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"MINED LAND REHABILITATION - IS IT SUSTAINABLE?"

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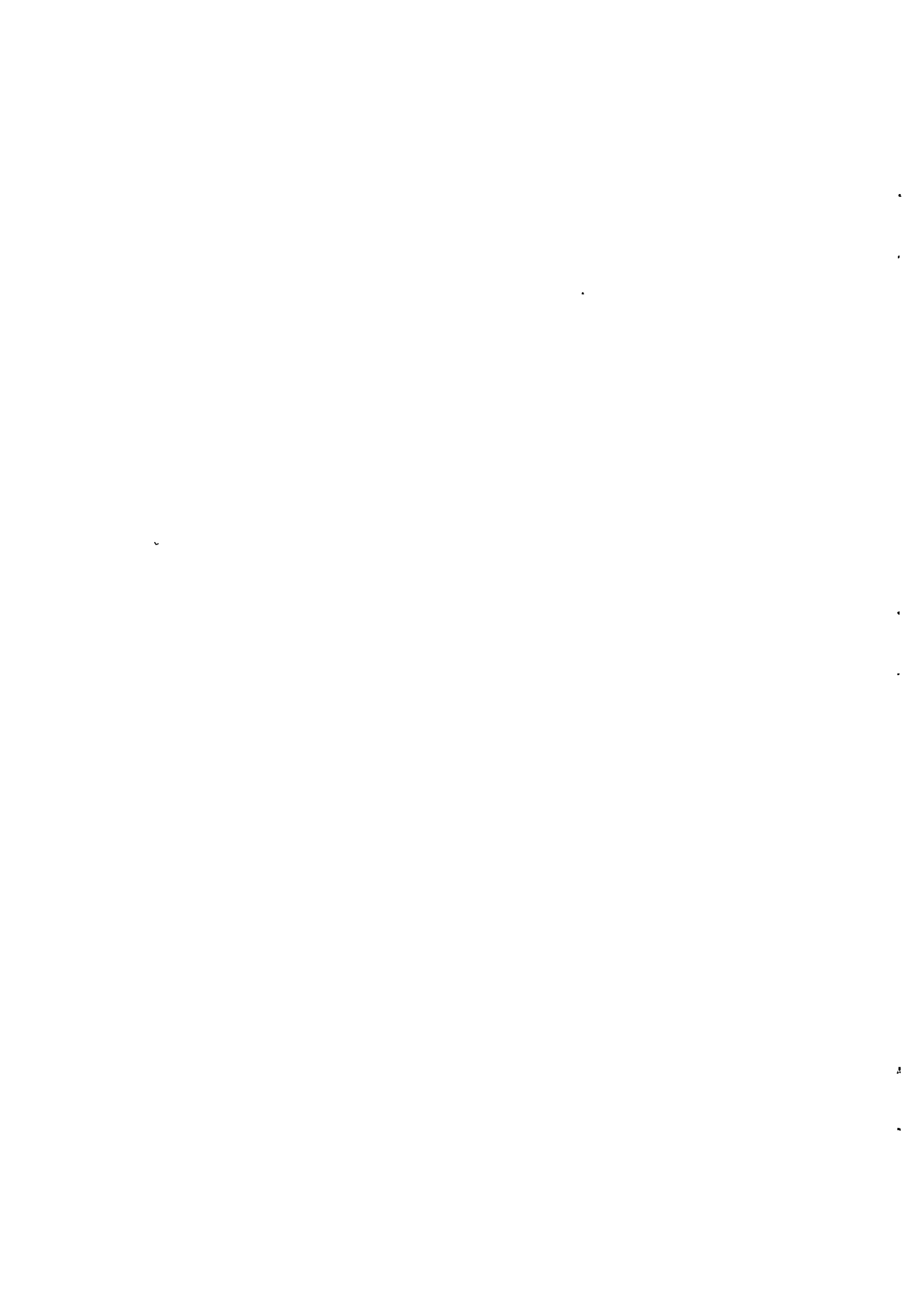
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PREFACE

B.G. Collins*

In May, 1983, a symposium, entitled "Mined Land Rehabilitation - Is It Sustainable?" was conducted at the Western Australian Institute of Technology, as part of the 53rd ANZAAS Congress. The symposium was convened by me and chaired by Dr. M. Mulcahy, of the Department of Conservation and Environment in Western Australia. Edited versions of papers delivered at the symposium appear on subsequent papers of this Bulletin.

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MINED LAND REHABILITATION - IS IT SUSTAINABLE?
INTRODUCTORY COMMENTS

B.A. Carbon *

Before we decide if "it" is sustainable, we need to decide what "it" is. It appears to me that rehabilitation has been designed sometimes to meet one set of criteria, but its success or failure judged on different criteria. For example, mining in native forest may be followed by rehabilitation to productive agricultural land. If you believe that agricultural production is important in a particular area, you may describe the rehabilitation as successful. If, however, you consider that the area should have remained as native forest, you are unlikely to be satisfied with anything less than an attempt to re-establish the functions of the original forest.

If rehabilitation is to be successful, then it would appear that a series of objectives should be formulated, and implemented in the following sequence.

1. Define the land-use capability of a particular mined area.
2. Define the end product we wish to achieve.
3. Define the form of effective rehabilitation we can afford.
4. Decide how to implement the rehabilitation.
5. Implement the rehabilitation.
6. Monitor and modify the results.

Often, we commence with the third objective on this list, i.e. we try to find an effective way of implementing rehabilitation that we can afford. I suggest, however, that it is most important to examine the question of what can be done with an area if it is mined, before we even contemplate the mining operation. It is obviously unreasonable to plan a snow ski slope for a minepit in Central Australia, but it is not axiomatic that we must always rehabilitate mined lands back to the land-use that existed before mining.

The first objective listed above is essentially scientific. It requires an analysis of information which may or may not be available. If this information is not available, we need to collect it. The second objective is one that was not addressed effectively during the 1960's and 1970's. We thought that because mining had a negative impact on land, at least during the operational phase, it was appropriate in every case to restore the land-use that preceded the mining operation. We now realise it is not always in society's best interest to do this.

Rehabilitation is something with which most people are familiar. However, while many gardens around Perth are not dissimilar to rehabilitated mine pits in the Darling Range, there are forms of

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rehabilitation that we often take for granted. In many parts of Australia, people visit picnic areas around waterholes, in exotic forest plantations, and on the banks of dams. Few of these are natural, in a pristine sense.

Surveys conducted by the W.A. Forests Department show that the general public enjoys a "natural" experience - "natural" in the sense that there are a few trees, some water, some close-cropped grass, and some open space. Hardly "natural" in a scientific sense, but nonetheless what many people want.

It is also important to accept that our environment, either natural or modified by man, has a shortage of some ecologically important features. For example, there is a shortage of wetlands in the south-west of Western Australia, with only 25% remaining of the wetlands that were present 200 years ago. It may therefore be appropriate to rehabilitate mined lands to wetlands in some areas of the south-west, even if the pre-mining state was quite different. Once an area had been mined, and its original use has been destroyed or significantly modified, is it rational for us to say that the best approach to rehabilitation is always to put it back the way it was?

Where we do decide that we want to replace the original environment, we should be realistic and try to replace the function rather than create an exact replica of the original ecosystem. In complex systems, it may not be possible or even desirable to put back the original environment. In nature, few things remain static. As systems change, so it is important for us to provide a functioning area that can adapt, rather than a "snap-shot" of a forest at a particular point in time.

Rehabilitated bauxite mines in the south-west of our State are designed to replace the original forest with an ecosystem having drought resistance, fire resistance, tolerance to low nutrition, compatibility with native fauna and productive capacity for timber, but not to be the original forest. In most cases, the original forest was susceptible to dieback and the new forest is not.

Major determinants of productivity in ecological systems include rainfall, sunshine, soil and genetic material. The impact of rainfall on plant production in Australia is especially important. For instance, the CSIRO Division of Land Research has shown that 90% of the variation in yield of crops throughout Australia can be predicted simply on the basis of rainfall. Similar predictions have been used with natural systems to estimate total productivity. Sunshine is also a major driving force. Neither sunshine nor rainfall changes with mining.

Soil is often heavily modified during mining. Such changes may not, in the long-term, be major determinants of the success of rehabilitation, although in the short-term they are of critical importance.

Genetic material may also change with mining, and any material that is permanently removed by mining may not return. I suggest, however, that it is rare for mining to totally remove genetic material from an area. In the case of bauxite mining, the most intensive mining operation in the south-west of Western Australia, approximately one third of a particular landscape may be mined. Two-thirds remain untouched, and provide genetic material for recolonisation of mined areas by both animals and plants. In most cases, man intervenes to assist that recolonisation.

I do not, however, wish to give an impression that there are no problems with rehabilitation. There are short-term problems with the death of young trees. These deaths may be part of a "natural" thinning process, as plants adjust to the carrying capacity of the site. There may also be deficiencies of native species in rehabilitated areas.

As mining often removes most of the biotic material, it may also remove most of the nutrients in the system. It is unlikely that application of fertilisers can, in the short-term, elevate the plain of nutrients on a site to its original level. Ongoing management will be required to achieve this objective. In the south-west of the State, we still have much to learn about nutrient management in rehabilitated eucalypt forests.

