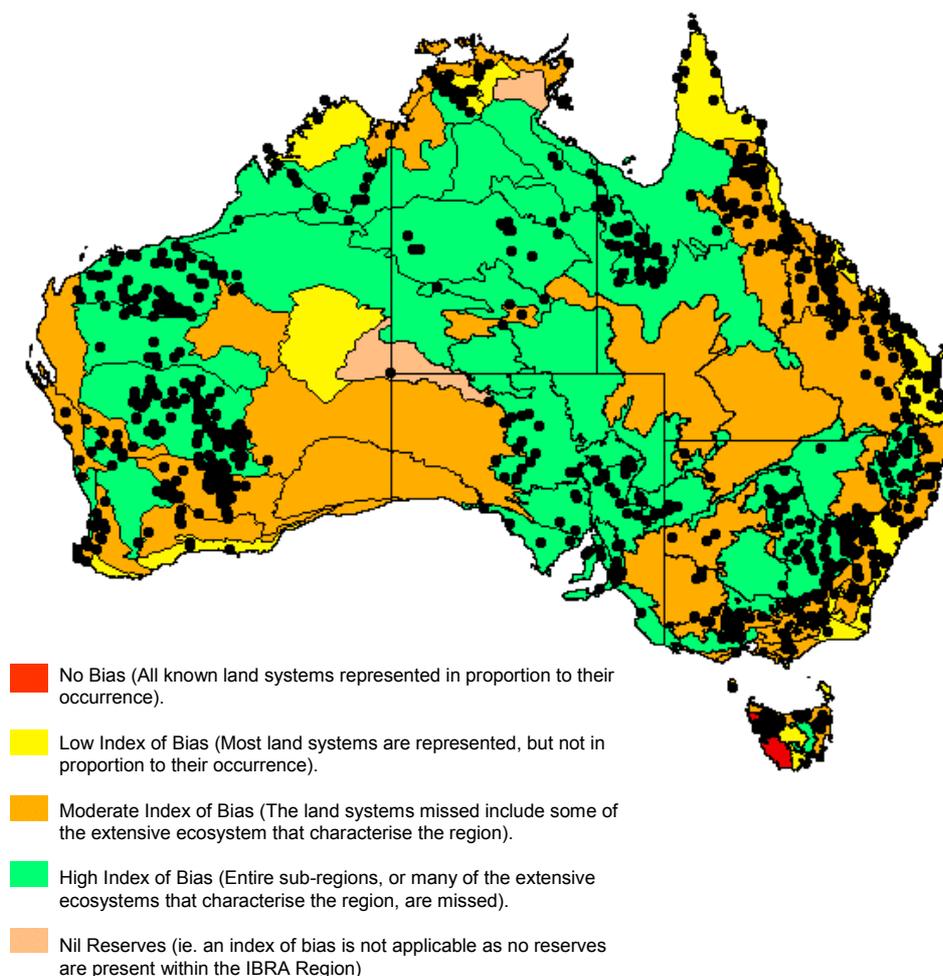


Figure 2.5. Distribution of OZMIN data and the level of bias within protected areas.

2.1.4 *Influence on Australia's flora and fauna*

There are few simple cause-and-effect relationships linking biodiversity loss or decline with a particular human activity (EPA QLD 1999). However, the Commonwealth Government through Environment Australia and the Australian Nature Conservation Agency, commissioned several 'Action Plans' for various fauna groups over the past decade which provide an indication of the impact the minerals industry has had on Australia's fauna. Similar information has been prepared for Australia's flora (e.g. Leigh and Briggs 1992). This information is summarised in Table 2.1.

Table 2.1 indicates that one species of plant is now presumed extinct due to the activity of the minerals industry, while 11 flora and fauna species were considered endangered by a historical threat, and a further 35 by current and future threats. However, when interpreting this information, it is important to realise that there is a certain degree of subjectivity and uncertainty regarding the extent to which the industry has played a part in the demise or decline of these species.

The plant species presumed extinct is *Euphorbia carissoides* (Bailey), which occurred in open-woodland habitat of Queensland. The causes of its extinction have been attributed to mining and domestic grazing (Leigh and Briggs 1992). This evidence appears to contradict the statement made by Woodside and O'Neill (1995) that:

' ... there is no data to suggest that any plant, animal or community has gone extinct in Australia as a result of mining.'

Table 2.1. The impact of the Australian minerals industry on the threatened status of the native biodiversity.

Lifeform	Number of presumed extinct species	Number of endangered species	
		Historical threat	Current and future threat
Plants	1	3	11
Birds		8	4
Frogs			1
Reptiles			6
Freshwater Fish			
Marsupials and Monotremes			4
Bats			9
TOTAL	1	11	35

Source: Leigh and Briggs (1992), Garnett and Crowley (2000), Tyler (1997), Cogger *et al.* (1993), Wager and Jackson (1993), Maxwell *et al.* (1996), Duncan *et al.* (1999).

Note: The column figures are the number of species affected. A species can be at risk from other threats in addition to those resulting from the minerals industry.

With regard to bats, Duncan *et al.* (1999) advise that many bat species use abandoned mines as daytime roosts and maternity sites. Often there are large congregations of

animals at these sites, and, in many bat species, the historical activities of the minerals industry has permitted their range to be extended. Duncan *et al.* (1999) advise that the closure of mines for public safety considerations, or the collapse, destruction or re-working of abandoned mines is now considered a threat to the population viability of nine threatened bat species that are dependent on these abandoned mines following the destruction of their natural roosts. The minerals industry has an important opportunity to engage other natural resource management agencies to develop on-ground management actions to protect the roosts of these threatened bats where possible. Grates have been developed that prevent human access to abandoned mines yet permit bats to enter the abandoned workings.

There appears to be no data to suggest that aquatic fauna and flora species have become threatened or endangered by activities of the minerals industry. Wager and Jackson (1993) suggest that specific sources of erosion, such as that resulting from mineral operations, can have a significant affect on aquatic biodiversity through the influence that increased sediment load has on streams and waterbodies. For example, EPA QLD (1999) has reported on the downstream impacts on biodiversity in the Dee River from contamination by the abandoned Mount Morgan Mine in central Queensland. They suggest that pollution-sensitive invertebrates, and all fish and submerged plants, were absent from sites within 20 km downstream of the mine as a result of acid rock drainage. In many cases, there is a lack of pre-mine baseline data on biodiversity to determine the impact of the minerals industry although it is presumed to be severe.

2.1.4.1 *Rare or threatened species or communities*

An important aspect of conserving biodiversity is the preservation of rare and endangered species, and this is particularly so in a country such as Australia which has notably high levels of endemism and species richness (Mummery and Hardy, 1994). The existence of rare or threatened species or communities has been a factor in determining whether mining is able to proceed.

A topical example is the occurrence of stygofauna and troglobitic fauna within mineral leases. These fauna reside beneath the ground surface with the former being aquatic, while the latter are terrestrial. One area where such animals abound is in the

limestone karst formations of the Cape Range province in the north-west (Pilbara) of Western Australia. These formations support one of the world's most diverse subterranean fauna with many species endemic to the area. A localised distribution of some of these species qualify them to be classified as rare or threatened under Western Australian legislation. Limestone has been mined in the Cape Range region, with proposals submitted to extend the impacted areas. In view of the capacity for mining to interfere with subsurface hydrology, this activity has been disallowed in some cases. A rich stygofauna has been detected elsewhere in the Pilbara region, and has become an issue in relation to the granting of permission for future mining in the area.

If rare species are identified within the project area, development approval is obtained only following evidence that the development will not negatively impact on the species' survival. Two examples of where development was allowed on the condition that a priority species was not threatened by the development proposal include the presumed extinct plant species *Hemigenia exilis* and the Priority fauna Pebble-Mound Mouse.

Case Studies

Hemigenia exilis

In 1995, the presumed extinct plant species *Hemigenia exilis* S. Moore (Figure 2.6) was rediscovered during vegetation surveys of the Murrin Murrin tenements of Anaconda Nickel Limited in the north-east goldfields of Western Australia. Despite thorough searching, this species had not been recorded for 100 years. The discovery of a declared rare flora species within the proposed project area required Anaconda Nickel to develop research programs and management objectives to ensure conservation of the species.

In response to this find, Anaconda Nickel commissioned surveys and conducted public and internal awareness programs to increase communication on the species. By the end of 1997, 65 populations of *H. exilis* had been discovered totalling more than 50,000 plants within the north-east goldfields.



Figure 2.6. Flowers of the Priority Four rare plant species, *Hemigenia exilis* S. Moore from the goldfields region of Western Australia.

These finds were significant in that they identified a presumed extinct plant species to have a wide distribution. By mid-1998, the conservation status of *H. exilis* was reclassified as Priority Four Rare Taxa – rare, but not threatened by identifiable factors. Government regulations require Priority Four taxa to be monitored every five years. To ensure that their activities did not impact on the survival of the populations that existed within their tenements, Anaconda Nickel conduct quarterly monitoring to record the health and biology of the populations. In addition, Anaconda Nickel commissioned research into the seed biology and genetics of *in situ* populations and redesigned the mine plan to minimise the effects of waste dumps, haul roads and mine voids on the located populations.

As a result of investigations commissioned by Anaconda Nickel, a detailed knowledge now exists of the distribution, demography, phenology, genetic diversity,

seed physiology and propagation of *H. exilis*. This knowledge will enable the expansion of populations within the project area to preserve the species within natural populations and the post-mined environment.

Pebble-Mound Mouse

The Pebble-Mound Mouse (*Pseudomys chapmani* Kitchener) (Figure 2.7) was discovered in 1980 in the Pilbara region of Western Australia. In developing its home, this species builds a mound up to 2-3 m in diameter from small pebbles. Due to a limited known population number and habitat, the Pebble-Mound Mouse was listed as a Schedule 1 endangered species. Fauna surveys commissioned by the mining company, Hamersley Iron Pty Ltd, found this species to occur within both its Marandoo development and Yandi Project Lease. Hamersley Iron commissioned surveys and research to further understand the distribution and ecology of the species. This research, in conjunction with the State conservation agency, CALM, determined the species to have a wider distribution throughout the Pilbara than previously known. The results of research into the species ecology has allowed mining companies, that are active in the Pebble-Mound Mouse's range, to manage their rehabilitated areas in accordance with the conservation of this species. A greater understanding of population numbers, distribution and species ecology, in association with the successful translocation of the species, have enabled the Pebble-Mound Mouse to be removed from the list of endangered species.



Figure 2.7. The Pebble-Mound Mouse, *Pseudomys chapmani* Kitchener, from the Pilbara region of Western Australia.

2.2 Activities of the Minerals Industry that Impact on Biodiversity

2.2.1 Terrestrial

As noted by EPA NSW (1997), most mine operators now have access to a wide array of modern technology and management approaches to account for and lessen environmental impacts. Nevertheless the immediate environment in which mines are located may be affected in a number of ways during mining, and sometimes long after mining has ceased. Woodside and O'Neill (1995) provide a good account of the wide range of environmental impacts associated with mining and exploration activities. This review, however, is more concerned with the activities that are causing specific impact on Australia's biodiversity.

2.2.1.1 Impacts of exploration and prospecting activities

Farrell and Kratzing (1996) advise that the primary impacts of exploration are the removal of vegetation and disturbance of ground in the immediate vicinity of the principal activities. Removal of vegetation obviously has an immediate impact on local biodiversity, while ground disturbance may influence the recruitment and survival within the rehabilitated areas. Recent exploration and prospecting activities are more environmentally friendly than in the past and have been outlined by White *et al.* (1996).

The use of bulldozers and graders to create gridlines in past exploration activities have left a legacy of tracks across Australia. Many of these tracks are clearly visible today despite the natural regeneration that has occurred. Whilst the tracks have increased access to remote locations, they also have the potential to impact on natural drainage patterns and, therefore, the recruitment and survival of vegetation communities (White *et al.* 1996).

Most exploration activities are now conducted with the use of non-intrusive techniques such as remote sensing and global positioning systems (White *et al.* 1996). Where field sampling is required, existing access tracks are used wherever possible to provide access for vehicles and equipment for further studies. Where existing tracks are unavailable, techniques such as folding vegetation instead of grading to minimise disturbance to root systems and enable vegetation regrowth, the use of lighter drilling rigs or helicopter-assisted drilling programs to transport the equipment into sensitive or rugged terrain are frequently being undertaken (White *et al.* 1996).

Some operators utilise wooden platforms to accommodate drill equipment and foot traffic during drilling operations. These wooden platforms are placed directly over understorey vegetation, and disperse the weight over a larger area to minimise soil compaction and allow vegetation regrowth once the wooden platforms are removed, causing minimal disturbance to local biodiversity.

Many drill holes remain uncapped and can act as pitfall traps for native wildlife (Figure 2.8) or, with time, become an area of erosion around broken drill collars. The use of buried concrete drill plugs prevent animal entrapment and are able to withstand vehicle traffic and corrosion, problems associated with the use of plastic or steel caps (White *et al.* 1996).



Figure 2.8. Uncapped drill holes can act as pitfall traps to native fauna that are unable to escape. The skeleton of previous lizards can be seen deeper in the drill hole. Photo courtesy G. Wells, Botanic Gardens and Parks Authority.

2.2.1.2 *Vegetation clearance and surface impacts*

The clearing of vegetation is one of the most significant impacts of mining on biodiversity. The area of vegetation affected will vary according to the type of mineral extracted and the methods employed. For instance, sub-surface (underground) mining methods cause far less vegetation disturbance than surface mining methods such as strip mining and dredging. It should also be remembered that there is often considerable infrastructure associated with mining activities such as road, rail and port developments, which will most likely result in further vegetation clearance.

Once the vegetation has been cleared, the topsoil is removed and, if possible, immediately transferred onto a rehabilitated mine pit to maximise topsoil seed viability and native species recruitment. In many cases the direct transfer of the topsoil is not possible, and the topsoil is required to be stored for later use. The storing

of topsoil is known to decrease the viability of the soil seed reserves with time, resulting in depressed levels of recruitment that may be obtained when the topsoil is re-spread at a later date (Tacey and Glossop 1980; Nichols and Michaelson 1986; Dickie *et al.* 1988).

The excavation of the substrate materials and creation of the mine void alters the soil profile, hydrology, topography, and nutrient status of the substrate. These secondary factors have the potential to impact on the local biodiversity within the rehabilitated post-mined environment.

Extensive mining operations, mainly involving bauxite and mineral sands extraction, have historically destroyed extensive areas of vegetation and changed soil profiles and topography, but modern methods now focus on minimising this damage.

As noted by Saunders *et al.* (1996), the most serious environmental conflicts in the mining industry now revolve around access to mineral reserves in areas of significant habitat, high biodiversity or special cultural significance. Historically, sand mining has been one of the more contentious environmental issues for the industry. In the past, extensive rutile and zircon mining was undertaken on the north coast of NSW, although for the reasons mentioned above, in that State it is now confined to an area north of Newcastle (NSW State of the Environment Report 1997). Notwithstanding the progress that is being made in rehabilitation and the introduction of more stringent environmental requirements in the industry, Fox (1996) has found that sand mining has historically resulted in long-term changes to biodiversity.

2.2.1.3 Impacts of mining infrastructure and development

Mining-related infrastructure developments include corridors for roads, railways, pipelines and powerlines, port developments, through to the establishment of human settlements. Large increases in local populations can place pressure on National Parks and other relatively undisturbed areas through the use of off-road vehicles, littering, illegal fishing and hunting, spread of weeds and dieback disease. The combined extent of these impacts can be far greater than those occurring within the mining lease. These kinds of infrastructure developments can have significant negative consequences for biodiversity, for example, creating opportunities for weeds

and pests, modifying natural water flows, and acting as barriers to the movement of native organisms (Noble *et al.* 1996).

Historically, mining activities have given rise to many new settlements within Australia. For example, Ballarat and Bendigo in Victoria were established during the gold rushes of the mid 19th century. However, since the 1960s, Newman *et al.* (1996) suggest that more than 25 new towns and ports have been constructed to support mine sites. They argue that four different mining settlement strategies can now be recognised – new single-industry towns, expansion of existing communities, combined industry towns, and fly-in/fly-out strategies. The first three strategies result in increases in the local population, with consequent impacts such as those described above. By contrast, the fly-in/fly-out strategy results in a lower resident population and also better control as most resident personnel belong to the workforce. The strategy is also encouraged by indigenous negotiators (Manning 1997), and hence is becoming increasingly common as it probably has the least impact on biodiversity by reducing the pressure for infrastructure development in remote areas.