We also need to understand that forests tend to deteriorate when they are not growing. This may lead to a requirement for ongoing silvicultural intervention into the single-age stands of trees that exist in rehabilitated areas.

Apart from growing plants on rehabilitated areas, a faunal balance must be sought to meet the expected objectives of the area. Our impression is that this can be accomplished, provided sufficient care is taken with regard to the rehabilitation strategy used.

The next three papers will go into detail on specific points, but let me summarise the thrust of my comments. We must set appropriate objectives before we start any rehabilitation. It is futile to apply effort towards the wrong objectives. In the past, society may have sometimes expected mining companies to seek the wrong objectives. It is the soil which changes most as a consequence of mining. It is, therefore, the soil which must receive the most management input. The long-term driving forces of rainfall and sunshine are not affected by mining, and they therefore provide us with an excellent opportunity to make rehabilitation sustainable.

SOILS IN REHABILITATED AREAS

J.K. Marshall *

ABSTRACT

The first step in rehabilitation depends on conversion of mine waste to soil, that is, to a medium that will readily support plant growth. There are many properties of waste which, in extreme form, hinder plant growth. These properties are grouped as physical, chemical and biological. Examples of mined land rehabilitation in Australia are used to illustrate adverse properties of mine waste and to indicate practices for their amelioration. Attainability and sustainability of rehabilitation are discussed.

INTRODUCTION

Ecosystems disturbed by mining are often in a reduced condition. Their vegetation cover has been removed, their soils shifted and their subsoils exposed and mixed. Some original constituents are missing, and some new and even foreign components, may be added. Can this disturbance be made reversible? The present paper examines this question for soils in ecosystems disturbed by mining.

Initially, the material left behind after mining will be called waste, rather than soil. Many wastes, without modification, will only sparingly support plant growth. Conversion of waste to soil, as a medium which will readily support plant growth, is a first step in rehabilitation of land after mining. In what follows, properties of wastes which, in extreme forms, can make rehabilitation difficult, are identified and practices for their amelioration described.

Instead of relating case histories in detail, references are made to examples of mined land rehabilitation in Australia to give a broad indication of the range of locality, type of mining and people involved in what has been an actively worked-over area in recent years. Localities referred to are indicated in Figure 1.

GENERAL CHARACTERISTICS OF WASTES

Most wastes differ from soils by being unweathered and without microbes. They may have been mechanically crushed or compacted. They may also have had other substances added as an aid to mineral extraction, and usually contain no organic matter. Many

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wastes support little plant growth unless a long period of time elapses, or ameliorating rehabilitation practices are introduced.

Wastes vary in the degree to which they hinder plant growth, and this is broadly related to the type of mining. Those which are less difficult for plant growth are often the products of strip-mining, the name given to surface mining operations where the overburden is removed, minerals taken out as a layer or sifted out, and the overburden respread (Marshall, 1979).

Bauxite, mineral sands, iron ore, manganese, tin and coal are amongst the materials obtained by strip-mining in Australia. Areas affected by strip-mining are typically large, ranging from tens to thousands of hectares.

Wastes which are more difficult to grow plants on are often those from open-cut or deep mining, or from ores which have been treated to concentrate or refine the product (Marshall, 1979). Treatments may include washing, crushing, grinding, heating and mixing with chemicals. The wastes comprise rock or subsoil material in which the concentration of desirable mineral is too low to treat economically, as well as rock which has been finely ground for mineral extraction, and which is usually disposed of as a slurry. Gold, copper, lead, zinc, nickel and uranium mining give rise to wastes of these sorts. The areas occupied by such wastes usually comprise only a few hectares. An exception is at Kalgoorlie, where the slime dumps from gold mining occupy an area of several hundred hectares.

PHYSICAL PROPERTIES OF WASTES

Topography

Wastes are initially discarded after mining with a markedly different topography to that of the original landscape. Slopes may be steeper than would be stable under the local rainfall regime. The arrangement of depressions may also result in drainage patterns that are different to those of the landscape in which mining took place.

The first step in rehabilitating wastes typically involves their reshaping to more stable, sympathetic and manageable slopes, and to alignments conforming as closely as possible to local drainage patterns (Bartle and Riches, 1978; Hannan, 1979a; Kelly, 1979a; Lewis and Brooks, 1979; Craze, 1981).

Steep slopes are unavoidable sometimes, as with the walls of tailings dams such as those at Broken Hill (Thorne and Hore-Lacy, 1979). They are also acceptable where the mining is in rugged country, as in the Pilbara (Martinick and Atkins, 1978). Early stability is ensured by use of sprays or mulch, the latter often being applied by the technique of hydromulching, which may also

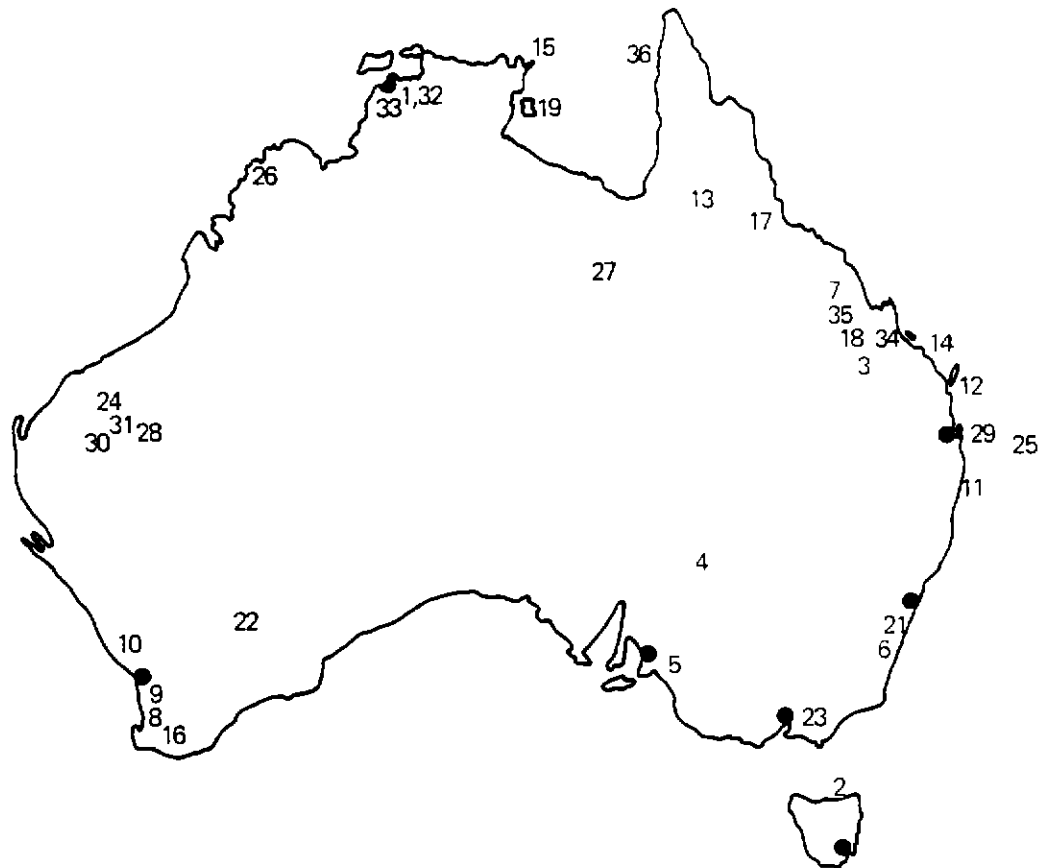


FIGURE 1

LOCALITIES OF STUDIES REFERRED TO IN DISCUSSION OF MINE WASTES, THEIR PROPERTIES AND REMEDIES REQUIRED FOR REHABILITATION.

Figure 1. Localities of studies referred to in discussion of mine wastes, their properties and remedies required for rehabilitation.

- | | | |
|--|--------------------|---|
| 1. Alligator Rivers | 13. Georgetown | 25. Mineral sands, Eastern Australia (Gosford to Yeppoon) |
| 2. Bell Bay | 14. Gladstone | 26. Mitchell Plateau |
| 3. Bowen Basin (central Queensland coalfields) | 15. Gove | 27. Mt. Isa |
| 4. Broken Hill | 16. Greenbushes | 28. Mt. Whaleback (Newman) |
| 5. Brukunga | 17. Greenvale | 29. North Stradbroke Island |
| 6. Captains Flat | 18. Gregory | 30. Paraburdoo |
| 7. Colinsville | 19. Groote Eylandt | 31. Pilbara |
| 8. Collie | 20. Hunter River | 32. Ranger |
| 9. Darling Range | 21. Illawarra | 33. Rum Jungle |
| 10. Eneabba | 22. Kalgoorlie | 34. Rundle |
| 11. Evans Head | 23. LaTrobe Valley | 35. Saraji |
| 12. Fraser Island | 24. Marandoo | 36. Weipa |

include plant seed (Petersen, 1980). Trickle irrigation is sometimes used initially to aid plant establishment, especially in arid areas such as the Pilbara (Atkins, personal communication) and at Broken Hill (Thorne and Hore-Lacy, 1979), where sewage effluent was used to stimulate rapid early growth.

Timing

Mining is frequently a continuous operation year-round, producing wastes without regard to season. The timing of production of wastes can, in itself, be a problem because the condition of the wastes is out of harmony with the climate. It may be too wet or too dry to work, the season may be wrong for plant establishment, special attention may be required to control erosion by water or wind.

In arid areas, such as the Pilbara of Western Australia, rainfall is erratic. Nevertheless, it is such a controlling influence on plant growth, when it occurs (Walker, 1979a), that interrupted contour pitting of the wastes is used as a means of water-harvesting and seed-trapping (Walker, 1984). Temporary, initial irrigation may be necessary to aid plant establishment as a substitute for the lack of rainfall in seasonally dry climates such as at Georgetown, in Queensland (Rice, 1981).

Deferment of the rehabilitation of certain wastes may also be practised. For example, excessive salts are naturally leached out of the surface layers of coal mining waste in the Bowen Basin of Queensland that have been left untreated for a rainy season (Kelly, 1979a).

Compaction

Compaction of subsoils by heavy machinery involved in mining can cause problems for the penetration of plant roots. Root penetration is known to decrease as the bulk density of the medium increases. As subsequent plant growth is often strongly related to root penetration (Burrows et al., 1981), reduction of the effect of compaction is important after sand mining (Burrows, 1983).

During strip-mining for bauxite, the subsoil clays exposed at the pit floors become highly compacted. A widely practised remedy is to rip open the compacted layer prior to attempting to establish vegetation (Middleton, 1979a; Olsen and Tacey, 1979; Hinz, 1981). Ripping has also been found advantageous following iron ore mining (Riches et al., 1978; Walker, 1979b).

Infiltration

Another problem with many wastes, especially heavy clay subsoils, is poor infiltration of rainwater (Hannan 1979a,b; Kelly 1979a,b; Marshall et al., 1983). The water which fails to enter the waste material runs off and may cause water erosion (Hannan, 1981). A second consequence is that insufficient water is available in

the waste to support plant growth. Addition of gypsum to improve the waste structure (Barrow, 1982; Grundy and Bell, 1981), and of fertiliser to stimulate plant growth (Koch, personal communication), can help to improve infiltration.

Surface crust formation occurs on some wastes, and this also reduces infiltration. In the coalfields of the Bowen Basin, in Queensland, this problem is overcome by deep ripping and cultivating on the contour (Kelly, 1979b).

Wind Erosion

Unvegetated surfaces of mine wastes can be susceptible to wind erosion with resultant sand drifts and dust clouds. Seed lodgement, germination and seedling survival can be particularly difficult. These wastes typically have a high proportion of fine sand.

In areas with moderately high but seasonal rainfall, instability coincides with the dry period. Surface treatment with stabilising sprays (Bolte, 1980), mesh (Reynolds, 1977) or mulch (Black, 1979) are required if waste movement is to be controlled. Establishment of vegetation in a subsequent rainy season usually remedies the problem (Bell, 1979).

In arid climates, there may be inadequate available water to sustain a sufficiently dense cover of plant growth to control wind erosion. Physical means of stabilising surfaces may have to suffice. These include a scattering of rock fragments over the unstable surface, as used for control of dust from slime dumps at Kalgoorlie (Marshall et al., 1978). Where warranted, spraying with a compound which binds the surface provides a temporary solution (Bolte, 1980).

CHEMICAL PROPERTIES OF WASTES

Deficiencies

Most wastes are subsoils or crushed rock. Of these, the majority lack adequate amounts of nutrients for plant growth, especially phosphorus and nitrogen (Farnell, 1979; Hannan, 1979b; Middleton, 1979b), although this is not invariably the case (Marshall et al., 1983). Some of these wastes also have a high capacity to fix phosphorus, and make it relatively unavailable for plant growth (Barrow, 1979; Fitter, 1974; Middleton, 1979a). Addition of fertiliser remedies these deficiencies. Bell (1981) has outlined how these fertiliser requirements can be assessed systematically.

Nutrient deficiencies have to be defined in terms of the vegetation that is to be established on the wastes, because plant species vary in their requirements for maximum growth. For example, Black (1979), in rehabilitation following sand-mining at Eneabba, Western Australia, found that members of the Myrtaceae responded well to added mixtures of nitrogen, phosphorus and

potassium fertiliser. In contrast, members of the Proteaceae required no fertiliser for the first six months, after which *Banksia* spp. responded well to nitrogen applications as urea, but not to phosphorus. At Marandoo, in the Pilbara, Burt et al. (1978) found that the establishment of native perennials was inhibited by fertiliser applications. After bauxite mining at Gove in the Northern Territory, Richards (1981), found that indigenous species were relatively unresponsive to fertiliser treatments, whereas introduced species showed no significant growth in the absence of superphosphate. A response to urea was obtained, but only in the presence of superphosphate. As a result of experiences gained with rehabilitation after manganese mining on Groote Eylandt, Northern Territory, Langkamp (1981) reported within the genus *Acacia*, some species are susceptible to high levels of phosphorus, others are tolerant, and still others are responsive to additions of phosphorus. He also noted the tendency for members of the Proteaceae to exhibit phosphorus toxicity at levels required for healthy growth by introduced pasture species. Richards (1981) has cautioned about the level of fertiliser application required to establish the initial stabilising cover of introduced pasture species, and the tendency for this to give them a competitive edge over native species. Fletcher (1979), who was concerned with rehabilitation to native vegetation after sand mining, has also made this point.

The problem of nutrient deficiencies is further complicated by the common occurrence of variations in the type and degree of deficiency for different layers of the subsoil profile as, for example, at Gregory (Evans et al., 1979) and at Saraji (Carter, 1981), coal mines in Queensland. For pasture growth on lateritic red earth wastes following bauxite mining at Weipa, Queensland, Grundy et al. (1979, 1981) showed various layers to be deficient in all or some of nitrogen, phosphorus, potassium, calcium, sulphur, copper and zinc. Of these, phosphorus was the major limiting element, with additions of from 75 to 400 kgP/ha being required for maximum growth, depending on soil layer and plant species.

To counteract the problem of the fixing of phosphorus, Middleton (1979a) briquetted granular superphosphate to provide a concentrated source of slow-release phosphorus in close proximity to planted trees. In a later development (Middleton, 1979b), seed of small-seeded tree species and ground rock phosphate were pelleted, ensuring the closest possible proximity of young plant and phosphorus in a combination that proved successful in field trials.

Excesses

Situations where excesses of elements antagonistic to plant growth occur in the waste are more difficult to counter than those where deficiencies occur.

Many subsoils are saline (Bennison, 1978; Kelly, 1979a; Marshall et al., 1983), and sometimes, as in gold mining at Kalgoorlie,

brackish water is used in processing. As a result, the wastes may be initially too salty for normal plant growth. Remedies include allowing the salt to be leached out by rain (Kelly 1979a) or by irrigation. On certain types of clay, gypsum (calcium sulphate) may be added to improve the physical structure of the waste and reduce salinity by promoting leaching out of salt.

Some elements are toxic to plants in comparatively small amounts. These include lead, zinc, copper and nickel. Problems with these elements become particularly acute with more acid waste, when heavy metals are released into solution. At low pH values, excess aluminium and manganese can also cause problems for plant growth. Acid wastes with heavy metal problems occur particularly in association with the mining of sulphide ores, as at Broken Hill (Andersen, 1981; Hore-Lacy, 1979), although acid wastes are also associated with coal mining (Bartle and Riches, 1978; Charles, 1981; Swaine, 1979).

The tendency for wastes to acidify on exposure to the atmosphere, with a consequent increase in availability of elements toxic to plant growth, is one of the main processes making mine wastes chemically difficult to rehabilitate. Fool's gold, or iron pyrites, is present in many of the rocks mined for base metals as well as in wastes associated with coal mining. On exposure to air, water and sulphur-oxidising bacteria, the pyrites is oxidised and one of the end-products is sulphuric acid (Swaine, 1979). At the acidities which can be reached (pH less than 3), many chemical factors render plant growth impossible.

Rehabilitation of excessively acidic wastes is especially important because they can pollute nearby rivers. Pollution of this kind is known to be associated with abandoned waste dumps at Rum Jungle, Northern Territory, (Ritchie, 1979), Captains Flat, New South Wales (Craze, 1977a,b) and Brukunga, South Australia (Doherty, 1978).

In general, pyrites in wastes from coal mining presents a less severe problem in Australia than in the U.S.A. (Swaine, 1979). Where the problem does occur, the amount of pyrites is relatively low, as in acid mine wastes from coal-mining at Collie, Western Australia. When plants were seeded on to the acidic overburden, at Collie, they failed to establish (Koch, 1980). However, liming, the addition of impure calcium carbonate, has counteracted the acidity adequately (Bartle and Riches, 1978; Koch and Bell, 1983). Without treatment, patches of acidic waste can persist for several years, as Charles (1981) found on coal-mining wastes at Colinsville, Queensland. There, natural colonisation by *Acacia* spp. 16 years after abandonment was restricted to areas of waste where the pH exceeded 4.3.

In some mine waste, the amount of pyrites is sufficiently high to make control by liming alone prohibitive. Instead, techniques are used to inhibit the activity of the bacteria. This is achieved by reducing the oxygen supply, limiting the percolation of water through the waste and raising the pH to a level that

inhibits bacterial action (Andersen, 1981; Harries and Ritchie, 1979). A combination of clay seal, 22cm thick, covered with shale rock fill, 45cm thick and topped with 30cm of soil was used to develop the appropriate conditions on waste dumps from abandoned mines at Captains Flat, New South Wales (Craze, 1977a, b).