2.2.1.4 Waste management and pollution impacts

The occurrence of waste dumps may be situated within the mineral lease or, in the case of mineral processing, occur at sites remote from the source of the extraction. In both cases, these deposits occur at the expense of underlying plant and animal communities. Slime dams, slurry ponds and similar impoundments are formed when the residues from ore processing are deposited in artificially dammed areas.

Hamblin (1998) advises that mining and associated processing operations require high levels of management care due to the hazardous nature of many of the materials being used, which often pose a significant environmental risk. Cyanide at toxic levels within tailings storage facilities have been responsible for the death of birds that are attracted to the expanse of shallow water (Donato 1999). Significant publicity has resulted in the minerals industry developing practical measures to minimise the effect of cyanide in tailings dams and ponds on wildlife and domestic animals.

According to Woodside and O'Neill (1995), the impacts of mining-related pollution on biodiversity have been significant in the past. For instance, the Rum Jungle Mine in the Northern Territory released 130 tonnes of copper, 100 tonnes of manganese, 40

tonnes of zinc and 13 000 tonnes of sulfate into the Finnis River in one year. A survey conducted in 1971 showed that the river was polluted to such an extent with heavy metals, acidification and radiation that it was virtually dead. Recent surveys of the same river (after the rehabilitation of the site in the 1980s) indicate that macro-invertebrates in the waterways continue to be less common downstream of the mining activities. In contrast, more recent mines such as Woodlawn in New South Wales and the Ranger Uranium Mine in the Northern Territory, operate on almost a zero water release basis, with controlled release only of collected rainwater in special circumstances.

Pollution from Australian mines in the past has primarily resulted from the oxidation of sulfidic minerals such as pyrite (iron), pyrrhotite (iron), chalcopyrite (copper), galena (lead) and sphalerite (zinc). Exposure of these minerals in waste rock dumps, tailings storage facilities, and along the walls of open pits and underground workings has resulted in the release of acid or neutral drainage with toxic metal concentrations causing loss of biodiversity within both terrestrial and aquatic environments. Surveys have found that, of the 317 active and abandoned mines in Australia that have the potential for the excavated material to be acid generating, 54 sites generate significant amounts of potentially acid-generating wastes (greater than 10% of their wastes), while a further 62 generate some potentially acid-generating wastes (less than 10% of the total waste) (Harries 1997). Rehabilitation of these sites, viz. Mt Lyell (Tasmania), Mt Morgan (Queensland), Brukunga (South Australia) and Rum Jungle (Northern Territory) have proved to be difficult.

Another source of pollution emerging from modern, large-scale mining within the Kalgoorlie and Bowen Basin regions of Australia, is salt release and erosion caused by the mining and exposure of sodic soils, subsoils and rocks (Grigg *et al.* 1997; M. Lee pers. comm.). Exposure of these materials has resulted in deep rilling, tunnel erosion, instability of mined landforms and increased concentrations of dissolved salts in streams and open pit lakes receiving discharges from these deposits.

Atmospheric pollution has caused significant loss of local biodiversity in the past, with Mt Lyell in Tasmania providing the most obvious example. As noted by Woodside and O'Neill (1995), point source anthropogenic sulphur dioxide (SO₂) emissions in Australia are dominated by mining-related smelting and roasting at Kalgoorlie in Western Australia and Mt Isa in Queensland. Yet it is considered that

the risks to biodiversity are minimal given the moderate to low acidity of Australian soils and relatively low rainfall over most of the country.

2.2.1.5 Impacts of unrehabilitated or poorly restored sites

Many abandoned mines around Australia remain unrehabilitated. In most States there is an active process of identifying those that pose the most serious threat to the environment and local biodiversity. These sites are then prioritised according to the level of risk they pose, and are progressively rehabilitated, usually at public expense. In NSW alone, there are an estimated 20,000 to 30,000 derelict mines that require clean-up and rehabilitation (NSW State of the Environment Report 1997). Perhaps the most serious threat to biodiversity from these abandoned mines are from those that leak acid waste. There are several rivers in Australia that have had significant lengths of their extent rendered biologically dead from such mining impacts. For instance, some sections of the Molonglo River, which flows into Lake Burley Griffin in Canberra, were damaged to such an extent by acid leaking from the Captains Flat mine that no aquatic biota could persist. Many parts of this river remain severely damaged.

With the exception of several industry leaders, rehabilitation practices at many of Australia's current mining operations are of a relatively poor standard with respect to re-establishment of biodiversity values. This is because the restoration of landscape function and partial vegetation structure is considered by many to constitute rehabilitation success, with far less regard for the restoration of species composition. As noted by Woodside and O'Neill (1995), little if anything is done to re-establish the fauna (invertebrates or vertebrates), with many mines of the opinion that within the post-mined rehabilitation, the fauna will migrate from adjacent areas. This is quite often not the case, particularly when opportunities for secondary succession are exacerbated by excessive fragmentation or lingering pollution (Lockwood and Pimm 1999). However, due to the relatively small size of the mineral operations in comparison to alternative land uses, poor rehabilitation is only likely to impact local biodiversity.

Case Studies

New South Wales

The extensive sand dune areas north of Newcastle have been the subject of much investigation over the past 15 to 20 years. Fox and Fox (1984) studied small mammal recolonisation (two rodents - the introduced house mouse and the native New Holland mouse) during the first 10 years following mineral sand mining at Myall Lakes National Park, New South Wales. The house mouse reached its maximum 3 years after mining and was associated with bare sand, soil hardness and vegetation structure. The New Holland Mouse reached its maximum 8-9 years after mining, after appearing at the 4-5 year mark and was associated with proportion of heath plants present, vegetation structure, amount of dead plant cover and topsoil depth. Fox and Fox (1984) found that this species replacement series in rodents is stretched in time such that the post-mining environment (as opposed to the post-fire environment) more closely approximates primary rather than secondary succession. Twigg *et al.* (1989) further studied this issue using chronosequence analysis along an old mining path in Myall Lakes National Park. A 'wave of succession' moved along the mining path with early colonisation by the House Mouse (*Mus musculus*), an introduced opportunist, followed by the New Holland Mouse (*Pseudomys novaehollandiae*), a native opportunist, and finally succeeded by the Common Dunnart (*Sminthopsis murina*), as the regrowth vegetation and hence habitat became more complex. The sequence was similar to that noted for post-fire small mammal succession. Twigg and Fox (1991) studied terrestrial lizard fauna in the same area and concluded that the successional process proceeded more slowly with terrestrial lizards than the small mammals. Some species colonised as early as 5 years post mining, but other species were still absent after 15 years. They estimated a period of at least 20 years post mining for the reptile fauna to achieve its pre-mining state. Fox (1996) summarises this work as well as the response of small mammals to fire.

Several studies have demonstrated that vegetation recovery has not yet been achieved in the mineral sands industry in NSW. Buckney and Morrison (1992) compared the floristic composition of mined and un-mined sand dunes in Myall Lakes National Park from 1982 to 1990. They found that the mined area was different from both adjacent un-mined dunes and the pre-mining condition. In fact, the vegetation showed a decreasing similarity over time to the vegetation previously on the site. While

species richness and diversity increased during the post-mining period, a large proportion of this was attributed to introduced species. McNair (1993) studied post mineral sand mining regeneration with transects undertaken at Salamander Bay in the Port Stephens area and Bridge Hill and Submarine Beach in the Myall Lakes Region. He also studied post silica sand mining regeneration with transects undertaken at Tanilba in the Port Stephens area. He found little resemblance of post-mining flora to pre-mining flora and an apparent decline in the native plant species in both mineral and silica sand mining flora regeneration with no change after more than 20 years.

Other studies are attempting to compare the differential effects of different types of disturbance. Fox *et al.* (1996) compared regeneration at 44 sites at Tomago New South Wales in relation to burning, clearing and mineral sand mining. As the study is an interesting contrast between regeneration resulting from different disturbances, it is worth quoting the conclusion section of the paper at length:

'The chronosequence data demonstrates that regeneration of cleared or mined sites at Tomago is substantially slower than regeneration following the endogenous disturbance by fire'... 'The severity of the impact of disturbance on vegetation structure increases from fire to clearing with mining the most severe impact. Seventeen years of regeneration on cleared and sand mined sites at Tomago has not been enough to return the vegetation structure or the soil characteristics to the pre-disturbance state. Understorey height and the amount of vegetation on cleared or mined sites have not achieved the levels in the original forest, although canopy cover does seem to have reached pre-disturbance levels.'

Jackson and Fox (1996) used chronosequence analysis on 72 ant species from the same 44 sites at Tomago New South Wales to examine whether ant community structure varied with the type of disturbance and time since disturbance. They collected 25 habitat variables at each site covering vegetation structure, floristics, ground cover and soil variables with the key variables being percentage canopy cover of the site, percentage of bare ground and a vegetation index. Their results suggest that fire has a minor effect on the community over time, while the impact of clearing and mining is much more severe. Species composition at cleared and mined sites, after 18 years, approaches but does not match controls. The ant species succession seems to closely follow the vegetation succession and hence may be used as a bio-indicator for evaluating the extent of habitat damage and recovery after disturbance.

Past mining for gold has also resulted in extensive areas of disturbed vegetation in central and southern New South Wales, although the impact is not easily documented. It is clear though that areas impacted by gold exploration and mining activities in the middle of the 19th century retain many biological values after mining has been abandoned and regrowth initiated. An example from southern New South Wales is the Major's Creek area south of Braidwood, which was mined for gold in the middle of last century and consists almost entirely of relatively recent regrowth, but still retains a diversity of native plant species, which include the rare Araluen Gum, *Eucalyptus kartzoffiana* (M. Doherty pers. obs.). Although the composition of the area is not known prior to mining, the present composition appears to be a successful regeneration event in response to a severe but relatively short-lived impact.

Queensland

Thatcher and Westman (1975) studied succession following mining for mineral sands on North Stradbroke Island, although the study only investigated the site 5 years after mining. One interesting result was that plots closest to un-mined vegetation showed a greater rate of native vegetation re-establishment due to the availability of propagules. Hill and Phinn (1993), studying Swamp Wallabies (*Wallabia bicolor*) in the same area, found that re-vegetated sites were most heavily used for grazing at night at 2 to 4 years post-mining where vegetation was shrubby or grassy. Older sites offered little forage and were not utilised. Wallabies rested during the day in adjacent undisturbed eucalypt forest.

Further north, Unwin *et al.* (1988) studied the area around Rossville, south of Cooktown in Queensland, where alluvial tin mining has been carried out for 100 years. The evidence indicates that natural regeneration followed the cessation of mining on almost all sites. Generally, areas that were eucalypt forest reverted to eucalypt forest and areas that were rainforest reverted to rainforest. They claim an encroachment of rainforest via regeneration in the absence of Aboriginal burning into previously eucalypt-dominated areas. However, the evidence presented is not sufficiently detailed to assess the validity of this claim, nor to assess how different the pre- and post-mining vegetation types are.

Western Australia

Curry and Nichols (1986) surveyed bird species in 5 to 10 year-old rehabilitated bauxite mining areas. They found 21 species nesting in the rehabilitation, but that 11 other species only nested in adjacent un-mined areas. The main reason for the difference was a lack of suitable hollows for nesting in the young regeneration.

Majer and Nichols (1998) examined successional changes in ant communities within rehabilitated mine pits over 14 years against a forest analogue and concluded that mine pit ant community composition converged towards the forest site as time since rehabilitation increased. However, distinct differences between the mined and unmined sites remained.

Ward *et al.* (1990) discuss bauxite mine rehabilitation in Western Australia and report on research undertaken over a 10 year period. Important factors in returning mined areas to as similar a state as possible to the pre-mining condition include using freshly stripped soil rather than stockpiled soil and returning log debris as habitat. They report relatively high proportions of reptile, bird, mammal, ant and collembola species returning to rehabilitated sites. Koch *et al.* (1996) found that soil handling operations in bauxite mining in jarrah (*Eucalyptus marginata*) forest tended to drastically reduce germinable soil seed stores for rehabilitation. They traced soil seed stores at all stages from undisturbed forest that was then cleared and burnt, the soil stockpiled, re-spread and then deep ripped. The final seed content was 16 % of the original forest seed store density. Direct return of topsoil, with minimal delays at all stages, was recommended as a way of maximising retention of viability of soil stored seed. They go on to state that the jarrah forest appears to follow the 'initial floristic composition' model of succession. In this model, the composition of the vegetation in the first few years after disturbance will determine the ecosystem functioning and floristics in the long term. Therefore, it is imperative that high plant diversity is established as early as possible within rehabilitated sites.

2.2.2 Aquatic

Although most of the mining activities have only indirect impacts on aquatic biota, they can be long lasting and difficult to rectify. The common habitat stresses on aquatic environments caused by mining are:

- 1) land clearing and subsequent erosion, siltation, sedimentation and turbidity;
- 2) acid rock drainage (ARD);
- 3) salinisation due to disturbance of saline aquifer and dewatering;
- 4) dredging and extraction from lake and river beds;
- 5) disposal of effluents and waste water from processing operations resulting in leaching of toxins and harmful chemicals (e.g. mercury, arsenic); and,
- 6) direct disposal of waste mine tailings, slimes and waste rock into streams and lakes.

Most of the worst habitat degradations that have resulted in biodiversity loss today, are the results of past mining practices. Several well-investigated case studies have been chosen to catalogue appreciable mine-related impacts on aquatic biodiversity, with regard to the geographic scale and severity of their off-site effects.

Case Studies

The Mount Morgan mine site and the Dee River, central Queensland

The Dee River, in the central west region of Queensland, is an intermittent river that receives acid mine drainage from the Mount Morgan mine site. Mining operations began in the 1880s with the first copper extraction occurring in 1902. It is reasonably assumed that ARD has been entering the Dee River for a long time. Investigations on the diversity of macroinvertebrates in the 1980s showed their severe reduction over more than 15 km downstream of the mine-site, with the fauna still not completely recovering to distances of 50 km downstream (Mackey 1988). Bankside vegetation was also absent in the vicinity of the mine site, and the distribution of submerged macrophytes indicated their severe reduction over 50 km. However, some recovery in both macroinvertebrate diversity and submerged macrophyta was observed in 1985/6 that was attributed to the generally dry conditions that resulted in reduced ARD seepage into the river system (R. Jeffree pers. obs.).

More recent studies in the Dee River have confirmed the continuing nature of the pollution impacts of the mine site, following heavy rainfall events that occurred between November 2000 and February 2001 (Taylor and Howse 2001). Results

indicate that mine-site runoff water during high rainfall events can effectively bypass the mine's pumpback system, that had been designed to intercept such water before entry into the Dee River. Ongoing studies indicate that metal-rich waters from Mt Morgan have also infiltrated into the groundwater during acid flows in the river. River surface sediments are contaminated with copper, zinc and sulfur to at least 49 km downstream of the pollution source. During low flow conditions, the concentrations of various metals in surface waters were well in excess of ANZECC criteria for the protection of aquatic systems (1992) to at least 10 km downstream. During a recent high flow event, copper, zinc and aluminium concentrations in surface waters exceeded ANZECC guidelines to at least 43 km downstream. Four fish-kills were observed and monitored along the Dee River over these periods of high flows. These extended over 10-20 km downstream of the mine site, with an average density of 20 dead fish observed per 100 m of river bank.

Mount Lyell mine site: the King and Queen River catchments and Macquarie Harbour, western Tasmania

One hundred years of copper extraction at Queenstown by the Mt Lyell Mining and Railway Company, western Tasmania, has exposed large amounts of ore rich in sulfide to weathering and has resulted in the discharge of tailings into the Queen and King Rivers (Figure 2.9). Over 100 million cubic metres of mine tailings, smelter slag and topsoil have been delivered to this freshwater system, which flows into Macquarie Harbour. An evaluation of the environmental impacts of the resulting ARD on these freshwater systems has been determined by measurement of both biological and water quality conditions. Riffle macroinvertebrates were repeatedly sampled at an array of exposed and reference sites, primarily using the National River Health Program rapid assessment protocol. These investigations showed that the macroinvertebrates within reference sites were diverse and characterised by high abundances of particular taxonomic groups. All sites exposed to ARD pollution did contain a macroinvertebrate fauna, although typically of low abundance with the dominant taxonomic groups different to those found within the reference sites. All sites investigated in the Queen and lower King Rivers using this technique were highly or extremely impacted by ARD pollution, extending over more than 20 km of the river systems (Davies *et al.* 1996).

Exposed tailings on the river banks and in the delta continue to leach various metal contaminants into waters and sediments of Macquarie Harbour. Fish and benthic macroinvertebrate communities have been found to be lower in abundance and species diversity than other estuaries in south-eastern Australia. Phytoplankton in Macquarie Harbour were also characterised by low species abundance (Stauber *et al.* 2000).

(a)



(b)



Figure 2.9. Mineral operations at the Mt Lyell the mine site in the early 20th century releasing fumes as a result of the pyritic smelting process (a). The denuded hillsides were subject to erosion as a result of mineral operations (b).

Several streams in the Queen river catchment contained populations of introduced brown trout and rainbow trout, and tributaries of the lower King River supported three species of native fish whose occurrences and abundances declined with distance from Macquarie Harbour. Recruitment of native fish into the streams of the Macquarie Harbour catchment probably occurs on an annual basis (Davies *et al.* 1996).

Mining and the salt lake systems - dewatering

The myth of impoverished biodiversity of saltlakes (salinity $> 3 \text{ g L}^{-1}$) is being challenged by recent research work (Williams 1998a). While biodiversity of saltlakes is lower than that of freshwater, it is relatively high, except in extreme salinities. The invertebrates show a high degree of endemism. Australian salt lake fauna and flora of the semi- and arid-zones represent a wide variety of taxonomic groups including those represented in fresh water zones. These are not exclusively saltwater taxonomic groups. The heterogeneity of salt lake biota is associated with varying salinity observed at different locations even in a single lake, at different periods of the filling and drying cycle. It is not unusual to find patches of waterbodies with salinity close to 3 g L^{-1} in one part of a salt lake with many freshwater biota, whereas in another part of the lake, salinity up to 200 g L^{-1} may be observed. Lakes Lefroy, Lake Carey, Lake Dundas, Lake Cowan, Lake Yingargooda, Lake Miranda, are among a group of large saltlakes in the arid and semiarid region of Western Australia, which get filled to different levels during the rainfall events mostly in winter and summer. The duration and intensity of the rainfall determine the survival and distribution patterns of the biota.

The salt lakes in Western Australia are located along the palaeodrainage systems and basins. This saline land includes the greenstone belts of the eastern Murchison, eastern Goldfields, Yilgarn and Great Southern, which are rich in gold, nickel and other minerals. Mining has been active in these regions for decades. As the more accessible orebodies are mined, more resources have been diverted to exploring the deep sediments of the salt lakes for further mining. Associated with special problems of underground mining in these sediments, are the possible impacts on biodiversity of the salt lakes. Discharging the deep underground hypersaline water of the salt lakes into playa lake beds has been practiced for the past two decades or more. The effects

of such dewatering on a few playa lakes in the Kambalda region have been total loss of habitat of aquatic fauna and microalgae and destruction of peripheral vegetation (J. John pers. obs.). The mining industry is involved in conducting environmental assessment surveys to assess possible impacts of dewatering on biodiversity and is keen to avoid habitat loss and biodiversity.

Apart from the 'aquatic fauna and flora' which exploit the episodic rainfall events for their survival, there are also characteristic terrestrial fauna (mostly spiders, beetles and ants) which have made the lake bed their home, but unlike the former, the challenge for the latter is to endure or escape the inundation for their survival rather than exploit it. Here there are two sets of biota with conflicting needs (Williams 1998b). The impact of dewatering, physical destruction of habitat, acid drainage and the leaching of toxic chemicals on the biodiversity of salt lakes needs to be further investigated.

3.0 MANAGING IMPACTS ON BIODIVERSITY

3.1 Biodiversity Measurement

Notwithstanding the continuing scientific debate over the biodiversity concept, natural resource managers are under increasing pressure to operationalise the concept in order to report on the state of biodiversity and trends in its condition (Doherty *et al.* 2000).

It is widely recognised that there are three levels of biodiversity – ecosystem diversity, species diversity and genetic diversity – thereby forming the key units of biodiversity measurement (Beattie 1995). However, due to the complexity associated with assessing multiple levels of biodiversity, natural resource managers tend to evaluate only one or two of these levels. The majority of studies focus on species diversity as the preferred unit of biodiversity assessment and management, largely because of the ease with which different species can be recognised, but also due to the roles in ecosystem functioning that many species are now known to play. Conserving species across their range is also likely to contribute to the conservation of genetic diversity within these species.

Ecosystem diversity is considered by many as too difficult to operationalise as a unit of measurement because of problems with ‘on-ground’ delineation of ecosystem boundaries. Genetic diversity, while being fundamentally important as the basic unit of biodiversity, is also considered by most natural resource managers as too difficult and costly to evaluate.

Measuring biodiversity using species diversity involves a complex combination of values such as species richness, species composition and taxonomic range (Gaston 1996; Williams *et al.* 1996). Species richness alone, as a measure of biodiversity, has been used in several experimental studies investigating the functional significance of biodiversity on ‘ecosystem processes’ (Naeem *et al.* 1994; Tilman *et al.* 1996), but has been criticised as being inappropriate (Beck 1998), because it does not account for differences between component species. Species richness alone is consequently a poor measure of diversity, although it must be recognised that biologists have historically assessed species diversity in other more complex ways (Ghilarov 1996).

The rehabilitation of disturbed lands to an ecosystem representative of the pre-disturbed state cannot be undertaken without first assessing ecosystem complexity. Frequently undertaken as part of an environmental impact assessment, a baseline study is conducted to characterise the abiotic and biotic features of the area subject to development (see Mattiske *et al.* 1986). The outcome of this investigation has an impact on all stages of the mine life from start-up to mine closure. Should investigations determine the presence of gazetted rare species, mine planning is required to take into account the populations of these species. If relocation is not an option, then the baseline study may dictate the extent of all development and disturbance activities.

Considerable literature exists on monitoring programs to assess the impact and recovery of ecological communities following disturbance, e.g. Asher and Bell (1998; 1999). The taxa of Australian inland waters, particularly stagnant surface and subsurface water bodies, and their response to disturbance events have not been investigated to the same degree as terrestrial or marine systems (McComb and Lake 1996). Studies on the biota of temporary wetlands are rare (Lake *et al.* 1989). The ‘cuddly and charismatic’, ‘flagship’ and ‘icon’ species mostly hail from studies within terrestrial or marine environments. It is not surprising then, that the vast majority of

studies on the impact of the minerals industry have been on terrestrial or marine systems, with the latter mostly relating to petroleum extraction.

Diatoms and cyanobacteria often play a vital role in sustaining an array of invertebrates that, in turn, are a food source for the larger animals. Many of these microalgae are sensitive to environmental changes and hence may be utilised as biomonitors to assess aquatic health (John 1993). Indeed, the presence of diatomaceous earth within many aquatic habitats may be used as a historical record of water quality due to fluctuations in diatom species and numbers with changes in water quality.

3.2 Contribution of the Minerals Industry to Biodiversity Management

The loss of biodiversity is often related to implementation of development projects and changes in land use. The increased public concern and education in environmental issues may generate opposition to development projects with a poor environmental history. Aside from the issue of maintaining access to mineral resources, it is important that the Australian minerals industry both assesses and manages its impact on biodiversity for a host of other reasons. Biodiversity may provide, for example, ecosystem services (e.g. water purification), a source of biological resources (e.g. options for innovative technologies) and social benefits (e.g. recreation).

With an increasing community concern for environmental matters has come an increasing demand for best practice environmental management. The development of best practice techniques requires a detailed understanding of environmental issues and is directly linked to the resources that can be allocated to those pursuits. Within Australia, these resources are largely generated through revenues obtained from development processes, namely mining and agriculture (Webb 1990). Through taxes and revenues obtained from the minerals industry, the industry has become a major indirect source of funds that are available for environmental initiatives (Webb 1990).

The minerals industry conducts a considerable amount of in-house and commissioned research as part of environmental impact assessments for mining proposals and for

rehabilitation of the post-mined environment. As a result, the industry may be credited with contributing a substantial amount of knowledge on Australia's biodiversity.

Many of Australia's mineral reserves are located in remote locations and away from major population centres. The mineral leases are selected on the basis of geology rather than ecology or archaeology, and therefore are not necessarily areas that would receive thorough biological studies (Webb 1990). In many cases, biological research and surveys undertaken, or commissioned, by mineral and exploration companies, have revealed new populations or a greater understanding of the existing diversity and biology of flora and fauna of the region (Oliver 1994). For example, pre-mining vegetation surveys at Eneabba (300km north of Perth, Western Australia) over 20km² of the orebodies recorded 429 species, of which 15% could not be identified to species level, and 10% were classified as rare or poorly known (Brooks 1987). In addition, studies undertaken by Hamersley Iron Pty Ltd have contributed substantially to the understanding of regional flora in the Pilbara (NW Western Australia). Collections by the company have included over 50% of the known occurrences in the Fortescue Botanical District and further increased the understanding of the distribution and biology of these species (Mattiske *et al.* 1986).

Key strategies for biodiversity conservation and management should be based around the concept of bioregional planning, whereby biodiversity considerations are fully integrated with regional biodiversity management policies and programs. In some cases, such as areas impacted by rising salinity, the presence of feral animals and the proximity to sensitive environments, ecosystems that occur in adjacent areas may have an impact on the choice of management strategy occurring within the mineral lease. In many cases the minerals industry has undertaken to consider biodiversity issues of regional importance; however, in others, the minerals industry may be considered to be contributing to the loss of biodiversity and overall degradation of the landscape (Section 2.1.2). Because of its experience in landscape planning and coordination, the minerals industry can only benefit from opportunities to take a major leadership role in developing bioregional planning and management approaches to biodiversity issues in association with larger land holders such as the State governments and other industries.

The minerals industry owns a substantial amount of land within Australia despite much of this land not being mined. Occasionally, ownership of these lands is

maintained to ensure future access to the mineral resources within, when cyclical trends in the global mineral prices enable extraction to be profitable. More frequently, however, these lands are retained and managed under alternative land uses to facilitate profit for the company. The minerals industry, in managing these lands not allocated for mining, has developed management options that enable biodiversity considerations to be integrated with production.

The minerals industry has been an active participant of feral animal eradication programs and has sponsored research and practice into the application of feral eradication programs across broad scale areas of Australia. Several companies are also sponsors of initiatives to reintroduce native species into protected areas where these species were once known to exist.

Case Studies

Mount Weld Pastoral Company Pty Ltd

Mt Weld Station is a pastoral lease situated in the north-east goldfields region of Western Australia and is owned and run by the Mount Weld Pastoral Company Pty Ltd, Placer Dome Asia Pacific, Granny Smith Mine. The region has been the focus of mineral extraction for over 100 years, and hence contains hundreds of abandoned shafts, abandoned and active pits, drill holes, grid lines and infrastructure associated with mineral extraction. In addition, the Station has a long history of pastoral use and contains a number of priority flora species. In association with CSIRO Sustainable Ecosystems and the World Wide Fund for Nature, the Mount Weld Pastoral Company has developed a conservation strategy that accommodates the various ecosystems and habitats that occur on the lease, facilitates the rehabilitation of degraded areas and allows for an integration between mineral extraction, pastoral and conservation agendas.

The conservation plan allocates the paddocks within the lease to management uses to achieve a number of objectives including pastoral production, erosion control and rehabilitation, mining, catchment management and other uses.

Hamersley Iron Pty Ltd

Hamersley Iron Pty Ltd is a manager of several pastoral leases in the Pilbara region of Western Australia. It operates three pastoral stations that border Karajini National Park. In managing these pastoral stations adjacent to the conservation area, Hamersley Iron has developed a Memorandum of Understanding (MOU) with the State conservation agency, CALM (S. Anstee pers. comm.). The MOU enables the National Park to be managed in a manner similar to the biosphere reserve concept developed by UNECSO's 'Man and the Biosphere' Programme. Under this management regime, the pastoral stations adjacent to the National Park are managed as buffer zones to protect the integrity of the Park. The pastoral stations are managed on a graded system, with areas closer to the National Park managed to maximise biodiversity, while areas away from the Park are managed for cattle production. Through management of grazing, feral animal control and fire regimes within the pastoral stations, management of the National Park for biodiversity is not constrained by the Park boundaries, and multiple land use between conservation and production, or ecologically sustainable development, is shown to be possible.

Western Shield

In Australia, feral animals, namely foxes and cats, have decimated small mammal populations contributing to the extinction of 10 species of native animals and threatening extinction of 30 more. In 1996, a program initiated by CALM aims to bring these species back from the brink of extinction by controlling foxes and feral cats, on almost five million hectares of land.

The program, called 'Western Shield', introduces meat baits tainted with 1080, a naturally occurring poison found in the native plant genus *Gastrolobium*, into bushland throughout south-west Western Australia. Sponsorship, through financial assistance or in-kind support from mining companies, is essential to increase the benefits from feral predator control.

Financial support for the widespread baiting program has been obtained from the mining companies, Alcoa World Alumina Australia, Cable Sands (WA) Pty Ltd, Iluka Resources Ltd, Tiwest Joint Venture, the owners of the Boddington Gold Mine (Normandy Boddington Pty Ltd, AngloGold Australasia Ltd and Newcrest Operations

Ltd) with logistical support from the petroleum companies WAPET, Woodside and Apache (Armstrong and Batini 1998). The program has been successful in controlling fox numbers to the point where endangered native animals are beginning to thrive after being reintroduced into forest inside and outside reserves.

The provision of baits to private land owners adjacent to conservation reserves and State forests provides an extended buffer to assist in conserving native fauna populations and, to date, three forest-dwelling mammals have been removed from the State's Threatened Fauna List as a result of successful conservation management under the Western Shield program.

Other projects exist within Australia involving feral animal eradication from vast enclosed areas. Two projects in which the minerals industry is active include the Heirisson Prong Biosphere Reserve in Western Australia (Shark Bay Salt Joint Venture), and the Arid Recovery Project in South Australia (WMC Limited).

3.3 ESD and the Precautionary Principle

The conservation and appropriate management of biodiversity is a key requirement for achieving ecologically sustainable development (ESD). The precautionary principle has appeared in a number of broad policy statements, in particular, the National Strategy for Ecologically Sustainable Development (1992; p 8) and the National Strategy for the Conservation of Australia's Biological Diversity (1995, p 5). It also appears in the Intergovernmental Agreement on the Environment (IGAE) (paragraph 3.5.1):

'If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation'.

There are considerable gaps in the understanding of the levels of resilience in ecosystems and other aspects of biodiversity. As such, one often doesn't know how much, and what kind of, external perturbations a system can tolerate before it is significantly ecologically degraded, and for how long it will be degraded. Because of this uncertainty, there is a need for the Australian minerals industry to adopt the precautionary principle and proceed within ecologically sustainable limits if longevity

of the operations are to be maintained. Only as better information on the impacts of disturbance on biodiversity is obtained, can the need for its application be reduced.

3.4 Learning from Doing – Management ‘Experiments’

One of the major constraints to the effective management of biodiversity is the paucity of scientific data regarding the way biodiversity changes in response to disturbance. However, many biodiversity researchers are now recognising that there is a significant opportunity to improve the understanding of biodiversity by maximising the learning from the significant number of large-scale management ‘experiments’ that are occurring on a daily basis across many of Australia’s natural resource management sectors. Unfortunately to date, much of the potentially useful information from these activities has been rendered unusable due to a lack of formal experimental design such as a lack of controls and replication, changes in techniques and technologies over time, and a lack of basic before and after monitoring (see RAC 1992). In the absence of proven linkages, it is premature to suggest that there are such things as reliable ‘indicators’ of biodiversity, and it may be the case that certain components of biodiversity can only be assessed using direct measures.