Where levels of heavy metals are generally high, with or without association with low pH values, one remedy has been to cover the waste with a layer of material that is more suited for plant growth. The tailings dams from copper mining at Mt. Isa, Queensland, are treated in this way with a 1m covering of siltstone fines from a local quarry (Challen, 1979; Farrell, 1979).

Conditions for plant growth can also be difficult when waste is extremely alkaline (pH greater than 8), both because of high pH and the decreasing availability of plant nutrients (Bell, 1981). An extreme condition is found in red mud lakes, which are a caustic by-product of bauxite refining. These wastes commonly have a pH in excess of 10 (Bell and Meecham, 1978; Olsen, 1978; Broadhurst and Mitchell, 1981; Barrow, 1982; Hinz, 1982). A promising remedy in Western Australia for this problem is the mixing of the alkaline red mud with gypsum, a waste-product from the manufacture of fertiliser (Olsen, 1978; Barrow, 1982). The combination provides a potentially useful additive on the structurally poor sands of the coastal plain south of Perth. Another novel remedy has been suggested by Koch and Bell (1983) who used the alkaline red mud to successfully counteract the acid mine waste from coal mining at Collie. At Gove in the Northern Territory, it has been found sufficient to cover the red mud with a 10cm thick layer of lateritic red earth (Hinz, 1979, 1980 a). At Bell Bay, Tasmania, a 1.5m layer of bark waste from local woodchip mills has been used to cover the red mud (Broadhurst and Mitchell, 1981).

Amendments

Treatment of the more difficult acid and alkaline wastes often includes other materials added as amendments, the function of which can be physical, chemical or both.

The addition of gypsum to red mud, and of red mud to acid coal wastes already cited are examples of such amendments. In both, the primary aim was control of pH. An amendment used on tailings at Mt. Isa as an alternative to the siltstone fines mentioned above was a 5cm layer of flyash mixed into the surface (Farrell, 1979).

At the Saraji mine in the Bowen Basin coalfield of Queensland, the properties of successive layers of waste have been studied (Kelly, 1979b). It has been found possible to ameliorate surface crusting and poor infiltration of sandstone and Tertiary clay wastes by an amendment of a stony mulch prepared from rock that had been separated from the coal.

At Rundle, in Queensland, the mixture of spent shale, a high pH, coarse-textured waste, and overburden, a low pH, heavy clay waste, provides a better material physically and chemically for plant growth than either material on its own (Marshall et al., 1983).

Other substances

Tailings at Mt Isa are an example of a waste that includes added foreign substances used in the processing of ore. These include dioxanthogens, calcium sulphate, sodium sulphate and sodium cyanate from the flotation process (Farrell, 1979). The finely ground rock, together with these substances, produces a crusted waste that has poor infiltration and is high in salt.

A further example of foreign substances added to tailings results from the processing of uranium ore in the Alligator Rivers region, Northern Territory (Davy, 1979). For the Ranger 1/1 mine, these substances include sulphuric acid, pyrolusite, lime, ammonia, amine and kerosene. The implications these additions are to have for rehabilitation are not yet known. Usually, the amounts are low by comparison with subsoil and crushed-rock wastes, and burial is a prospective remedy.

BIOLOGICAL PROPERTIES OF WASTES

Mine waste is frequently biologically inert. There are essentially no bacteria and fungi to break down plant residues and make available nutrients such as nitrogen and phosphorus that are needed for plant growth (Jehne and Bowen, 1981; Langkamp, 1981). No plant seeds or vegetative fragments capable of sprouting new plants are present. Organic matter, important in ameliorating the soil environment, is absent (Barrow, 1979). Waste also lacks small animals (Majer, 1978, 1980).

One of the most common and important techniques used to overcome the above problem is to add a layer of topsoil to the mine waste surface. Topsoil is defined here as that layer at the ground surface prior to mining which can be removed by machinery and used for subsequent respreading. The layer usually varies from 5cm to 20cm in thickness. As such, it has imprecise meaning pedologically, as it may correspond to part or all of the A-horizon and may include some of the B-horizon (Grundy and Bell, 1981).

Many studies have reported superior growth of plants when topsoil has been added to mine wastes. Examples of topsoil use come from mineral sand mining (Black, 1978, 1979; Brooks, 1979; Fletcher, 1979; Lewis and Brooks 1979), bauxite mining (Tacey, 1978; Middleton, 1979a; Olsen and Tacey, 1979; Hinz, 1980b, 1981; McDonald, 1980; Morton, 1980; Tacey and Glossop, 1980; Farrell, 1983), coal mining (Hannan, 1979a, b; Kelly, 1979a, b; Koch, 1980; Koch and Bell, 1983), iron ore mining (Burt, et al., 1978, Riches et al., 1978), manganese mining (Farnell, 1979), tin mining (Bennison, 1978) and oil shale mining (Marshall et al.,

1983). Topsoil is, however, not always necessary or desirable. For instance, rehabilitation of tailings from manganese mining (Farnell, 1982), red mud from bauxite refining (Hinz, 1982) and some of the wastes from coal mining (Kelly, 1979a, b) has been achieved with greater success without topsoil respreading.

Detailed evaluation of the many factors associated with topsoil that could be important has not been made. Indeed, the relative importance of the several properties of topsoil may vary with each waste situation. In addition to bringing those biological components already mentioned to the inert mine waste, there are physical and chemical properties of topsoil which are frequently superior to those of waste. Topsoils are often good seed-bed material, with superior water-holding capacity and infiltration characteristics. They often contain a balanced store of plant nutrients, although the magnitude of this contribution varies with the thickness of the added layer of topsoil.

There is some evidence to suggest that the usefulness of topsoil deteriorates with time of storage and conditions of storage (Fletcher, 1979; Lewis and Brooks, 1979; Tacey and Glossop, 1980). Ideally, topsoil should be spread in time for the spring or rainy season following its collection. The value of topsoil also depends on the timing of its collection in relation to seed set of species occupying the topsoil site. These aspects of topsoil management are somewhat complicated and contentious. This is not surprising, considering the wide range of climates, soils and vegetation types in which mining takes place.

The importance of topsoil as a seed store is well recognised, with the greatest abundance of seeds occurring in the uppermost layers (Fletcher, 1979; Tacey and Glossop, 1980). Brooks (1979) found regeneration of *Xanthorrhoea resinosa* was most practically accomplished using topsoil after mineral sands mining near Evans Head, New South Wales. Topsoil used after oil shale mining at Rundle, Queensland, was found to contribute seed of 40 to 50 species (Koch, personal communication).

Topsoil also contains spores and fragments of bacteria and fungi, the natural colonisation of which may otherwise be slow (Khan, 1978). In association with plant roots, mycorrhizal fungi have a role in nutrition, particularly the uptake of phosphorus. The question of how important these fungi may be in the rehabilitation of mined land was raised by Lewis (1980). Research has subsequently been undertaken to examine this question (Jehne and Bowen, 1981). Bacteria and algae have a role to play in the fixation of nitrogen in soils. Many rehabilitation programmes have included plants capable of forming an association with nitrogen-fixing bacteria. Such plants have usually, but not invariably, been legumes (Hartley, 1979; McDonald, 1979).

Langkamp (1981) and Langkamp and Dalling (1980) have assessed the contribution of a dense stand of nitrogen-fixing *Acacia* spp. to the nitrogen economy of a developing ecosystem on land

rehabilitated after manganese mining on Groote Eylandt. Langkamp (1981) found that about 20% of the annual nitrogen requirement of the developing vegetation was supplied by bacterial fixation.

The role of invertebrates in soil development on wastes after mining is being studied by Majer (1978, 1980). One of his approaches is to investigate the rate of reappearance of invertebrates on mined land sites.

Whether the life which comes to a topsoil-covered waste dump, given adequate rainfall and favourable temperatures, will survive depends greatly on the conditions the plant roots encounter in the underlying waste material. Where the waste material is particularly difficult, and rehabilitation regarded as essential, a sufficiently thick layer of covering material is the only means of ensuring the developing vegetation will not fail at a later date. On acid-producing waste at Captains Flat, Craze (1981) allowed 30cm of soil for pasture growth. On alkaline red mud, Hinz (1982) allowed 10cm of lateritic red earth, and reports that roots of the developing native vegetation, including several woody species over 5m tall, were penetrating the red mud.

ATTAINABLE AND SUSTAINABLE REHABILITATION

Attainability depends on setting a rehabilitation objective or goal. Except in so far as the objective was to do nothing, rehabilitation of waste from early mining activity cannot, by and large, be said to have been attained because no objective was actively set. There continue to be examples where destruction of native vegetation is occurring, but for which no objective is apparently being set. An example is the rash of surface diggings and scrapings for gold in the Eastern Goldfields of Western Australia, which has accelerated considerably since 1979.

With increasing environmental awareness in the 1970's, rehabilitation objectives were set with increasing frequency and in increasing detail. On occasion, the objectives were perhaps unrealistic in terms of what could reasonably be achieved. Where this has occurred, rehabilitation has not been fully attainable, but in hindsight we can appreciate better why this has been the case. In many cases, however, rehabilitation goals have been set recognising existing limitations, and so have been attainable (Evans et al., 1980). From the point of view of mine wastes, this has been achieved using the kinds of remedies referred to earlier to overcome adverse properties of wastes.