In 1996, the minerals industry sponsored a project that would lead to the development of a technique to determine whether the underlying ecological processes that are required for the re-establishment of biodiversity occurs within rehabilitated mine-sites. Termed ‘Ecosystem Function Analysis’ (EFA), this technique was based on 20 years of research into rangeland ecosystems and examines a range of factors to determine the extent to which an ecosystem is achieving self-sustainability and nutrient cycling at a given time period (Bell 2001). The methodology consists of three modules (1) landscape function analysis (LFA), (2) vegetation dynamics, and (3) habitat complexity (Tongway *et al.* 1997a). Briefly, LFA examines how ecosystem resources such as water, soil, organic matter and nutrients are retained and cycled within the system, vegetation dynamics contrasts analogue sites with the rehabilitated areas, while habitat complexity is assessed on the basis of a number of features, i.e. canopy cover, shrub cover, ground vegetation cover, amount of litter, fallen logs and rocks, and free water availability (Kearns and Barnett 1999).

Industry personnel as well as other rehabilitation practitioners can benefit from the development of this technique. Through the use of simple tools, environmental

personnel will be able to assess whether the rehabilitated site is developing an ecosystem structure and habitat complexity according to the desired end-use.

This technique has been developed utilising data from 13 mine-sites from various mineral operations located across Australia and covering a range of climatic and community types. Presently the EFA technique is being assessed through further testing on mine-sites with a view to the technique subsequently being adopted by industry and government as part of an industry-financed study through the Australian Centre for Mining Environmental Research (ACMER).

3.5 Industry's Capacity to Protect Biodiversity

Mining activities and the infrastructure associated with them are just one of many land uses that impact on Australia's biodiversity. While there is much that the minerals industry can do to ensure that biodiversity is both adequately assessed and managed within its leases, the wide-ranging and cumulative nature of many of the processes that are now threatening Australia's biodiversity, demand holistic and coordinated bioregional planning approaches to the assessment and management of biodiversity. Such approaches are generally beyond the responsibility and capacity of the minerals industry alone, although there are significant opportunities for the industry to take major leadership and catalytic roles in bioregional planning and management activities.

3.5.1 Adequacy of skills and expertise

There is little accurate information available on the skills and expertise of the minerals industry with regard to biodiversity assessment and management. As such, the capacity of the industry in terms of skills and expertise can only be inferred through crude assessment of the level of education, training and networking among the industry's environmental management professionals. An industry-wide perspective has been gauged by exploring the level of access and effectiveness of the industry's key research and development providers.

3.5.1.1 Industry's environmental management professionals

As noted by Hancock and O'Neill (1996), since the mid 1990s, most new environmental management recruits in the Australian minerals and energy industries are products of the many specialist undergraduate courses now in place, and are thus qualified environmental professionals. Universities focussing on environmental management as it relates to the minerals industry include The University of Queensland, The University of Western Australia, and Curtin University, although there are many other universities around Australia offering more general environmental courses. Most of these universities have experienced high levels of student enrolment in their environmental courses during much of the 1990s; however, in the past few years, this popularity seems to have waned among some, as student interest in courses such as information technology increases.

It is clear that the skills and expertise of environmental professionals in the minerals and energy industries have greatly improved over recent years; however, accompanying this improvement, are rapidly increasing community expectations regarding the environmental performance of the operations and activities for which they are responsible. This has led to an increase in demand for environmental recruits with specialist post-graduate training in environmental science or management, in addition to the disciplinary backgrounds obtained during their undergraduate degrees. However, as the calibre of recruits required steadily rises, so too does the difficulty in filling environmental positions. As a result, there appears to be a trend for the industry to out-source some of its environmental management and R&D requirements to consultants and research providers. This is particularly true for specialist issues such as biodiversity assessment and management. In many ways, the use of consultants can provide cost-effective solutions to plan, manage or monitor environmental issues as they have access to broad-based expertise, or expertise in particular fields, e.g. specialist hydrogeologists.

Not all mining companies having followed this out-sourcing model. For instance, the Australian subsidiary of the Alcoa company (Alcoa World Alumina Australia) has developed considerable skills and expertise in the rehabilitation of jarrah forest ecosystems in Western Australia, following three decades of extensive research and development. Alcoa World Alumina Australia now possess a very competent team of environmental scientists who regularly publish the results of their studies of

ecosystem development in Australian and international scientific journals. Many consider that this research and development has now reached a point where restoration of the pre-existing jarrah forest ecosystem is a realistic target (May *et al.* 1996). In recognition of their achievements, Alcoa of Australia Ltd (Alcoa World Alumina Australia) was listed in 1990 by the United Nations Environment Program on its 'Global 500 Honour Roll'. Several other large mining companies, including Hamersley Iron Pty Ltd and Energy Resources of Australia, have also established teams of qualified environmental professionals. Other companies employ smaller teams and access the required expertise through consulting companies and/or links with Universities.

It is vitally important that environmental management professionals are able to keep pace with changing technologies and new scientific developments. Regular access to training and networking opportunities is therefore critical. Hancock and O'Neill (1996) stated that there are now significant opportunities for training within the industry through the variety of short courses and distance learning opportunities that are available. With regard to networking, the Minerals Council of Australia (MCA) has established a long tradition of annual environmental workshops, which provide an important opportunity for practitioners and researchers to get together (May *et al.* 1996). In addition, many regional groups have now formed throughout Australia, with the purpose of identifying and discussing common problems relating to environmental management of mine sites in the region (Hancock and O'Neill 1996). These groups meet more regularly than the annual MCA environmental workshops and have become a very effective way for the environmental management professionals in the minerals and energy industries to interact and liaise with government representatives, consultants and researchers within their region.

Short courses and workshops, focussing on the technical aspects of environmental issues faced by the minerals industry are also organised by the Australian Centre for Mining Environmental Research (ACMER) at locations around Australia, and these complement the more general awareness-raising national workshops conducted by MCA and the Australian Minerals and Energy Environment Foundation (AMEEF).

3.5.1.2 Industry's research and development providers

May *et al.* (1996) notes that much of the industry's environmental research is typically characterised by a single company focus on short-term site-specific needs. While this focus still dominates, there has been an increasing focus on longer-term strategic research in recent times, particularly on issues where the outcomes have industry-wide relevance. The ACMER through its research partners, the Australian Nuclear Science and Technology Organisation (ANSTO), Commonwealth Scientific and Industrial Research Organisation (CSIRO), Curtin University of Technology, The University of Queensland and The University of Western Australia, are addressing a range of biodiversity research projects relevant to the minerals industry.

3.5.2 Experience and environmental reputation

It cannot be denied that the mineral industry's reputation has suffered from some of its poor environmental performances in the past. The legacies of some of the earlier mining practices throughout Australia, for example, the denuded landscapes of Mt Lyell in Tasmania and the pollution of the Finniss River in the Northern Territory, have contributed to this. However, many of the country's eminent environmental scientists are now recognising that the modern mining practices of today's industry pose far less of a threat to biodiversity than many of Australia's more extensive land uses such as agriculture (see Beattie 1995; Saunders *et al.* 1996; and White 1997).

Professor Andrew J. Beattie, Macquarie University, Sydney, has stated in his book, 'Biodiversity – Australia's Living Wealth', which provides one of the most comprehensive accounts of Australia's biodiversity, that:

'Australia is leading the world in many kinds of restoration technology, especially for mine sites' (Beattie 1995, p124).

He goes on to state:

'(researchers and the) ... environmental officers of many mining companies are beginning to understand how to re-assemble species into communities that have a chance to grow, develop and rebuild local biodiversity. This is a major advance over previous techniques, which usually involved merely covering the site with a layer of green, often exotic grasses or pine trees.'

Further evidence of Australia's international reputation in mine-site rehabilitation is provided by the inclusion of Alcoa of Australia Ltd on the United Nations Environment Program's Global 500 Roll of Honour for its rehabilitation of jarrah forest ecosystems in Western Australia following bauxite extraction.

3.5.3 Willingness, interest and obligations

In many instances, the current operations within the minerals industry are taking the initiative to rehabilitate historical operations that occur within their mineral lease (Section 3.1: Mount Weld Pastoral Company Pty Ltd). It has been argued that, in some remote, arid areas, there has been an over allocation of resources for mine-site rehabilitation with the costs disproportional to the expected benefits (Johnston 1993). It is acknowledged however, that mining is a temporary land use and that mined land should be left in a manner that will not compromise the activities of subsequent users (Farrell 1993).

In ensuring that mined lands are effectively rehabilitated, both the industry and Government prefers self-regulation through the use of education and encouragement as opposed to the use of a 'big stick' by regulators (Fitzgerald 1993). In ensuring that self-regulation is effective, the minerals industry has produced the Australian Minerals Industry Code for Environmental Management and, in conjunction with Environment Australia, has published a number of modules containing information on a variety of topics related to best practice environmental management in Australia's minerals industry.

3.5.3.1 The Code for Environmental Management

As reported by MCA (2000), by signing the Code, signatories voluntarily commit to excellence in environmental management through seven principles:

- Accepting environmental responsibility for all actions;
- Strengthening relationships with the community;
- Integrating environmental management into the way we work;
- Minimising the environmental impacts of activities;

- Encouraging responsible production and use of products;
- Continually improving environmental performance; and
- Communicating environmental performance.

Commitment to the Code brings with it a number of obligations. In summary these are:

- Application of the Code wherever the company operates;
- Production of an annual public environmental report within two years of registration;
- Completion of an annual Code Implementation Survey to assess progress against implementation of Code principles; and
- Verification of the survey results, by an accredited auditor, at least once every three years.

However, in a review of mining environmental reports, the World Wildlife Fund believe that, as it currently stands, such a wide spectrum of environmental and social performance complies with the code (from very poor level of performance to industry leaders) and stakeholders such as WWF are unable to use compliance with the Code as assurance that an acceptable level of environmental and social performance is being met (WWF 2000).

3.5.3.2 Environmental management and regulation

Bradfield *et al.* (1996) provide an indicative list of legislation relevant to the minerals and energy industry. As noted by Brooks *et al.* (1996), the introduction of the *Environmental Protection (Impact of Proposals) Act 1974* by the Commonwealth Government was one of the most significant pieces of Federal environmental legislation, requiring the preparation of an Environmental Impact Statement (EIS) for those projects needing approval at the Federal level. However, this Act was subsumed by the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) on 16 July 2000. Under this new legislation, actions that are likely to have a significant impact on a matter of national environmental significance are

subject to a rigorous referral, assessment, and approval process. An action includes a project, development, undertaking, activity or series of activities.

The Act currently identifies six matters of national environmental significance:

- World Heritage properties;
- Ramsar wetlands of international significance;
- Listed threatened species and ecological communities;
- Listed migratory species;
- Commonwealth marine area; and
- Nuclear actions (including uranium mining).

Because Australia's States are responsible for environmental regulation within their own borders, they have also developed their own procedures for assessing the environmental implications of projects. This autonomy has led to differing environmental legislation around the country. For instance, in Queensland the Mineral Resources Act 1994 (and subsequent amendments to) requires the holder of a mining lease to have developed an approved Environmental Management Overview Strategy (EMOS), which is an agreement between government and the mining company or leaseholder to undertake environmental protection measures and rehabilitate disturbed land. There are similar formal requirements for environmental management plans in NSW. Many of these kinds of regulations include a system of security deposits to cover the cost of rehabilitation. Unfortunately, in some cases, these security deposits have been set too low, which, coupled with inflationary pressures, has meant that some rehabilitation has been subsidised by State Governments (Lee 1999).

According to Bradfield *et al.* (1996), there have been several key trends in environmental management and regulation within Australia during the past decade. The first of these was the development of more holistic and integrated legislation in recognition of the systemic nature of most environmental issues. As such, all States have now enacted environmental protection legislation, which subsume the many previous single-issue pieces of legislation. This integrated legislation is often now administered by a single government organisation. The second important trend has been the increasing Australian and international concern for the environment, which

has led to increasingly stringent legislation being passed in a number of Australian States to further discourage activities that damage the environment.

With all this in mind, there has been a significant move in the past five years towards much greater self-regulation in the Australian minerals industry, and far less emphasis on the traditional 'command and control' approach to environmental management. The major elements of this move towards self-regulation include the development and update of the Australian Minerals Industry Code for Environmental Management, self-audit of Code signatories to ensure compliance with self-imposed standards, and the development of pollution reduction targets and incentive schemes. With regard to the latter, the NSW EPA introduced a 12-month, pilot tradeable salinity credits scheme in 1995, as a means of using economic incentives to limit saline discharges in the Hunter River during low flows to protect the river's ecosystems and the interests of irrigators (EPA NSW 1997). This innovative approach differs markedly from the traditional approach of progressively increasing the complexity and restrictiveness of license conditions.

3.5.3.3 *National Parks and conservation reserves*

Within Australia there are 3216 national parks and conservation reserves, the majority of which have been declared and managed according to State legislation. The Commonwealth Government declares and manages parks and reserves only on land owned or leased by the Commonwealth, in Commonwealth waters and on Aboriginal land leased to the Commonwealth, with the remaining areas being under State management. As there is no coordinating legislation between the States, over 50 designations have been developed to determine the activities of these areas, although the occurrence of national forums and joint programs do exist to ensure that these protected areas achieve a common purpose. Management of these different designations vary from strictly protected areas with limited public access, to areas where recreation is encouraged but resource development is not, to multiple use areas where resource utilisation, recreation and nature conservation are all practised.

Exploration activities have identified more than \$10 billion worth of mineral deposits that are alienated in conservation reserves and other developments across Australia (Allan *et al.* 1988; Allen *et al.* 1990; Batini 1997). There are many cases both for and

against mineral extraction occurring within National Parks and other areas designated for conservation. The respective arguments often depend on whether the author is sympathetic to the minerals industry or the conservation movement, as the opposing views appear irreconcilable (Batini 1997).

Frank Batini, a leading environmental manager within the Western Australian Department of Conservation and Land Management has reported that, as of 1997, of the recognised vegetation types outlined within Beard's vegetation mapping for Western Australia;

- 21 percent were adequately reserved,
- 34 percent were represented below accepted adequate levels,
- 47 percent were not represented at all in formal reserves.

Given then that a large percentage of these vegetation types are not adequately reserved and that some of the existing reserves exist only as a result of their poor suitability for alternative land uses (Section 2.1.3), conservationists state that adequate resources exist outside of reserves to placate the minerals industry (Batini 1997). Indeed, it is claimed that given the highly fragmented nature of many of our ecosystems, excision of a mineral lease from an existing National Park is likely to have an effect on ecosystem structure and community integrity (Batini 1997).

The minerals industry recognised the need for ecologically sustainable development long before the Commonwealth government published the National Strategy for Ecologically Sustainable Development in 1992. The minerals industry cites best practice techniques that are less intrusive than historical operations and operations where the post-mined rehabilitation is comparable to analogue sites. Indeed, studies contrasting the successional patterns within the post-disturbance environment following sand mining against fire have suggested that the response to the two disturbance events is comparable. The variation between the two events occurs in the time scale, with restoration of the mature community being more rapid within the post-fire environment (Fox 1990). When operating within sensitive environments, the minerals industry has demonstrated that its activities may be compatible with conservation objectives provided that planning, monitoring and rehabilitation objectives are rigorous (Allan *et al.* 1988; Allen *et al.* 1990; Fitzgerald 1993; Lewis 1996). The area of a mineral lease that is impacted by mining is frequently very small

and, in addition, due to effective management of these areas outside of the active area (fire, feral animal control, weed control), the mineral lease may be in a more 'pristine' environment than the surrounding National Park (Webb 1990).

Examples of multiple land use compatibility between development and conservation include the Ranger uranium mine adjacent to the World Heritage-listed Kakadu National Park and absorption of the rehabilitated Bridge Hill Ridge mineral operations into the Myall Lakes National Park. While these operations may at first seem inappropriate as examples of multiple land use compatibility due to the public outcry associated with these operations, at both locations, the minerals industry undertook rigorous planning and monitoring to minimise its environmental impact.

The uranium orebodies at Energy Resources of Australia Ltd mine at Ranger were identified by an airborne radiometric survey in 1969, and open-cut mining commenced in 1980. In the 20 years that the mine has been in development and operation, there have been no environmental impacts of the mine on the values of Kakadu National Park (EIA Network 1998). Monitoring by the Supervising Scientist has determined that any elevation of radionuclides above background levels in the water or air in the World Heritage property has been within the established limits and has not harmed the surrounding ecosystem or the people that utilise these resources (EIA Network 1998).

Mineral Deposits Ltd's (MDL) Bridge Hill Ridge mine commenced mineral sands operations in the mid-1970s. Progressive rehabilitation of the mined out areas was undertaken during operations. In planning for rehabilitation that would facilitate a rapid plant cover to stabilise the dune surface and promote the return of a self-sustaining forest ecosystem similar to the pre-mined environment, MDL pioneered the direct replacement of the topsoil that is still promoted as best practice today (Lewis 1996). Reshaping of the tailings has ensured that the major topographical features of the landscape has remained intact, the vegetation is developing into mature communities, fauna have recolonised the post-mined environments and succession is proceeding along desired pathways (Lewis 1996). Relinquishment of much of the mined area has taken place, with the post-mined environment being absorbed within the Myall Lakes National Park.

Case Study

Iluka wetlands – sand mine pits into a sustainable wetland system

It is estimated that more than 70% of the natural wetlands in Western Australia have been lost since European settlement due to filling and draining. This has resulted in a shortage of habitats for aquatic biota and waterbirds, including migratory birds.

Rehabilitation of mine-voids or pit-lakes into sustainable ecosystems is considered to be a positive contribution towards restoration and enhancement of aquatic biodiversity. The Iluka wetlands at Capel (formerly the RGC Wetlands Centre), 200 km south of Perth, Western Australia, are an excellent example of such a venture. In addition, it is one of the few created wetlands for conservation of biodiversity whose ecological and taxonomic components have been monitored throughout its entire history with the involvement of a multidisciplinary team of experts. The ultimate goal of the project was to create habitats to attract a maximum diversity of birds. The chronological sequence of development of the chain of wetlands at Capel has been presented by Brooks (1991), Brooks and Nicholls (1996) and Doyle and Davies (1998).

The success of the rehabilitation of the Iluka wetlands from acidic pit-lakes can be attributed to: concept plans implemented in 1987, 1990 and 1993 involving intense modifications of the physical habitat of the lakes to cater for birds, planting of appropriate emergent fringing and peripheral vegetation, colonisation of macrophytes especially Charophytes, macroinvertebrates, fish, frogs and reptiles, and continuous biological monitoring and biodiversity surveys involving all groups of biota by researchers, as part of the management strategy.

The wetlands centre has become an educational resource for primary, secondary and tertiary students. The centre is open to the general public, and there is a constant array of visitors.

3.6 Rehabilitation Progress in Impacted Areas

The effort that the minerals industry has undertaken to develop a greater understanding of native ecosystems, and hence allow improved rehabilitation of impacted areas, has dramatically improved the quality of the post-mined areas. The applicability of these techniques to broad scale areas has become increasingly relevant

as modern mining techniques impact larger areas in search of viable resources and economies of scale.

Historical operations were frequently underground and had a lower surface impact (despite being greater in number with little attempt to manage environmental impacts on surrounding surface areas). Today, large open cuts are more common within the minerals industry, and thus the impact of the mine void is greater than the smaller underground operations. Waste dumps and tailings resulting from modern mineral operations, however, are rehabilitated to a high standard, whereas, historically, a lack of community concern and understanding for environmental issues meant they often were not rehabilitated at all.

New mines may also have satellite pits with linking haul roads and infrastructure that impact on biodiversity function as previously mentioned, i.e. hydrology and fauna movement. Thus, to minimise the impact on the local environment, the new mines are required to be more rigorous in monitoring and planning.

3.6.1 Practices

3.6.1.1 Topsoil manipulation and seedbed management

The importance of viable topsoil for rehabilitation of degraded areas and mined lands has been emphasised in many publications (Iverson and Wali 1982; Koch and Ward 1994; Grant and Koch 1997; Izaurrealde *et al.* 1998). It is estimated that up to 77% of species within the rehabilitated bauxite mine pits within the jarrah forest community of Western Australia are derived from topsoil seed reserves (Koch and Ward 1994; Ward *et al.* 1996). Soil seed banks are often the only source of seeds of many species that are no longer present in the vegetative biomass, particularly so for early successional species which contribute to the development of the seed bank in the initial period following disturbance (Leck and Leck 1998).

In many of the older sites where the minerals industry was active, soil seed bank dynamics were poorly understood, and the location of germinable seed within the soil horizons was equally unknown. Consequently, the upper horizons containing the soil seed reserves were mixed with soil lower in the profile upon stockpiling or return of

the soil to reformed mined pits. This resulted in a dilution of the seed bank to depth from where some species were unable to emerge.

Seed burial studies have revealed an inability of many species to emerge from depths greater than 5–10 cm (Grant *et al.* 1996; Rokich *et al.* 2000). In addition, stockpiling of soils have been found to decrease the viability of the soil seed bank (Tacey and Glossop 1980; Nichols and Michaelsen 1986). These findings would help explain the results of Tacey and Glossop (1980) and Nichols and Michaelsen (1986) who found improved recruitment and species composition amongst emergents when the upper 5 cm of the topsoil was transferred, without stockpiling, onto the rehabilitated mine pit. Although it is not always feasible to undertake direct replacement of topsoil, the majority of mineral operations utilise this technique whenever possible and minimise the time that topsoil resources are stockpiled.

There have been reports regarding the use of rock armouring to minimise erosion and facilitate microclimates which assist in the establishment of native vegetation (Williams *et al.* 2001). The use of topsoil alone on steep batters may not resist erosion and can result in lower rates of vegetation establishment if the topsoil is utilised on steep inclines (Williams *et al.* 2001). The importance of topsoil as a source of microorganisms, organic matter and nutrients is recognised, and hence techniques have been investigated to concentrate the topsoil seed bank (Ward and Koch 2000). When applied in combination with rock pitching, this technique may allow for the application of the topsoil to promote biodiversity conservation within rehabilitated areas, while retaining the protection of the rock pitching as insurance against unforeseen circumstances, e.g. heavy rainfall events or fire, that may expose the surface to erosional forces.

In an attempt to enhance the establishment of rehabilitated areas, many companies utilise fertilisers to facilitate the initial growth and establishment of seedlings within rehabilitated areas until the organic matter can build up and nutrient cycling processes can begin. The incorporation of phosphorus-absorbent residues from bauxite refining to sandy soils to increase soil fertility has also been investigated with some success (Ward and Summers 1993).

Repeated passes by heavy machinery over the soil surface during rehabilitation operations may result in the development of subsurface hardpans. Deep ripping along

the contour to 1.5 m by a DC10 bulldozer and winged ripping tine can assist to break the subsurface compaction layer and enable long-term survival of deep-rooted species within the rehabilitated area (Ward *et al.* 1996). Soil scarification techniques, such as moonscaping, can assist in the development of microclimates, enable water infiltration and therefore minimise erosion, as well as assist in the development of source/sink areas to facilitate nutrient cycling.

3.6.1.2 Broadcast seed technology

The use of broadcast seed within a revegetation program can assist in the establishment of native species. The use of topsoil has been found to account for a large majority of recruits within post-mined lands in some communities (Koch and Ward 1994; Ward *et al.* 1996); however in many situations (for example where topsoil has been stockpiled or contained a high percentage of weeds), the use of broadcast seed is a vital component for re-establishment of native communities.

The importance of broadcast seed to revegetation programmes is indicative of the effort that has been undertaken into maximising recruitment from these seed reserves. A substantial effort has been undertaken by the industry leaders to maximise recruitment from this seed resource from seed handling and storage techniques, the timing of broadcast seed application, the development of dormancy-breaking techniques and engineering solutions to produce cost-effective techniques of applying broadcast seed.

The minerals industry utilises direct-seeding techniques to rehabilitate the post-mined lands, while the planting of tubestock seedlings represent a minor component of the rehabilitated landscape. In many cases, the protocols that the minerals industry has developed are applicable to the rehabilitation efforts of other groups (e.g. Landcare, bush regeneration) and hence have beneficial applications beyond the minerals industry. For example, as the success of broadcast seed applications is reliant on weather patterns and post-germination rainfall, to maximise the chances of successful establishment within arid areas, the minerals industry typically pre-treats only 30-50% of the broadcast seed to ensure that a residual seed bank remains should the initial recruits fail to become established (MCA 1998).

The minerals industry is aware of the importance of provenance in revegetation and, despite the difficulties in determining how 'local is local', the industry attempts to source seeds as close to its operations as possible.

3.6.1.3 *Smoke-stimulated germination*

The application of smoke to seeds has been found to promote germination in a large number of plant species from a number of ecosystems across Australia and hence, there is a great potential for smoke to assist in the revegetation of the post-mined environment (Dixon *et al.* 1995; Enright *et al.* 1997; Roche *et al.* 1997; Kintrup and Enright 1999; Read and Bellairs 1999).

Smoke may be utilised as a treatment to overcome dormancy within broadcast seed prior to sowing or storage. These effects have been reported to last for at least a year following smoke application to the seeds and storage under appropriate conditions (Brown and van Staden 1997).

Studies undertaken in *Eucalyptus* woodlands of Victoria have suggested no adverse affects of smoke on germination of species that are not smoke-responsive (Enright *et al.* 1997). This finding supports the use of smoke as a routine treatment for broadcast seed and is a technique utilised by some mining companies in Australia to improve recruitment and biodiversity within rehabilitated areas.

3.6.1.4 *Long-term sustainability of rehabilitated lands*

An important aspect of rehabilitation is investigation into the long-term sustainability of the restored ecosystem. This has necessitated research into many ecological processes, e.g. seed biology, fauna habitat reconstruction and completion criteria.

Following mineral extraction, the development of a mature, self-sustaining forest that fulfils all functions of the unmined forest will take a long period to develop as mineral extraction leads to a complete renewal of ecological processes within the active area (Fox 1998).

The use of fire within post-mined landscapes has been investigated and found to be successful in further enhancing species establishment (Koch 1992; Smith *et al.* 2000). More evidence of the slow development of self-sustainability was presented in the

findings that 11–15 year-old rehabilitation within the jarrah forest community in south-west Western Australia had to be treated with a different fire regime to the surrounding forest, due to different vegetation and fuel composition (Grant *et al.* 1997).

Plant disease has the potential to impede the development of community sustainability. The fungal disease *Phytophthora cinnamomi* (dieback), for example, has the potential to be dispersed across areas where the minerals industry is active through stockpile drainage, transfer of infested soil by way of vehicle movement and drainage from infected mining and rehabilitated mined areas (Crosbie and Colquhoun 1999). Studies have suggested that the total potential for dieback spread due to mine clearing (under current practices) in SW Western Australia is an average of 0.01 ha per hectare cleared for mining (Crosbie and Colquhoun 1999).

Despite setbacks such as disease, and the slow development of old rehabilitation toward sustainability, studies are indicating that functional ecosystems can develop on rehabilitated mines (Ward 1998; Tongway *et al.* 1997a). Early recognition was made of the need to develop whole ecosystems, rather than just ameliorating physical and chemical conditions and establishing vegetation (Nichols and Bartle 1986). As revegetation initiatives have become more successful, many flora studies have focussed on researching those species that are hard to germinate. To achieve maximum plant diversity, a combination of the use of applied seed, soil seed reserves and recalcitrant species are being utilised by the majority of operations.

3.6.1.5 *Vegetation management*

Exotic species of plants (and animals and microorganisms) have the potential to significantly alter Australia's biodiversity (BDAC 1992). In some cases this has already occurred, to the detriment of the ecosystem. Problems can also occur where native species extend their range. One of the objectives in the national strategy for biological diversity is to encourage the use of local indigenous species in rehabilitation and discontinue the use of non-local species (native or exotic) to halt the spread of species not local to areas (BDAC 1992). In the past, exotic nitrogen fixers or nurse crops were used to help improve the mine soils, provide organic matter and stabilise the soil surface (Fox 1984). Many of these species have persisted in the post-

mined landscape via recruitment from the soil seed bank with at least one (Bitou Bush; *Chrysanthemoides monilifera* ssp. *Rotundata*) having become listed among Australia's top weeds of national significance as a result of being actively planted (Csurhes and Edwards 1998). The newer strategies have reduced these old practices, which helped spread exotic species and endangered biodiversity.

In areas that have been mined, the magnitude of a weed problem is a function of the availability of plant propagules (Panetta and Groves 1990). Where mines are located in pastoral land, there is ample opportunity for weed species to invade. For example, in the Ord River region, a development vegetation survey found the introduced *Calotropis* sp. growing densely along riverbanks and in the unused agricultural fields, along with the introduced *Parkinsonia* sp. (Meagher and LeProvost 1980). Often, because native seedlings remain small for long periods, they are disadvantaged when competing with introduced species (Panetta and Groves 1990). Most rehabilitation practices now refrain from using exotic species in the rehabilitation mix or utilise sterile, non-seeding species to assist in soil stabilisation to enable native species establishment. Where the species that are utilised as cover crops to assist in soil stabilisation are perennial, careful monitoring is essential to ensure that this species does not extend its range beyond the immediate area.

3.6.1.6 Habitat development

A number of mining companies are addressing the fact that some faunal habitats will take a long time to develop in rehabilitation, for example hollows in trees, logs and stumps, piles of branches, and tall perches. Many companies are constructing faunal habitats from materials pushed aside during clearing operations prior to mineral extraction. The habitats may consist of logs, log piles, stumps, rocks or various combinations of these, with soil carefully placed around them. Operational procedures describe how habitats should be constructed to provide shelter niches and opportunities for animals to burrow underneath. The reintroduction of habitat logs following mining has assisted in the succession of native fauna within the post-mined environment (Sainsbery *et al.* 1999). Various mammal and reptile species, including the rare Southern Brown Bandicoot, have been recorded utilising these constructed habitats and several other rare species are expected to do so (Nichols pers. comm.).

The use of nest boxes in rehabilitation have been undertaken by the minerals industry and have been found to be utilised by a range of small arboreal mammal and reptile species.

Consolidated Rutile Limited builds both log piles and tall perches in its rehabilitated mineral sand mines on North Stradbroke Island. The perches are designed to attract raptors and other bird species that are expected to bring plant seeds and nutrients into the rehabilitated area.

3.6.1.7 Monocultures and exotic species

Whilst rehabilitation using monocultures and exotic species was acceptable in the past, in most mines it is no longer so today. The activities of Alcoa World Alumina Australia are a good example of the differences in old and contemporary mining and their effects on biodiversity through rehabilitation procedures.

Alcoa World Alumina Australia has been mining bauxite in the jarrah forest of southwest Australia for over 30 years (Nichols *et al.* 1991). This period of time has encompassed continuing changes in the standard of mine-site rehabilitation. Up until the early 1970s, the post-mined environment was rehabilitated with exotic pines (e.g. *Pinus pinaster*), and up until the late 1980s, the post-mined environment was rehabilitated with eastern states eucalypts (e.g. *Eucalyptus resinifera*) (J. Koch pers. comm.). Exotic pine plantations were sown with no understorey seeding (Grant and Koch 1997). Pines are not conducive to the development of a native understorey, and hence few understorey species established leaving essentially a monoculture of pine trees.

Pine plantation rehabilitation ceased in the early 1970s. Non-local eucalypt species were then chosen for rehabilitation due to uncertainty regarding the susceptibility of local overstorey species to dieback disease caused by *Phytophthora cinnamomi*. Sites planted with eastern states eucalypts were seeded with an understorey of local native plants. While these may have had a higher biodiversity than the pine sites, they were not conserving the full range of biodiversity that existed in the pre-mined environment.

To help with difficulties in establishing trees in the elevated salt conditions that may be experienced when mining moves into the lower rainfall eastern jarrah forest, an

elite variant of jarrah was developed that could tolerate the elevated salt balance (Kabay and Nichols 1989). Although the genetic superiority ensured that the trees did well, these variants were propagated via clonal techniques which significantly reduced genetic biodiversity within the rehabilitated stand.

There were a number of reasons at the time for Alcoa to consider the use of exotic species and the development of monocultures, viz. resistance to dieback, future timber potential and the cheaper and less labour intensive option than establishing some of the difficult native species. Land could be stabilised and saved from problems such as erosion much quicker using species better suited to that purpose. The rehabilitation aims of the minerals industry as a whole have changed considerably over the years in response to improved knowledge, increased awareness of the importance of biodiversity (Ward 2000), and developing technology. Alcoa's current strategy of restoring a stable, self-generating forest ecosystem which maintains or enhances water, timber, recreation, and conservation values is a more suitable plan, when considering the complex, high diversity system that is the jarrah forest (Nichols *et al.* 1991) (Figure 3.1).

(a)



(b)



Figure 3.1. Alcoa World Alumina Australia operations in south-west Western Australia during mineral extraction (a) and after rehabilitation (b) showing rehabilitation that is consistent with the values of the surrounding forest ecosystem.