It is not easy to say whether rehabilitation that has been achieved is sustainable. There are at least three reasons for this difficulty. Firstly, in many cases it is simply too early to tell. Time scales of tens to hundreds of years, depending on climate, waste and rehabilitation treatment, will be required before it can be certainly stated whether a particular rehabilitation programme has produced a result which is sustainable.

Secondly, the criteria by which sustainability may be measured are still ill-defined scientifically and legally. More precise definition is required, and is being worked towards, but that will take time.

Thirdly, in cases where rehabilitation objectives are aimed at developing complex ecosystems based on native plant communities, achievement of these objectives is dependent upon a thorough knowledge of natural ecosystems. Ecologists, in many cases, are only just beginning to be familiar with these ecosystems at a quantitative level.

Returning to problems of wastes in particular, it has been shown that wastes from mining are of many different types. It may not be possible to rehabilitate the more difficult of these within practical limits of time and money. Less difficult wastes, however, can be treated to remedy any adverse properties that they may have. Application of knowledge that is now widely available should provide the basis for sustainable rehabilitation. Advances will depend on the development of better techniques and on a critical examination of any failures that occur.

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THE FLORA OF REHABILITATED AREAS

D.T. Bell*

ABSTRACT

Sustainable rehabilitation of mined lands requires a detailed knowledge of the ecological requirements of plant species that are to be established, and an accurate assessment of the physical environment in these regions. Western Australian rehabilitation projects in the iron ore mining region of the Hamersley Range, the bauxite deposits of the Darling Range and the coal mines of the Collie Basin are used to illustrate three general principles of rehabilitation research. Firstly, native species have an inherent capacity to tolerate local climate conditions and are generally preferable to introduced species in re-vegetation programmes. Secondly, amelioration of a post-mining habitat can ensure the establishment of plants under difficult circumstances. And, thirdly, long-term functional aspects of the rehabilitation areas may be of great importance to the future well-being of the region.

INTRODUCTION

Establishment of plant species on rehabilitation sites requires site - specific information on a number of facets, but several general ecological principles apply to all revegetation problems. To provide examples of these principles, I have chosen three very different revegetation problems under consideration by staff of the University of Western Australia (Bell, 1980). The first involves the iron ore mining region of the Hamersley Ranges in north-western Western Australia. The second is associated with bauxite mining areas of the Darling Range, and the third problems of revegetation in the Collie coal mining basin. The latter two mining areas are in the south-west of the State.

LAND USE OBJECTIVES

As pointed out in earlier chapters, the goal of developing a sustainable vegetative cover in mined lands is only achievable after a conscious decision has been made concerning the types of vegetation that are best suited to the future land-use requirements of the region.

Native vegetation of the low rainfall sites where iron ore mining is undertaken in the Pilbara is a low open woodland dominated by species of *Acacia* with an understorey of several *Trilodia* species and a diversity of drought-hardy sub-shrubs (Fig. 1 Upper). In these areas, no man-oriented land-use is anticipated for the future, so the rehabilitation programme is designed to return the area to vegetation that is similar to the pre-mining condition.

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FIGURE 1

NATIVE VEGETATION IN REGIONS OF WESTERN AUSTRALIA WHERE SELECTED REHABILITATION PROBLEMS HAVE BEEN STUDIED. (TOP) OPEN ACACIA - EUCALYPTUS SAVANNAH OF THE PILBARA, (MIDDLE) JARRAH FOREST IN THE BAUXITE MINING REGION OF THE DARLING RANGE, (BOTTOM) OPEN JARRAH FOREST IN THE COAL MINING REGION OF THE COLLIE BASIN.

In the wetter areas of south-western Western Australia, the natural vegetation is a forest. In the Darling Range region, where bauxite mining is being carried out, the forest is dominated by *Eucalyptus marginata* (jarrah), with a diverse understorey of sclerophyllous shrubs and small trees (Fig. 1 Middle). Bauxite mining in the Darling Range occurs in areas that also serve as sources of drinking water for the Perth Metropolitan area. Currently, mining is restricted to the western portions of the range where soils have little inherent salinity, and any excess runoff from these catchments is usually of potable water. If bauxite mining moves into the lease areas of the eastern portion of the Darling Range where salt storage in the soil profiles can be considerable (Dimmock et al., 1974), the cleared landscapes will need to be re-vegetated quickly because the rainfall leaching of these areas would result in salting of the downstream drinking water supplies (Shea and Herbert, 1977). The problem of re-establishment of a jarrah-dominated forest in these post-mining landscapes is complicated by an introduced root rot fungus (*Phytophthora cinnamomi*) which causes the degenerative disease "jarrah dieback", which is capable of killing the *E. marginata* (Batini, 1973). Species other than *E. marginata*, which are resistant to this pathogen, must therefore be used to rehabilitate disturbed areas of the Darling Range. The objective of rehabilitation in these regions is primarily to re-establish a forested vegetation type which is capable of maintaining the soil-salt-water balance of the metropolitan drinking water catchments.

The Collie coal basin originally harboured a vegetation dominated by *E. marginata* as well. The stature of the remaining forest areas is generally shorter and more open than other areas of the northern jarrah forest (Fig. 1 Lower). Much of the basin, however, has been cleared for pasture and many abandoned coal mine pits have filled with water, creating a very mixed landscape in the region. Open-cut extraction of coal in the basin has added to the landscape overburden dumps that are inherently highly acidic and very difficult to revegetate. Most mining now is going on in the forested area, although re-establishment of a forest vegetation type is only one of several possibilities for the future. Pasture grazing would be an alternative development for the region as would the conversion of former extraction pits into lakes that could be used for recreational and ecological purposes.

GENERALIZED REHABILITATION PROGRAMME

General procedures that should be followed in order to obtain important information that is necessary in order to formulate rehabilitation programmes are listed below. The plan outlined is very much simplified, but it does provide a framework for research.

1. Determine the environmental conditions existing before mining.
2. Determine the relationships between naturally-existing plant

species and the pre-mining conditions.

3. Determine the environmental conditions in the area that is to be rehabilitated.
4. Predict the potentially successful rehabilitation plant species, and determine methods of habitat amelioration that are needed if objectives are to be achieved.
5. Carry out large-scale rehabilitation planting programme.

Initial efforts in any rehabilitation programme should actually start before the existing habitat is affected by mining. If this is not possible, similar areas still in their original condition should be monitored to determine environmental conditions that exist before mining. This information provides a standard to work toward, and details information on habitat conditions that existing native plant species can be expected to tolerate. Knowing the existing magnitudes and ranges of environmental variables and the existing species of the area, allows some documentation of the relationship between naturally existing plant species and the pre-mining environmental conditions. Once this information has been gathered, the objective should be to determine environmental conditions in the area that is to be rehabilitated. Comparing the ranges of habitat tolerances for the species on which you have information, and the conditions in post-mining habitats, will give you some idea whether these species could tolerate altered conditions in the mined areas, or whether site conditions must be ameliorated before re-vegetation can be achieved. Predicting the potentially successful rehabilitation species and methods of habitat amelioration needed to reach your objectives is the most difficult step, and will be illustrated later in this paper. Lastly, once a sufficient research base is established and small scale field trial knowledge has been gathered, a plan for the large scale rehabilitation of the land can be implemented.

ENVIRONMENTAL CONSTRAINTS TO RE-VEGETATION

Vegetation capable of tolerating conditions at post-mining sites can only be predicted after a number of tests. For each of the three sites under consideration, the most difficult environmental constraints have been chosen, to illustrate some of the research that has been undertaken and to illustrate some further general points. At Collie, the major environmental constraint relates to the tolerance of plant species to the acid overburden material. In the Hamersley Ranges, plant establishment is restricted primarily by low rainfall conditions. In the Darling Range, matching the water-use characteristics of the rehabilitation species to that of the original forest is the most difficult constraint to overcome.

COLLIE COAL MINING REHABILITATION RESEARCH

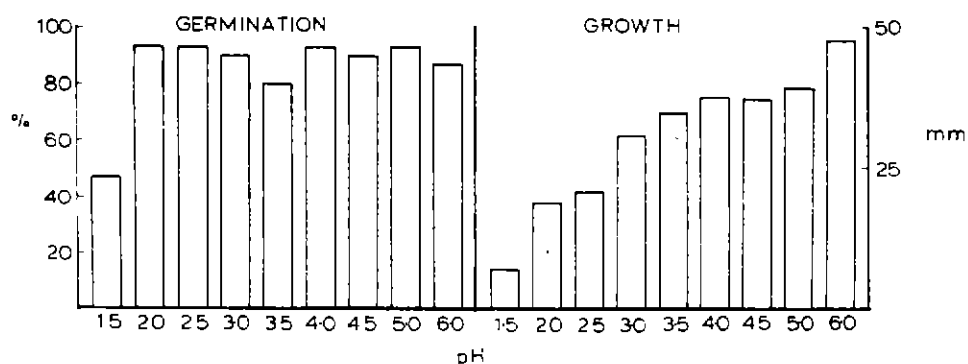
For the Collie Basin rehabilitation programme, a series of petri

plate experiments provided some useful information on the establishment of low pH tolerance for native species of the area. In these experiments, seeds of each of numerous potential species were placed on moist filter paper which was supplied with water solution of pH's ranging from 1.5 to 6.0. The percentages of the seeds which germinated in each pH solution, and the average growth of the epicotyl and radicle after two weeks, is shown for three of the most promising species in Fig. 2. *E. calophylla* had excellent germination, even in solutions with pH's as low as 2.0. Growth tended to be retarded with decreasing pH, but this species had the best overall growth achieved in this series of tests. With *E. rudis*, germination occurred at quite low pH values, but not as low as for *E. calophylla*. Growth in *E. rudis* increased with increasing pH, but was much less than growth achieved by *E. calophylla*. The results of the test on *E. marginata* were somewhat similar to each of the other two illustrated here, but lower germination percentages throughout may have been due to a relatively poor seed source. All three of these species, however, could be expected to germinate and grow in the low pH spoils of the coal mine wastes at Collie.