3.6.1.8 *Aquatic habitats*

Two case studies from tropical northern Australia have been selected to illustrate contrasting mine-site environmental management practices, particularly with respect to mining impacts on downstream aquatic biota and its biodiversity. The first case study describes a decommissioned and rehabilitated copper-uranium mine, Rum Jungle, that caused severe downstream ecological impact due to acid rock drainage (ARD) from the site. The second case study describes the extensive chemical and biological monitoring programs that have been developed and implemented at an operating uranium mine (Ranger), to ensure that no adverse downstream ecological impact occurs. The severe ecological impacts observed at Rum Jungle, for example, increased public awareness of environmental issues, and played an important role in the requirement for the rigorous environmental management practices currently in place at Ranger.

Both mine sites have been extensively studied over the last 25 years, and hence provide a long-term dataset to quantify both actual and predicted ecological effects in relation to measured contaminant (e.g. metal and/or pH) levels. This has led to an increasing number of studies investigating the mechanism(s) of metal-organism interactions (i.e. uptake, toxicity), particularly an understanding of biological responses in relation to aqueous metal speciation, including how water quality variables (e.g. pH, hardness, alkalinity and dissolved organic matter) may influence trace metal bioavailability. Such an approach enhances the capability of predicting the biological effects of metals across a range of water chemistry conditions. The measurement of metal speciation and bioavailability permits national numerical guidelines for protecting aquatic ecosystems to be potentially relaxed on a site-specific basis.

The Finnis river below the Rum Jungle mine has been contaminated by ARD (principally copper (Cu), zinc (Zn), manganese (Mn), uranium (U), aluminium (Al), sulfate and acidity), a product of oxidation of sulfide minerals in the mine waste, originating from multiple sources. Between 1983 and 1985, the site was rehabilitated by the Federal Government at a cost of A\$18 million. This resulted in a substantial (ca. 70%) reduction in the annual loads of trace metals and sulfate entering the Finnis River. These reductions in contaminant loads have been followed by an

increase in the diversity and abundance of freshwater biota downstream from the mine.

Ranger is a currently operating a uranium mine that commenced mining and milling operations in 1981. It is located a short distance upstream from the floodplain of Magela Creek, and is surrounded by the World Heritage listed Kakadu National Park. In contrast to Rum Jungle, the Ranger mine is mono-metallic, with uranium being the only metal present in significant concentrations in the orebodies. Uranium is of potential ecotoxicological significance in the mine wastewaters. The highest quality water stored on site may be released into Magela Creek during the wet season (December to April), subject to strict legislative requirements and regulations. Indeed, over 57 Acts of Parliament and associated Regulations cover mining and milling operations at Ranger. It is arguably the most regulated mine in Australia. Biological monitoring of Magela Creek and toxicity evaluation of the mine wastewaters have been undertaken on a continuous basis for some 20 years. No detectable impacts of mine waste waters on aquatic ecosystems downstream of the Ranger mine have been demonstrated to date (see Section 3.6.1.8.2).

3.6.1.8.1 Rum Jungle copper-uranium mine

Rum Jungle is a decommissioned copper-uranium mine that was operational from 1953 to 1971. At the time of development, there was no legislative requirement for mining projects to undergo environmental impact assessment, so the environmental damage which subsequently resulted from mining operations at Rum Jungle was not of significant interest at the time, but was of enormous concern later on. The major environmental impact at Rum Jungle was the pollution of the East Branch and the main channel of the Finnis River (Jeffrey and Williams 1975; 1980) (Figure 3.2).

It was obvious by the mid 1960s that effluent from the treatment plant and leachate from the mine waste dumps were adversely affecting the riparian vegetation at the mine site. More importantly, the aquatic biota in both the East Branch of the Finnis River, which flows through the mine site, and the Finnis River downstream of its confluence with the East Branch, were being severely impacted. The major pollutants in the East Branch and the Finnis River were copper, zinc, manganese, sulfate and acidity.

Over the period 1969/70 to 1973/74, the calculated annual loads of copper, zinc, manganese and sulfate delivered into the Finniss River system ranged from 44 to 106, 22 to 30, 46 to 110 and 3300 to 13000 tonnes, respectively (Jeffree *et al.* 2000).

In the East Branch at the end of the dry season, when water flow ceased to the Finniss River, total concentrations of copper in the surface waters of billabongs (permanent water bodies) were as high as 250 mg L⁻¹. In the Finniss River, the highest concentrations of contaminants (copper, zinc, manganese, cobalt (Co), nickel (Ni), uranium, sulfate, and acidity) occurred when convective thunderstorms caused early wet season flows in the East Branch, and these coincided with low flows from the remainder of the Finniss catchment. During these 'first flush' events, fish-kills in the Finniss River were observed to extend between 15 km, and somewhat less than 30 km, downstream of its confluence with the East Branch. These toxic events were most likely responsible for the general reduction over the subsequent dry season in fish diversity and abundance (Jeffree and Williams 1980).

In the East Branch downstream of the mine, no rooted or submerged plants were observed, and live bank-side *Pandanus* were rare, although their dead stumps were present. The absence of the stabilising effect of bank-side roots was associated with shallow gullying, gently sloping banks and considerable deposits of sand along the banks, indicative of erosion and consequent deposition. Fish were virtually absent from the pools of the East Branch, although the physical and structural characteristics of these pools were similar to those at sites unexposed to pollution, that contained about seven species. A number of fish species were found in the unpolluted tributaries of the East Branch (Jeffree and Williams 1975).

Many groups of Insecta, that are indicators of an unpolluted state, as well as the phyla Mollusca and Porifera, were absent in the East Branch downstream of the mine.

In the Finniss River there was also an appreciable decline in fish diversity and abundance for at least 15 km downstream of the confluence with the East Branch. Sites in the Finniss River immediately downstream of the confluence with the East Branch showed lower numbers of species and individuals than those upstream, or further downstream. There was a gradual recovery in both the number of species and individuals in the Finniss River with increasing distance downstream of the confluence with the East Branch.

(a)



(b)



Figure 3.2. Waste dump at the Rum Jungle copper-uranium mine prior to rehabilitation (a) and after rehabilitation (b).

Although the maximum and median concentrations of copper, zinc, manganese and uranium have decreased substantially in the surface waters of the East Branch (and the Finnis River) following remediation of the Rum Jungle mine, the present concentrations still exceed the national water quality guidelines (ANZECC and ARMCANZ 1999) for the protection of freshwater ecosystems by a factor of 220, 45, 20 and 11, respectively (Jeffree *et al.* 2000).

Field studies that commenced in the early 1990s indicated that there has been only a small degree of recovery in the riparian vegetation of the East Branch following the remediation of the mine site, and associated reductions in annual contaminant loads and surface water concentrations. The description given above for the pre-remedial level of impact still generally applied.

A study of macroinvertebrate community composition and associated water quality in the East Branch, that was very similar in design to pre-remedial investigations in its choice of sites and sampling methodologies, but more quantitative in nature, was conducted. This study indicated no apparent increases in the number of macroinvertebrate taxa in the section of the East Branch receiving effluent from the mine, following remediation of the Rum Jungle mine site. However, there does appear to have been some ecological improvement in the lowest reaches, indicated by the presence of freshwater Atyid shrimps (Jackson 1993).

Sampling of benthic algae in the East Branch was undertaken from 1993 to 1995 during the period of recessional flow that occupies the early dry season. An obvious, and roughly exponential gradient of pollution (trace metals, sulfate and acidity) develops during this time. At the site of lowest pH (3.0) and highest metal concentrations (e.g. 30 mg Cu L⁻¹), the species richness was less than 10% for diatoms, and 50% for non-diatoms, relative to control sites. Collectively, the algal species richness in the East Branch downstream of the Rum Jungle mine-site was, on average, less than 50% of that typically found at control sites. Furthermore, the relative contribution of three major algal groups (blue-green algae, green algae and diatoms) to the overall number of taxa present at a site changes with position along the pollution gradient. The blue-green algae were absent from the most polluted end of the gradient leaving only green algae and a few species of diatoms. Overall, the quantitative data on benthic diatoms provide a potentially useful basis for measuring

any further improvement in the ecosystem health of the East Branch, based on primary producers at the base of the food chain (J. Ferris pers. comm.)

Within the Finnis River, ecological studies conducted following remediation have shown the following environmental improvements over the first 15 km downstream of the confluence with the East Branch:

1. the indicator fish species, eel-tailed catfish, banded grunter (*Amniataba percoides*) and archer fish (*Toxotes chatareus*), that were virtually absent, have returned;
2. fish diversity and abundance has increased to levels comparable to sites unexposed to ARD contaminants; and
3. ecotoxicologically-sensitive species of crustacea (Atyid shrimps, e.g. *Caradina nilotica*) occur within impacted regions of the river where no living specimens were found prior to remediation.

It is important to note that partial ecological recovery is occurring in the Finnis River even though the concentrations of Cu, Zn and Ni in the sediment, and Cu, Zn, Mn, U and Al in the surface waters, often substantially exceed their respective national guideline values for the protection of aquatic ecosystems (Jeffrey *et al.* 2001).

Physiological and/or genetic tolerance of freshwater biota in the waters of the Finnis River to metals such as Cu and Zn is an additional mechanism to explain their partial recovery, despite concentrations in the sediments and water that exceed the recommended national guideline values (Gale *et al.* submitted).

3.6.1.8.2 *Ranger uranium mine*

Over the past two decades, there has been a major research effort to gather environmental data in the Alligator Rivers Region. This is largely as a consequence of the Australian Government's decision to permit the mining and milling of two (Narbalek and Ranger) of the four extensive deposits of uranium known to exist in this area. The Narbalek deposit was mined out and has recently been rehabilitated.

The Ranger deposit (Figure 3.3), located adjacent to Magela Creek, is currently being mined by a conventional, simultaneous mining/milling, open-cut operation. Mining and milling operations are expected to continue until about 2006. In 1996 the Ranger

mine was the third largest producer of uranium oxide in the Western world, accounting for 10% (4149 tonnes) of the world's production (ERA 1998).

As a consequence of heavy wet season rainfall, one of the most important environmental issues associated with the operational phase of uranium mining at the Ranger mine, has been the management of excess water that accumulates within the mine retention ponds. The options for water management are severely constrained as a result of the location of the project area upstream of the Magela Creek floodplain, which forms part of the World Heritage-listed Kakadu National Park. The Ranger mine is the most tightly regulated mine in Australia with respect to discharges of water from the site, and is required to adhere to detailed environmental requirements determined by government authorities (NT DME 1982).

Magela Creek is an ephemeral stream consisting of a series of braided sandbed channels with sandy levees and a series of billabongs and channels that expand onto a seasonally flooded black-soil floodplain. High peak flows occur in response to intense storm events in the upper catchment. High flow conditions ($20\text{--}2000\text{ m}^3\text{ s}^{-1}$) during this period impart a uniform and common water chemistry to Magela Creek. Water quality is very good, reflecting the essentially pristine nature of the catchment. For this reason, the potential for impact of waste water on aquatic ecosystems downstream of the Ranger mine is of particular concern. Hence, any mine waste water releases need to be carefully controlled to minimise ecological detriment. Uranium is the primary element of potential ecotoxicological concern.

Whilst chemical analysis of the surface water of Magela Creek indicates a slight chemical signature from the mine, no deleterious effects on aquatic biota in Magela Creek downstream of the mine have been detected since operations commenced. This record stands in marked contrast to the legacy of substantial downstream impacts from the Rum Jungle mine, and is a testament to the very high standards of environmental management on the Ranger leases.

The following description for the Ranger site describes the use of multi-tiered biological testing and monitoring (using local invertebrate and vertebrate species) to evaluate impacts downstream of the mine site, and the research that is being done to develop locally applicable numerical guideline criteria for solutes (especially

uranium) present in mine water. The framework described should be applicable to other types of mining operations throughout the world.

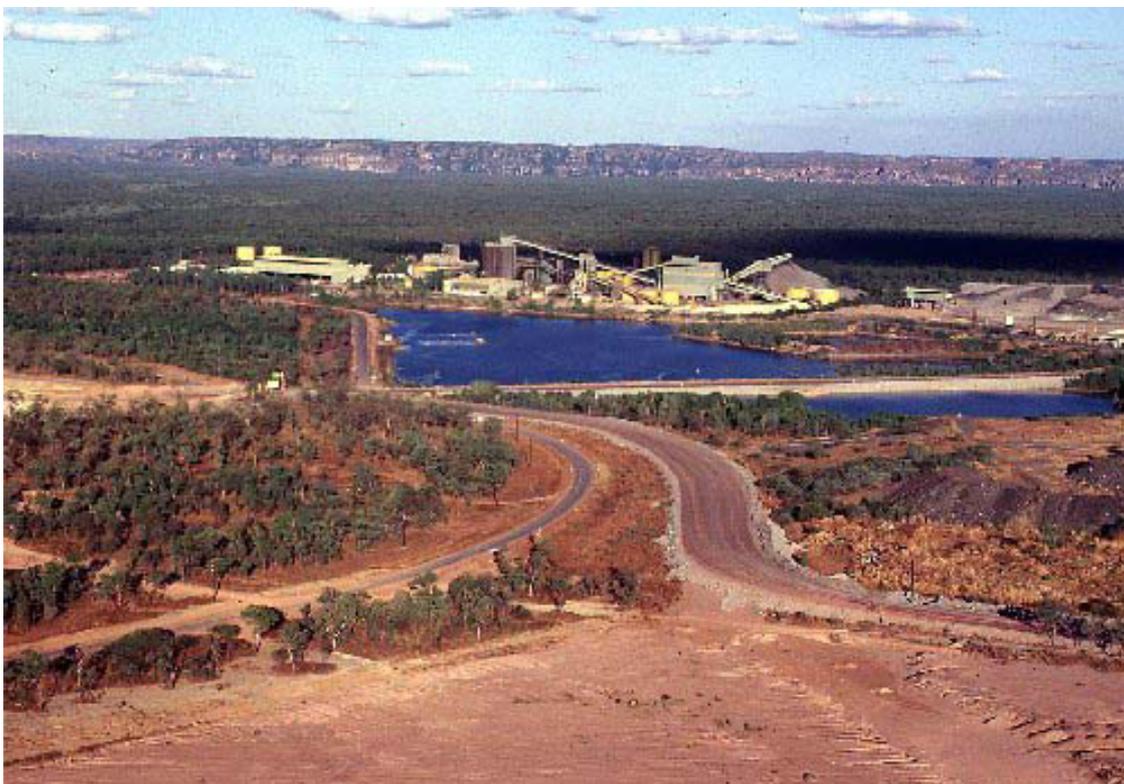


Figure 3.3. Ranger uranium mine adjacent to the World Heritage listed Kakadu National Park.

Biological assessment of mine wastewaters

During the wet season, the quality of the surface water is regularly monitored in Magela Creek, upstream and downstream of the mine-site, as well as water bodies on site, as part of the statutory water quality monitoring program. This is complemented by non-statutory, laboratory-based, pre-release toxicity testing of release water. Creek-side toxicity testing has also been conducted, during periods of water release, since the 1991/92 wet season.

The laboratory and creek-side toxicity tests are complemented by measurements of metals and radionuclides in the flesh of the freshwater mussel, *Velesunio angasi*, collected from a billabong downstream of the mine, to assess the bioaccumulation of

metals and radionuclides over time. Baseline metal concentrations in the flesh of *V. angasi* were determined throughout the Magela Creek catchment, so that future concentrations may be compared. Apart from being a suitable indicator species for biomonitoring over the longer-term, *V. angasi* is also a food source for the traditional (Aboriginal) owners of Kakadu National Park. The annual sampling and analysis of mussels for metals and radionuclides forms the only part of the biological work at the mine that is specified as a statutory (regulatory) requirement in the Authorisation to Operate (NT DME 1982). To date, there is no evidence to indicate that metal or radionuclide concentrations in mussel flesh have increased over time. Furthermore, the metal concentrations in the flesh of *V. angasi* from Magela Creek, downstream of the Ranger mine, are consistent with other minimally-polluted waters (Markich 1996).

As part of a 'whole ecosystem' approach, a program has been developed and trialed since 1994 to assess the health of aquatic ecosystems comprising the Magela Creek catchment (Corbett 1997; Sewell *et al.* 1997). This approach involves comparing the numbers of key trophic levels occupied by organisms in billabongs and riparian areas at test and control sites. It provides a tool for monitoring the health of aquatic ecosystems over long periods to determine if there are any significant ($P = 0.05$) chronic impacts from mine waste water releases. The whole ecosystem approach represents the highest tier in the biological systems approach for assessing mining impacts at Ranger. To date, this approach has not provided any evidence of deleterious impacts on the aquatic ecosystems downstream of the Ranger mine.

Pre-release laboratory toxicity testing of mine wastewaters

The management of excess waste water on the Ranger site during the wet season requires the controlled release of water in most years. Water from runoff and seepage from a waste rock dump typically contains uranium, magnesium and sulfate at levels 500, 250 and 2000 times higher, respectively, than the receiving waters of Magela Creek. The minimum dilution requirements of waste water are initially determined using pre-release toxicity testing. The actual rate of waste water discharge into Magela Creek is determined after consideration of water chemistry (Magela Creek and release water), the flow rate of Magela Creek and the results of biological testing. In short, because the impact of complex and varying waste waters on aquatic

environments cannot be predicted from their individual constituents (cf. water quality standards regulated by chemical analysis), testing the toxicity of mine waste waters on aquatic biota is desirable (Brown 1986).

An important prerequisite for the biological assessment of mine waste waters is the identification of biota in Magela Creek potentially at risk. In a comprehensive discussion on the use of freshwater biota to assess mine waste waters in the Alligator Rivers Region, it was concluded that soft-bodied and gill-breathing organisms (or their life stages) are most at risk from solutes present in the water (Johnston 1991).

The principal features of the toxicity testing approach are as follows:

1. the direct measurement of the change in toxicological responses (lethal and sublethal) of local biota selected from widely different taxa and trophic levels, to the actual wastewater as it is diluted with receiving (Magela Creek) water; and
2. the dilution of the wastewater required to render it harmless can be used as a control parameter to regulate its release; however, this must follow the application of a 'safety' factor to account for the possible occurrence of large undetected risks, additivity of undetected effects and protection of species other than those tested.

The suitability of 19 local freshwater organisms was assessed for their potential use in the pre-release tests. Several organisms were found to be useful, based on sensitivity, representation from different trophic levels (e.g. vertebrate predator, invertebrate predator and invertebrate herbivore) and suitability for laboratory culture. Three of these, [*Hydra viridissima* (green hydra), *Moinodaphnia macleayi* (water flea) and *M. splendida inornata* (chequered rainbowfish)] are currently used to assess the toxicity of waste waters following established protocols.

The principle of the pre-release toxicity tests is to compare organism response in a control water, obtained from a pristine billabong located upstream of the mine, with various dilutions [typically, 0% (control), 0.3%, 1.0%, 3.2%, 10% and 32%] of test water. From these tests, the maximum concentration at which no observed effect (NOEC), and the lowest concentration at which an effect is observed (LOEC), relative to the controls, are determined from statistical analysis (one-way analysis of variance) of the test results obtained prior to the release of waste water.

Creek-side toxicity testing of Magela Creek water

Ranger mine is currently trialing a field-based toxicity testing program to accompany the laboratory-based tests. The aim of the field-based program of testing is to check the efficacy of the pre-release tests and provide an early warning of impacts caused by the mine waste water releases. This is achieved by quantifying and assessing the relative toxicity of Magela Creek water, both upstream and downstream, before, during and after the release of waste water. Such a program is required to achieve the overall environmental protection objective, i.e. no observable effects upon local aquatic organisms in a comprehensive and sensitive biological monitoring program (Humphrey *et al.* 1995).

The results of the creek-side tests have verified the pre-release laboratory toxicity tests. These results are no surprise given that the rate of release of waste water was limited by the requirements imposed by the chemical standards (NT DME 1982) and by the dilution required on the basis of the pre-release toxicity tests. The monitoring data, therefore, confirm the adequacy of the controls imposed on the discharge of water from the mine-site.

A practical *in situ* technique used to assess the effects of mine waste water releases has been the measurement of the reproductive responses of freshwater mussels (*V. angasi*) held in mesh-covered containers buried along the creek edges (Humphrey *et al.* 1990). Adverse effects detected were of short duration only, and localised, being confined to a 'mixing zone' immediately downstream of the discharge point.

Monitoring the community structure of macroinvertebrates and fish in Magela Creek

Macroinvertebrate communities have been sampled from a number of sites in Magela Creek at the end of substantial wet season flows, on an annual basis from 1988 to the present, with the aim of developing a monitoring technique to detect any impact from mining.

Macroinvertebrate data for the 10 year period, 1987/88–1996/97, have been analysed for a site in Magela Creek upstream of the Ranger mine (control) and a site about 5 km downstream (identical to those used for the creekside tests) to illustrate

comparative changes in community structure. The results indicate that changes from year to year in community structure between the upstream and downstream sites are smaller than the natural variability that occurs at the control site. Hence, any change in community structure that has occurred downstream from the mine has not been ecologically significant and may have been due to natural variability.

Additionally, studies of fish community structure in several billabongs have shown no evidence of mining-related impacts since 1994. In one study, the fish in two billabongs, one on Magela Creek downstream of the Ranger mine and the other on a separate 'control' catchment [Nourlangie Creek (a tributary of the South Alligator River in Kakadu National Park)], have been monitored by a visual counting technique, using a canoe with a transparent bow. Multivariate measures of the dissimilarity between these two fish communities indicated that, although there were differences between streams, the differences remained relatively constant over the study period (Johnston and Needham 1999).

In summary, the biological monitoring program at Ranger has shown that operation of the mine has had no detectable impact on a range of sensitive indicators of ecological health and biodiversity.

3.6.2 *Performance measures*

It is difficult to obtain a national picture of the effectiveness of the Australian minerals industry in addressing issues of biodiversity, as much of the basic data that is required is not readily available throughout the industry. An agreement on completion criteria encompassing biodiversity issues needs to be considered with data collected in a regular, systematic and consistent fashion so that the potential cumulative effects of mining activities on biodiversity can be identified.

3.6.2.1 *Environmental reporting and independent assessment*

A fundamental obligation of committing to the updated Australian Minerals Industry Code for Environmental Management is the production of an annual public environmental report within two years of registration. In mid-2000, the World Wildlife Fund (WWF) conducted an independent assessment of 32 environmental

reports prepared by signatories to the Code (WWF 2000). WWF's major criticism of the Code as it stands, is the lack of discrimination between the varying levels of environmental performance of its signatory companies. As such, the WWF has developed reporting criteria for the purpose of assessing the reports produced by Code signatories. WWF have now undertaken two of these assessments, and see this as their contribution to improving the quality of environmental reporting.

WWF's 2nd annual scorecard on mining company environmental reports (WWF 2000) concluded that, despite a review of the MCA Code since the 1999 scorecard was produced, very little improvement in the quality of the environmental reports has been made, as assessed against WWF's criteria. In particular, WWF were concerned about the lack of progress with external verification of environmental and social performance, as well as the absence of any agreed reporting format. Unfortunately, the standard of reporting set by the industry leaders has not been extensively adopted by other companies.

In response to concerns regarding independent assessment of environmental performance, the industry has established the Australian Minerals Industry External Advisory Group (EEAG) as a new forum through which the industry can seek independent advice on how its environmental performance is perceived and can be improved (MCA 2000).

3.6.2.2 Proportion of disturbance being rehabilitated

Notwithstanding the limitations of the data on areas disturbed versus those rehabilitated, the following estimates provide some indication of the rate and extent to which ecosystems disturbed by mining are being rehabilitated. As pointed out by EPA QLD (1999), not all the area on mining leases is disturbed; the undisturbed parts of mining leases comprise buffer zones, areas included because of the linear nature of lease boundaries, prospective mine paths, proven and unproven reserves and non-surface rights to underground mines. Figures for NSW and Queensland are provided which attempt to estimate the actual area of these leases that has been disturbed and the proportion of rehabilitation that has occurred. In NSW it is believed that 14,000 hectares of land had been disturbed by mining, with approximately 2,900 hectares or 21 percent of this area being rehabilitated as of 1995 (EPA NSW 1995). In

Queensland, approximately 73,000 hectares is thought to have been disturbed by mining activities, with 23,000 hectares or 32 percent of this area having been rehabilitated as of 1997 (EPA QLD 1999).

3.6.2.3 *Expenditure on the environment*

There is paucity of specific data on environmental expenditure, thereby hindering ones ability to draw national conclusions regarding trends in the industry regarding expenditure on biodiversity related issues. The annual ‘Minerals Industry Survey Reports’ provide a useful guide, as they contain data on the amount of rehabilitation expenditure, but other substantial aspects of environmental expenditure are not considered such as research activities, pollution monitoring and control, clean-up and in capital expenditures designed to minimise the environmental impact of processing plant and equipment (MCA 2000).

When interpreting this data, MCA (2000) warns that the annual provision for rehabilitation represents the amount charged to the profit and loss statement during the period, which increases the total rehabilitation provision. Actual payments made will be made directly from the total rehabilitation provision, and will not necessarily equal the amount charged to the profit and loss statement.

Table 3.1. Rehabilitation expenditure derived from minerals industry survey reports

Item	1996/97 \$ Million	1997/98 \$ Million	1998/99 \$ Million	1999/00 \$ Million	2000/01 Forecast \$ Million
Annual Provision	178	245	275	242	285
Accumulated Balance of Provision	928	975	1,208	1,396	n/a

Source: MCA (1999; 2000)

The data in Table 3.1 suggest that, apart from the 1999/00 period, there has been a steady increase in the industry’s expenditure on rehabilitation. MCA (2000) suggest that this reflects an increased focus on environmental rehabilitation by the minerals industry over the past few years.

At the State level, EPA QLD (1999) reported that the Queensland mining industry's expenditure on environmental protection, including management of pollutants, land rehabilitation and change to production processes, was \$53.6 million in 1993-94 and \$79.5 million in 1994-95. Based on data from the Australian Bureau of Statistics (ABS 1998a;b), EPA QLD (1999) argues that about 70% of this was current expenditure, which includes personnel and material, related to rehabilitation. Nationally, about 0.5 percent of total mining industry current expenditure and about 0.7 percent of mining turnover is environment-related (EPA QLD 1999).

4.0 POTENTIAL FOR ENHANCEMENT OF INDUSTRY PRACTICES TO PROTECT BIODIVERSITY

There are a number of issues and practices that may be enhanced to ensure the protection of biodiversity whilst allowing the activities of the minerals industry to continue. The two key issues in ensuring environmentally sustainable development within the minerals industry are the transfer of existing technology to the whole industry, and continued research on improved methods to minimise environmental impacts.

In the mid 1990s, representatives of the mining industry in Australia and the Environment Protection Agency (EPA), worked together to collect information on a variety of topics that illustrate and explain best practice environmental management in Australia's mining industry. The end result was the publication of a series entitled 'Best Practice Environmental Management in Mining' containing various modules aimed at assisting all sectors of the minerals industry to protect the environment and to reduce the impacts of mining by following the principles of Ecologically Sustainable Development.

In addition, the minerals industry has access to a number of workshops and short courses designed to improve communication and technology transfer. There are a number of Centres across Australia that specialise in designing and holding courses specific to the minerals industry and rehabilitation. These courses enable the transfer of research results and best practice techniques in courses ranging from, for example,

landscape design, tailings management, acid mine drainage, revegetation on saline lands, fauna habitat reconstruction and native seed biology.

As a result, the minerals industry has the communication structure to enable dissemination of research results and best practice techniques. It is the continued investigation and research that is required to be undertaken by all mineral operations to ensure minimal impact of their activities on biodiversity that remains a concern. Over the last five years, research and development expenditure by the industry has been declining (MCA 2000). It is accepted that this is a by-product of takeovers and company mergers; however, it should not be the case that larger operations undertake research while small to medium operations do not. The public does not differentiate between the different sectors of the industry, and hence any environmental accident will impact on the credibility of the minerals industry as a whole.

There are a number of areas where the minerals industry may enhance its practices to protect biodiversity. These areas are discussed below.

4.1 Agreement on Appropriate Completion Criteria and Indicators

The minerals industry and governments are looking for criteria that determine when rehabilitation of mined areas is complete. Elliot *et al.* (1996) advise that, where these criteria have been developed elsewhere, they have usually been based on a narrow set of vegetation indices that are measured at an establishment or early development stage of revegetation. They correctly point out that achievement of these indices does not necessarily ensure that land is returned to a safe, stable and self-sustaining land use.

The Australian minerals industry has used ant species diversity (richness and composition) as an indicator of rehabilitation success for more than 20 years (Andersen 1997). In doing so, a broad level of general principles has emerged, notably that ant diversity at mine sites being rehabilitated may reflect recolonisation by other invertebrates (Andersen 1997) and soil microbial biomass (Andersen and Sparling 1997). More broadly, Andersen (1991) noted evidence that the relative abundances of ant species were strongly influenced by habitat disturbance. In mesic southern Australia, for example, opportunistic ant species will increase in abundance following fire, grazing, mining and intensive recreation.

Andersen (1997) (see also Andersen 1990; 1993) reviewed the use of ant functional groups as indicators of ecosystem restoration following mining. Despite ant species showing clear successional patterns at mine sites undergoing restoration, the link between these patterns and more general changes in ecosystems had been inadequately studied. However, Andersen (1997) gave examples of positive correlations between ant species richness and total invertebrate richness for areas mined for bauxite in Western Australia. There were also positive correlations between the composition of plant species, ordinal composition of invertebrates (on the ground and on ground vegetation) and species composition of beetles and grasshoppers in disturbed and pristine sites in and around Ranger uranium mine in the Northern Territory, and between ant species richness and soil microbial biomass at disturbed sites.

A number of studies have evaluated the effectiveness of rehabilitation of bauxite mines (Majer *et al.* 1984), sand mines (Majer and de Kock, 1992) and uranium mines (Andersen 1993). They have shown that ant community structure and composition are related to the state of revegetated areas in a number of ways following the succession of ant species through time and the build-up of species richness. These characteristics are also related to other biotic and abiotic variables.

Stage 2 of the ACMER 'Indicators of Ecosystem Rehabilitation Success' project that is being undertaken with funding from the minerals industry, is designed to further test a range of indicators that have been developed that identify the successional pathway that the post-mined rehabilitation is undergoing. This will enable the development of a predictive understanding of the ecosystem response to rehabilitation efforts in mine sites based on the theory that ultimate success is built on the firm foundation of earlier stages (Tongway and Murphy 1999).

While it is accepted that the determined completion criteria will vary according to the community perceptions of the post-mined land use, the EFA procedure (Section 3.3) will outline the variability between the rehabilitated site and that of analogue sites at a specific point in time and allow the user to determine whether the agreed completion criteria will be met without further intervention.

4.2 Improved Utilisation of Native Seed Reserves

Currently, the minerals industry is the major user of all native seed collected in Australia with reports of 70% to 80% of all seed collected utilised for mine rehabilitation (Mortlock 1999). The majority of this seed is utilised within direct seeding programs over the relatively small areas of Australia impacted by the minerals industry. With the area of degraded land within Australia, largely the result of other industries, expected to get larger in the future, it is anticipated that the supply of native seed may not be able to meet demand. For this reason, the minerals industry must address the usage of native seed resources to maximise return from this investment. There are a number of initiatives that the minerals industry can take to improve the effective utilisation of native seed.

4.2.1 Collation of existing information

The minerals industry conducts and commissions research into native seed germination and establishment. Much of this work remains as unpublished reports and is viewed only by the mine personnel. In addition, there is a substantial amount of research into overcoming seed dormancy that has been undertaken by universities, government departments and others involved in native seed research that has been published in scientific journals and conference proceedings. Finding and obtaining these published works can be difficult for environmental personnel in remote locations.

To prevent duplication of research and maximise biodiversity in rehabilitated areas, it would be beneficial for information on native seed biology to be collated into the one reference location with ready access to all rehabilitation practitioners. While not intended to become a substitute for seed tests on the broadcast seed, access to this information may, for example, provide an indication on seed viability and hence provide an estimate of the amount of seed required to be collected for a given plant community. It may also document methods of overcoming seed dormancy for a given species that have proven successful in other studies, enabling an increase in species germination within post-mined sites.