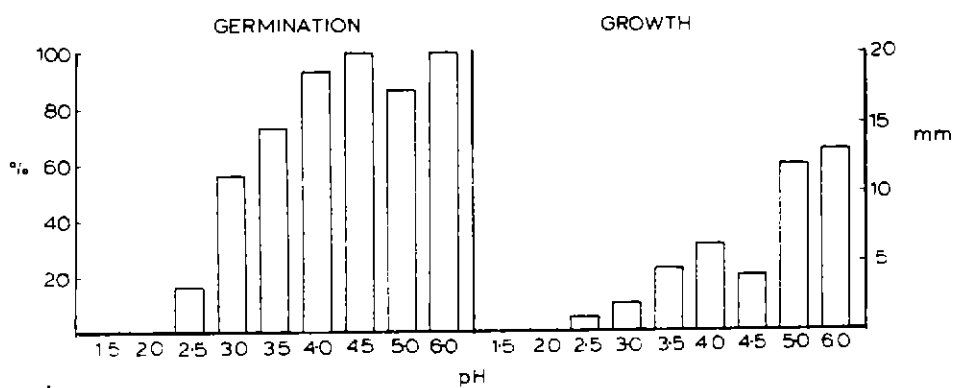
The short-term petri plate experiments suggested that species that would tolerate the low pH conditions could be found. However, longer-term survival, especially under field conditions, needed to be gathered before these particular species could be recommended. In the Collie Basin, a number of old abandoned coal mines have spoil overburden heaps where plants have invaded naturally. The spoils have pH values which range from 2.4 to 5.8 (Fig. 3). Measurements of pH for the rooting zone soils of plants found in these spoil areas are shown in Fig. 3. The lowest pH value recorded for an individual of a given species provides some idea of the limit of tolerance to soil pH for each of these species. Species found at the bottom of the list would, therefore, not tolerate low pH soils. For this reason, they would not be preferred species for revegetation of Collie coal mine overburden. Species at the top of the list, generally those that tolerate pH levels of less than 4.0, would be recommended rehabilitation species. *E. calophylla*, which was observed to do very well in laboratory experiments, was found to occur naturally in coal mine spoils with pH's as low as 2.9. *E. rudis* and *E. marginata*, also showed good potential by occurring in areas with pH's as low as 3.3.

Data from growth tests using *Lolium rigidum* suggest that amelioration of the habitat is required if pasture landscape is to be established on coal mining spoils (Koch and Bell 1983). In this test, pasture species were grown in coal mining spoils ameliorated by additions of jarrah sawdust, caustic soda - red mud residue from alumina processing, and agricultural lime. The sawdust had no effect on pH and no grass seeds germinated and grew under the test conditions (Fig. 4). The red mud residue and agricultural lime additions raised the pH values of the coal

EUCALYPTUS CALOPHYLLA



EUCALYPTUS RUDIS



EUCALYPTUS MARGINATA

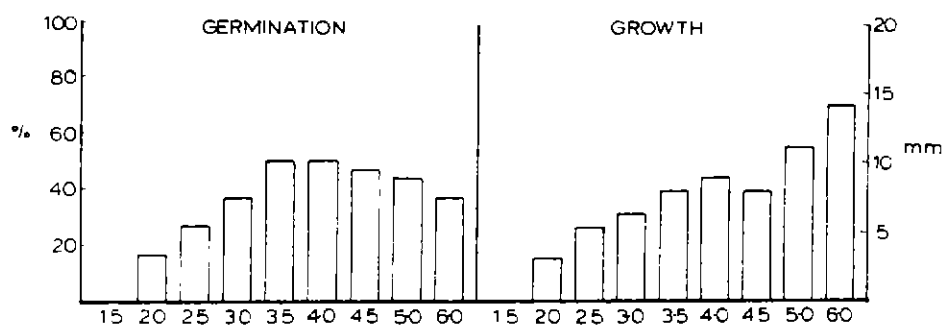


FIGURE 2

IMPACT OF A GRADED SERIES OF pH SOLUTIONS OF H₂SO₄ ON THE GERMINATION AND GROWTH AFTER 14 DAYS OF EUCALYPTUS CALOPHYLLA, E. RUDIS and E. WANDOO SEEDS.

SPECIES

SOIL pH

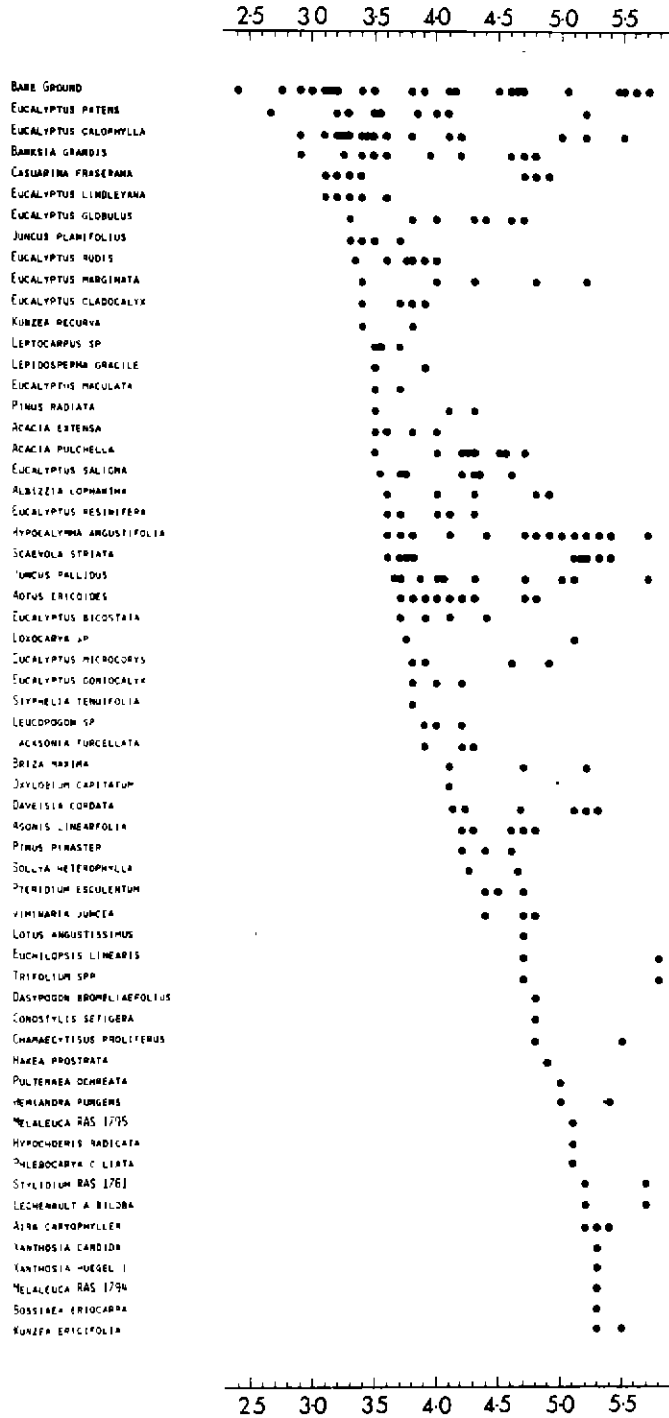


FIGURE 3

BARE GROUND AND ROOTING ZONE SOIL pH VALUES FOR SPECIES FOUND GROWING NATURALLY ON ABANDONED COAL MINING OVERBURDEN IN THE COLLIE BASIN.