Collation of a substantial amount of this information was undertaken by Langkamp (1987) and, since then, there has been a substantial improvement in the understanding

on native seed biology. The CD-ROM publication 'Floradata' (Mortlock and Lloyd 2001) does update this information but is not complete for all species utilised in the rehabilitation of post-mined environments. Further collations that add to these publications will improve the efforts of rehabilitation practitioners through ready access to the results of research and experience of others.

4.2.2 *Seed quality assurance*

The term seed quality refers to the purity, viability and genetic background of a seed sample (Luscombe 1994). All are components that can impact on the rehabilitation strategy and effectiveness in the post-mined environment. In many cases, seed purchased by the minerals industry is selected on the basis of price with little regard given to seed quality (Cockerton 2000). The price per kilogram is not an accurate guide as to the true cost of the seed (Luscombe 1994). A poor quality seed batch can have an impact on the density and composition of the rehabilitated landscape.

To ensure the acquisition of a quality seed resource, the minerals industry would benefit from obtaining seed quality certificates from every seed purchase. Information on the purity, viability and germinability of the seed lot will determine the number of available, germinable units per unit weight of the seed (Dixon 1997). The slight increase in cost would be compensated by the knowledge of the quality and background of the seed supply. In this way, a greater knowledge of the broadcast seed mix can be obtained and the expected germination estimated with greater accuracy.

4.2.3 *Improved dormancy-breaking techniques*

Successful revegetation that incorporates direct seeding relies on the germination of broadcast seed. Seeds that remain dormant within the seedbed are at risk of predation; hence, there has been a conscious effort to understand and overcome both seed coat and embryo-imposed dormancy to induce rapid and synchronous germination following broadcast. The germination cues of many Australian native species have been determined; however, there remains a number of species for which recruitment following the broadcast of viable seed is not reliable.

To ensure that the minerals industry has minimal impact on native communities, an understanding of seed dormancy within the community that is impacted will facilitate improved revegetation. This understanding is of direct relevance in dollar terms as the application of effective seed pre-treatments will enable maximum recruitment from the broadcast seed program.

There are currently a number of groups across Australia that are capable of developing effective methods to overcome seed dormancy in native species. It is desirable that the end result of such research is the development of techniques that will enable the seeds to be treated in large numbers by revegetation personnel prior to broadcast. While it is accepted that some companies invest in technologies to maximise recruitment from their seed investments, the minerals industry will only benefit by this work being widely available for the benefit of the industry and revegetation in Australia broadly.

4.2.4 Enhancement of survival of seedlings on modified mine soils

In most areas where mining takes place in Australia, the major part of the biodiversity is usually contained in the soil. As well as seed and nutrients, healthy soil contains macro- and micro- invertebrates, bacteria and mycorrhizal fungi which together play a critical role in nutrient cycling and in the establishment and sustainability of plant communities. Topsoil management techniques which conserve these values are therefore an important component of many successful rehabilitation programs. The direct transfer of topsoil is increasingly being used in the bauxite, mineral sand and other mining industries. The technique has been shown to enhance recruitment and seedling survival in many ecosystems due to, among others, better conservation of microbes, nutrients and organic matter. In some circumstances, however, it is not always possible to utilise topsoil, e.g. where there is a risk of weed proliferation, presence of disease, and high angle of batter slope. In addition, mine soils frequently have soil conditions that are not ideal for plant growth and establishment. Corbett (1999) outlines some of the physical, chemical and microbiological properties of waste rock dump soils. Briefly, they can have low infiltration rates, subject to dispersion and erosion, may contain elevated metal and salt concentrations, pH,

electrical conductivity and cation exchange capacity, in addition to lower levels of symbiotic microorganisms than undisturbed soils.

With studies suggesting that vegetation cover is an important factor in minimising erosion (Loch 2000), further investigations into the successful establishment of native vegetation on mine soils and mine soil remediation techniques will continue to benefit the minerals industry.

4.3 Development of Artificial Seeds

Despite the latest understanding of seed biology and dormancy breaking techniques, there are a number of species that are unable to be propagated with conventional technologies. In addition, there are many species that produce few viable seeds, and hence there is a difficulty in obtaining sufficient numbers of propagules to include these species within broadcast seed programs.

Recent developments with the production of synthetic seeds have shown promise for the production of propagules to enable recruitment of species that either are rare and endangered, produce few seeds, or have resisted attempts at propagation by conventional means.

Researchers at the Botanic Gardens and Parks Authority in Western Australia are developing a method of propagating species that produce few viable seeds and for which it has not been able to restore populations with conventional methods. They are attempting to produce viable synthetic seeds through somatic embryogenesis.

Simplistically, synthetic seeds are produced by applying growth hormones and other chemicals to plant cells and culturing them to develop embryos. With this method, a 2 mm piece of leaf may produce up to 200 embryos or seeds. This technique is used extensively in the northern hemisphere for commercial crops such as lucerne and certain tree species such as spruce. Work is now being undertaken on two species, one from the Restionaceae family and one from the Epacridaceae. Clearly this is an expensive method of propagation and is intended for species as a last resort to prevent them from becoming extinct.

Although genetically identical, further studies may reveal the potential of this technique to recover endangered species from other families.

4.4 Improved Understanding of Ecology of Reconstructed Landscapes

The ecology of reconstructed landscapes is of vital importance to the minerals industry in achieving its agreed completion criteria. While several researchers have found the ‘initial floristics model’ of succession to be the most successful in determining the structure within the mature plant community (Tongway *et al.* 1997b; Ward *et al.* 1996), it would be beneficial to establish the relationship between selected biota, habitat complexity and ecological processes that contribute to habitat quality within reconstructed landscapes (Tongway *et al.* 1997b). Hence a greater understanding of successional processes would contribute to the ability of the minerals industry to rehabilitate according to the end goals that are required for relinquishment of the lease (Grant *et al.* 2001).

There are species of algae (Charophytes) that have been reported to hyperaccumulate metals from aquatic habitats (Hutchinson 1975; John and Gayton 1994). The use of these species may assist to rehabilitate mine voids and aquatic waste waters of relatively shallow depth as they have been found to accumulate high levels of iron, manganese, copper, magnesium, zinc and phosphorous as well as providing shelter and food for macroinvertebrates, fish and waterbirds (John and Gayton 1994). Lakes colonised by charophytes (specifically *Nitella*) are often found to be crystal clear with very little turbidity (Figure 4.1). The algae develop annual spore banks within the lake sediment and, through translocation of this sediment, are able to colonise adjacent water bodies with desirable results. Due to the potential for charophytes to assist in the remediation of degraded wetlands in Australia, and the potential for mine voids to become productive wetland ecosystems, the use of these naturally occurring algae may be a cost-effective avenue for the rehabilitation of reconstructed landscapes (Ward *et al.* 1997; John 1999).

4.5 Development of Better Monitoring Techniques

In many operations, the re-establishment of a self-sustaining ecosystem is the end goal of the rehabilitation programme. The minerals industry can have many unforeseen impacts on the environment, and hence extensive monitoring of the pre- and post-mined environment is required to ensure the development of the ecosystem towards

the agreed completion criteria. Comprehensive monitoring programs are now a legal requirement in all States. For example, in Queensland, companies must prepare an Environmental Management and Overview Strategy which explains in general terms how environmental impacts will be managed. A subsequent Plan of Operations describes the environmental management program in detail. Both documents are required to address monitoring. Approval to mine is given by the issuing of an Environmental Authority, which may require the preparation of an Environmental Management Program which specifically documents the mine's Rehabilitation Monitoring Program.

As a result of these requirements and the adoption by many companies of Environmental Management Systems compatible with the requirements of ISO 14001, commitment to monitoring and the quality of monitoring programs continues to improve. For example, the development and utilisation of EFA and other monitoring techniques are being used by operations to monitor and appraise whether the rehabilitated land is continuing along the appropriate successional pathway or whether further intervention will be required. Only through efficient monitoring will potential problems be detected allowing remedial action to occur before they become a major issue.



Figure 4.1. The occurrence of *Nitella* meadows within Plover Lake at Iluka wetlands (Capel) have resulted in high clarity of the water body and improved water quality.

4.6 Enhancement of Fire and Weed Management Techniques

The indigenous Australians extensively utilised fire across the country to modify habitats for hunting prior to European settlement. This facilitated the development of a number of mosaics in various states of succession that ensured the provision of habitats and niches suitable for flora and fauna utilisation. The minerals industry has begun to consider the inclusion of fire regimes within its rehabilitated areas after a suitable period of time to assist in the development of the post-fire community dynamics and long-term sustainability of the post-mined environment.

Corbett (1999) states that research emphasis should be placed on the determination of time required for the development of fire tolerance of rehabilitated areas. The accidental introduction or inappropriate use of fire within immature rehabilitation areas could be a major setback to the redeveloping system.

Non-indigenous invasive plants are a poorly recognised threat to Australia's biodiversity (Csurhes and Edwards 1998). They have the ability to impact on ecosystem function through increased competition for resources, preventing recruitment of local species, alteration of geomorphological processes, hydrological

cycles, soil nutrient content and fire regimes, or by changing the abundance of indigenous fauna that may be required for pollination or seed dispersal of local species (Csurhes and Edwards 1998).

Improved monitoring and awareness raising through environmental induction programs, progressive rehabilitation of disturbed areas and rapid response following the identification of weed outbreaks can ensure that the minerals industry is not responsible for the establishment and degradation of native ecosystems by weeds in native ecosystems (Brearley *et al.* 2001).

5.0 OPPORTUNITIES FOR INDIGENOUS COMMUNITIES TO ASSIST THE MINERALS INDUSTRY WITH BIODIVERSITY ISSUES

The 1992 High Court Mabo native title ruling and the subsequent Commonwealth Native Title Act 1993 has presented the indigenous communities of Australia with many opportunities. This Act has resulted in increased negotiations between the minerals industry and the local indigenous populations. Investigations have discovered that these opportunities are not one-sided and that benefits of the increased negotiations can be found for the minerals industry and the Commonwealth government as well as the indigenous inhabitants that surround the mineral reserves.

To accommodate the Commonwealth Native Title Act, it is estimated that the cost to the minerals industry has been an increase of one percent expenditure (Manning 1997). Industry must negotiate access to land for exploration and mining with the indigenous owners and provide royalties to the local people. In return for this investment, the minerals industry has guaranteed legal access to the mineral reserve, improvements to the local social environment, an opportunity to develop a local labour force, and contracting enterprises which may allow them to reduce their reliance on importing labour from the cities at high cost (Manning 1997).

On the whole, mining and exploration occur in remote environments away from the main population centres, and as such, the minerals industry is best positioned to improve the economic development of these isolated centres. Several companies have realised the value of negotiations and education of the local communities to assist with the management of biodiversity issues.

The ability of local indigenous communities to negotiate with mining companies has brought about greater opportunities for both the local communities and the minerals industry. This relationship has been realised by several companies that have now developed policies on the employment of indigenous people. Several case studies illustrate the opportunities that indigenous Australians have accepted in assisting the minerals industry to manage biodiversity issues.

Case Studies

Energy Resources of Australia (ERA)

Energy Resources of Australia (ERA) operates the Ranger uranium mine adjacent to the World Heritage Listed Kakadu National Park in the Northern Territory. It has developed an Aboriginal employment strategy that aims to improve employment and training opportunities for Aboriginal people. ERA has engaged both the Gagudju and Djabulukgu Associations and has established contract arrangements with Aboriginal businesses for environmental rehabilitation work at the mine and within the region.

Delegates from both organisations have been sent on an ERA-sponsored tour of indigenous development foundations in South Africa, Zimbabwe and Namibia where they were able to observe first-hand successful projects in education, trade skills development and business enterprises.

As a result, local indigenous communities have been employed for a variety of biodiversity projects within the region. These opportunities have included clearing fire breaks for fire research, the development of a native plant nursery to supply tubestock for waste rock revegetation trials, and contracts to undertake soil conservation work. Traditional owners have also directed research into the commercialisation of native flora and fauna. This research is intended to provide alternative land use possibilities for the rehabilitated mine sites following mine closure and return to the traditional owners.

Hamersley Iron Pty Ltd

Hamersley Iron Pty Ltd operates six open-cut iron ores mines in the north-west of Western Australia and employs around 2000 people. Hamersley operates on the

traditional lands of nine Aboriginal language groups in the Pilbara and works with the people from seven other language groups.

To ensure that Aboriginal people benefit from the companies activities in the Pilbara, in 1992 Hamersley Iron established the Aboriginal Training and Liaison Unit (ATAL). ATAL is a nationally registered training organisation that provides specialised training, support and resources in several key areas including biodiversity management within the exploration and pastoral industries.

The focus on developing self-reliance through the business development program has proven successful and has resulted in a number of diverse businesses becoming established. Ventures such as recycling, seed collection, weed spraying, drill hole plug manufacturing, earthworks and pastoral activities are now being successfully run by Aboriginal people.

Hamersley owns several large pastoral leases in the Pilbara region with some of these leases adjacent to the Karajini National Park. Hamersley's Memorandum of Understanding with the Department of Conservation and Land Management ensures trainees gain first hand experience in managing these pastoral leases in sympathy with the adjacent National Park.

For its achievements in Aboriginal development and cross-cultural programs, Hamersley Iron has received a number of national and State awards including the Australian Reconciliation Award in 1997 and a commendation in the National Indigenous Peoples Training Awards (1998).

Tiwest Joint Venture

Tiwest Joint Venture extracts mineral sands from the northern sandplains of Western Australia. Early mining occurred on agricultural lands, but recent activities have concentrated on extraction of the mineral reserves under native ecosystems, thus the post-mined rehabilitation requires revegetation with native species. To meet their broadcast seed needs, Tiwest assisted members of the local Billinue Aboriginal Community to develop a native vegetation seed picking enterprise employing approximately 30 people.

Tiwest engaged established native seed merchants, LandCare Services, to provide training for Billineu Community members in species identification and native seed picking and processing techniques. To assist in the business establishment, Tiwest ceded 12 hectares of its freehold farm property next to the mine to the Billineu Community and provided support for land improvement, fencing needs as well as basic services and infrastructure.

While encouraging the development of external customers, Tiwest remains as the Billineu Communities key commercial customer by contracting the Community as the sole provider to meet their rehabilitation needs.

6.0 CONCLUSION

Although the activities of the minerals industry is confined to less than 0.05% of the land surface area of Australia, its impacts on both terrestrial and aquatic environments may be disproportionately high. The long lasting nature of acid rock drainage, mobilization of heavy metals and toxic chemicals, combined with the sulfidic nature of soils in some parts of Australia, have impacted on native ecosystems and are graphically illustrated in several operations across the country. The lack of appropriate monitoring and development of completion criteria by the minerals industry in the past was consistent with community attitudes of the time (Norris 1986; Richards *et al.* 1996; Brooks 1998).

The increasing community concern for the environment has been reflected by these concerns within the minerals industry and, to their credit, the minerals industry in Australia has developed a substantial knowledge on the identification and management of biodiversity issues that are consistent with the concepts of ecologically sustainable development. Through the development of environmentally sensitive practices and ongoing research and monitoring, the minerals industry has, for the most, demonstrated it to be a responsible land manager that is aware of the temporary nature of its activities and its commitment to future land users. A number of case studies, both positive and negative, have been presented in this report to illustrate the improved awareness of biodiversity issues by the minerals industry.

The activities of the minerals industry within Australia have allowed a greater understanding of Australia's biodiversity both directly through its research activities

and indirectly through the provision of royalties that are a source of environmental funding. Given the potential for environmental disaster as a result of its operations, the minerals industry cannot afford to be complacent in the implementation and monitoring of its activities. Although well organised, the minerals industry must focus attention not on the industry leaders, but on those operations that do not utilise the extensive information that is available on best practice techniques, for it is these operations that receive the attention of the media during environmental mishaps and largely downgrade the perceptions of the minerals industry in the minds of the public.

A number of areas have been suggested for potential enhancement of industry practices to ensure that the minerals industry minimises its impacts on biodiversity. Given the applicability of many of the rehabilitation techniques developed by the minerals industry for rehabilitation initiatives by other industries, coupled with its willingness to communicate and share this knowledge, the minerals industry can be found to have contributed to the conservation of biodiversity through the reduction in the current degradation to the agricultural landscape as a whole (Hobbs 1993). With continued planning and environmental awareness, the minerals industry has demonstrated it to be a responsible proponent of ecologically sustainable development.

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