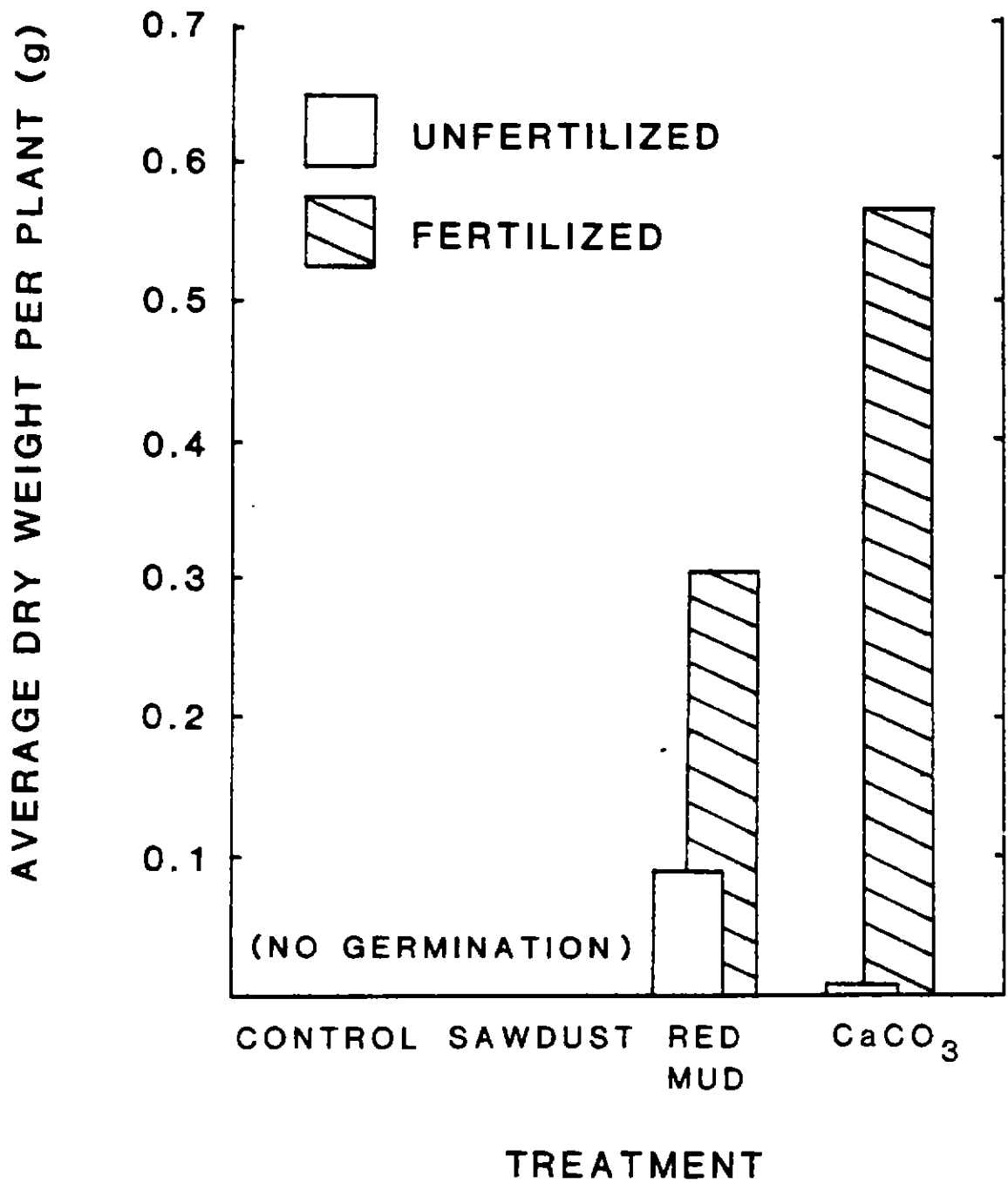


FIGURE 4

GROWTH OF *LOLIUM RIGIDUM* AFTER 7 WEEKS IN COLLIE COAL OVERBURDEN (CONTROL), OVERBURDEN MATERIAL AMELIORATED WITH JARRAH MILLING SAWDUST, ALUMINA REFUSE RED MUD AND LIME (CaCO_3).

spoils, and germination and growth of *L. rigidum* was achieved. Growth achieved in red mud - ameliorated spoils was better than that in spoils treated with lime, probably due to nutrients added from the red mud. Once fertilizers were added to spoils whose pH's had been adjusted, the latter produced enough growth to be considered acceptable for pasture cover. Significantly more red mud than agricultural lime is required to raise pH levels to circum-neutral values. For this reason, it may not be economically feasible to ameliorate spoils by adding red mud residues.

PILBARA REGION REHABILITATION RESEARCH

The major environmental constraint to re-vegetation in the Hamersley Range region is the low natural rainfall regime. The establishment of plants under natural conditions in this area appears to occur only when cyclones bring extensive summer rainfall. Rehabilitation programmes in this region use irrigation water from artesian bores to successfully establish vegetation in iron ore mine overburden (Atkins, 1983).

Fig. 5 shows the results of a study on the survival of plant seedlings in the iron ore mining rehabilitation research programme. Data from a number of individual species have been grouped to illustrate another general ecological point. In this study, one-year-old pot-grown seedlings of a number of native legume and eucalypt species from the Pilbara of W.A., and legumes and eucalypts introduced from other dry region habitats of Australia, were transplanted into iron mine waste areas. All seedlings were irrigated regularly from sprinkler lines. Some initial losses occurred when transplanting the seedlings from pots to the field area, but little additional mortality was recorded during the following winter. Summer mortality was severe in some species, however, even though the seedlings were irrigated throughout this period. Mortality tended to be greater in the eucalypt species, probably because they have larger leaves than the legumes and, therefore, have greater surfaces through which transpiration can occur. The important observation, however, is that in each case, species native to the Hamersley Range area survived better than species from other regions. Presumably, native species are already adapted to the general climate of the region and need only be tolerant of the soil environment of the rehabilitated area. Introduced species must adapt to both a new climatic regime and new soil conditions. Once seedlings survived the first summer period, little more mortality was apparent after another year in the field. Subsequent records have revealed that survival percentages are much the same now after three years (Atkins, 1983).

DARLING RANGE REHABILITATION RESEARCH

Many of the problems associated with rehabilitation in bauxite mining areas have been successfully overcome (Tacey, 1979).

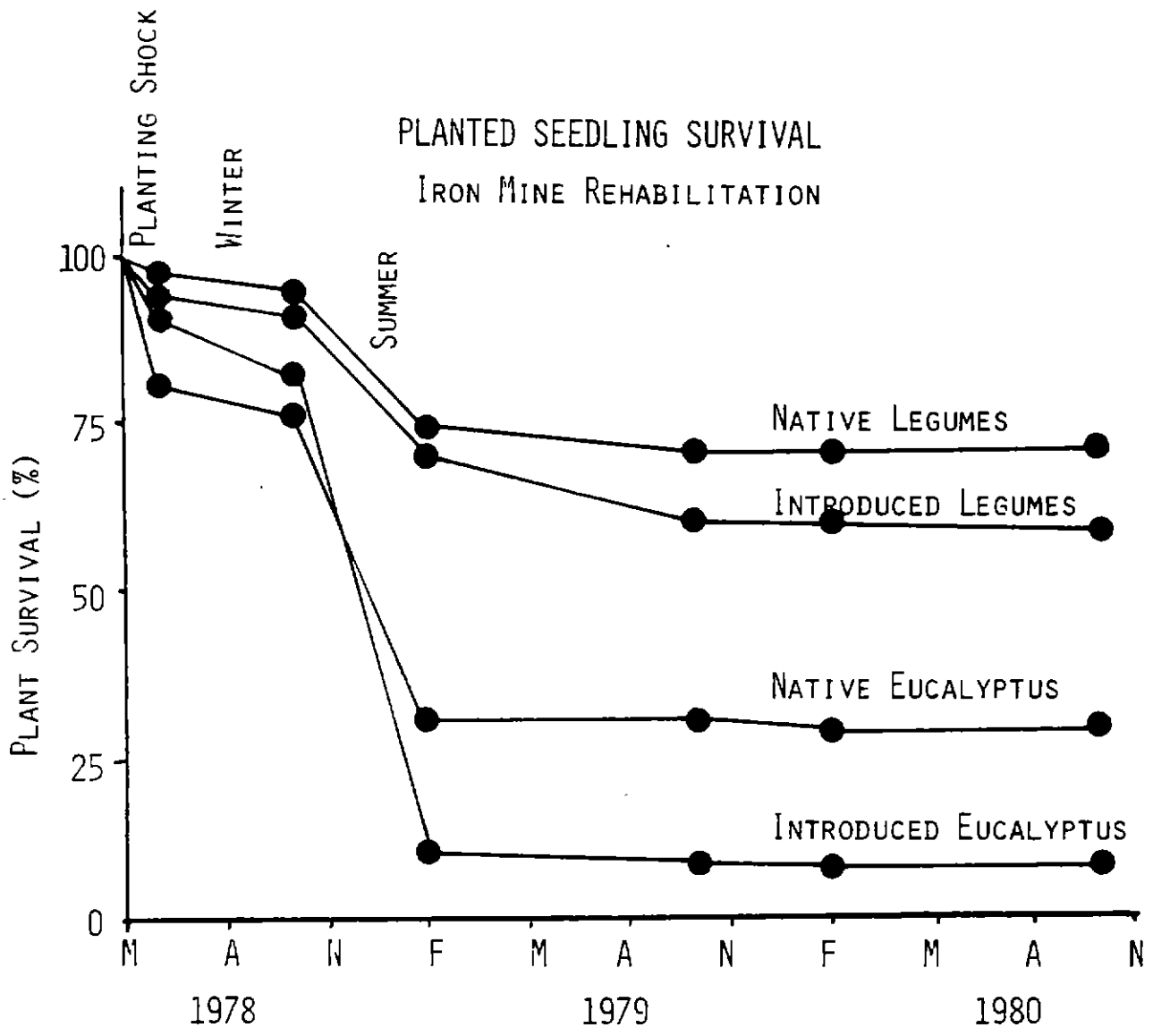


FIGURE 5

PERCENTAGE SURVIVAL OF SEEDLINGS OF PILBARA REGION NATIVE LEGUMES AND EUCALYPTS, AND INTRODUCED LEGUMES AND EUCALYPTS FROM OTHER ARID REGIONS OF AUSTRALIA, IN IRON MINE OVERBURDEN IN THE HAMERSLEY RANGE.

However, matching water-use characteristics of the original native forest remains a major difficulty. If bauxite mining is allowed into the eastern Darling Range, rehabilitation species used must transpire extensive amounts of water to prevent soil salt from leaching into drinking water reservoirs. Two instruments that measure ways in which plants respond to water availability and water use are the leaf resistance porometer (Monteith and Bull, 1970) and the pressure chamber (Scholander et al., 1965). The leaf resistance porometer measures the resistance a leaf exerts to prevent transpiration water loss. Primarily, it measures the degree to which the stomata are open or closed. The pressure chamber is used to measure the tensions that develop within plant conducting tissue due to the loss of water by transpiration. The tensions that develop within the plant are matched using nitrogen gas pressure. At the point when water is forced from the excised end of an enclosed plant cutting, the pressure required within the chamber of the apparatus exactly balances that already developed within xylem tissue within the plant. Pressure is measured by a gauge and recorded as xylem pressure potential.

Data shown in Fig. 6 are from a more extensive study of 3-5 year-old trees growing in bauxite rehabilitation arboreatae during the summer of 1980-1981 (Colquhoun et al., 1984). The graph at the top left of this figure shows the profile of temperature and vapour pressure over the study day. Temperature values peaked at about 1400 h; vapour pressure deficit, which measures the evaporative demand of the atmosphere, peaked slightly later in the afternoon. *E. marginata* is the dominant tree species of the Northern Jarrah Forest, but its susceptibility to *P. cinnamomi* prevents it from being seriously considered for the large scale replanting programmes now being undertaken in the Darling Range. Its water utilization patterns, however, provide the model to compare rehabilitation species patterns, because the original soil-salt-water balance is due to the transpiration capacity of this species.

Daily transpiration patterns in *E. marginata* tend to be very simple. With increasing temperature, transpiration rates increase, causing a water tension to develop in the xylem conducting tissues. Tension develops because water uptake by the roots lags behind transpiration loss by the leaves. The pressure chamber records this tension. As leaf resistance measurements are low throughout the day, indicating that stomata are fully open, transpiration is governed by external physical conditions. The total amount of water picked up from the soil profile and transpired to the atmosphere is, therefore, very high each day. If leaching of salt from the soil by excess water is to be prevented, a substitute rehabilitation species must have a similar pattern or at least a total water consumption which is equivalent to that of *E. marginata*.

One potential rehabilitation species which is resistant to the root rot fungus in *E. maculata*, a species native to the eastern states of Australia. However, it does not appear to a good

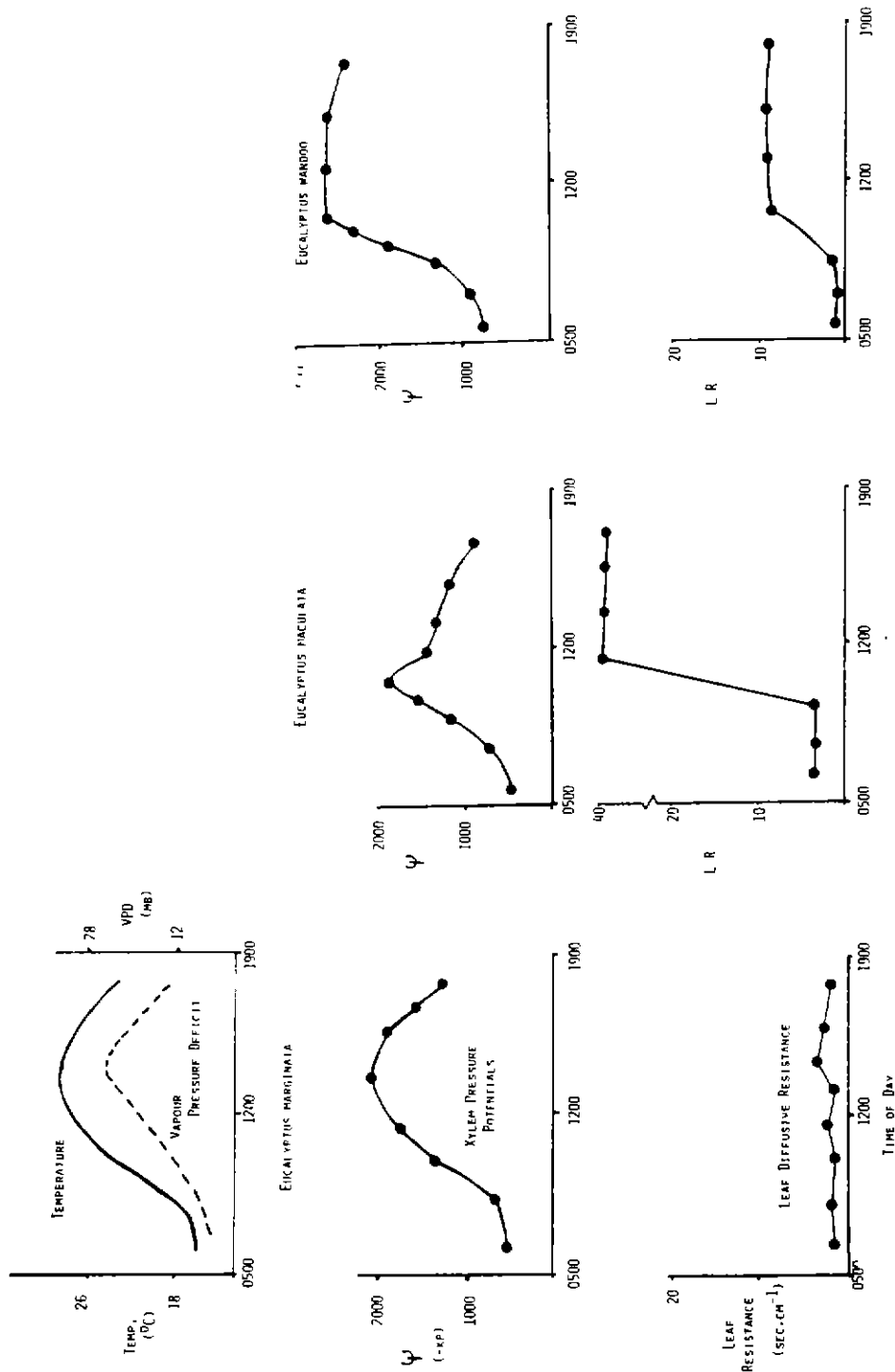


FIGURE 6

ENVIRONMENTAL DATA DURING SUMMER 1981 TEST DAY, AND LEAF RESISTANCE AND XYLEM PRESSURE POTENTIAL DATA FOR EUCALYPTUS MARGINATA, E. MACULATA, AND E. WANDOO. (AFTER COLQUHOUN et al., 1984).

candidate for replacing the functional role of *E. marginata* because it exerts extensive control of its water utilization. By observing the patterns of xylem pressure potential and leaf resistance, one can see that in the morning transpiration tends to increase with increasing atmospheric demand for water. When conducting tissue tensions reach values of about -1500 kPa, the stomata close, as indicated by an increase in leaf resistance. After stomatal closure, water uptake by the roots lowers the tension because no further transpiration is causing water loss. The total amount of water extracted from the soil profile by this species would be expected to be less than the *E. marginata* model. A watershed planted with this species might be expected to contain considerably more water after annual transpiratory loss. This would result in the leaching and run-off of saline water.

E. wandoo has some water-use characteristics which make it more promising as a species to replace *E. marginata* in the bauxite regions. Data presented in Fig. 5 suggest that this species allows xylem tensions to greatly exceed those of the *E. marginata* model, although it exerts some stomatal control. Total water utilization is, therefore, expected to more nearly match that of the original dominant, than would be the case for most other potential species replacements. *E. wandoo* is also a Western Australian native species, although it tends to occur in the margins of the Darling Range. It is now one of the most commonly planted species in bauxite rehabilitation programmes in the Darling Range. Eastern-States rehabilitation species like *Eucalyptus maculata*, even though they exert control of water loss in summer, have higher leaf area indices than jarrah (Carbon et al., 1981), and it could be that their total annual water utilization is really equivalent to that of jarrah. Studies of year-round water utilization by this species are now being carried out.

REVEGETATION SUCCESSES

Re-vegetation of mined areas has been accomplished at each of the study areas discussed in this paper. Fig. 7 (Top) illustrates a rehabilitated iron ore mine containing three-year old plants. The area shown is on flat land, but successful establishment of plants on waste dump slopes has been accomplished as well. Fig. 7 (Middle) shows one area in the Darling Range which is being rehabilitated after bauxite mining. The rehabilitation species shown here, adjacent to an area of uncleared jarrah forest, are predominantly *E. calophylla* and *E. wandoo*. Fig. 7 (Bottom) provides an idea of the three potential future uses of the abandoned open pit coal mining areas of the Collie Basin. The old pit has been allowed to fill with water, grass pastures have been established in the background, and trees of the future forest have been planted in the region to the left.

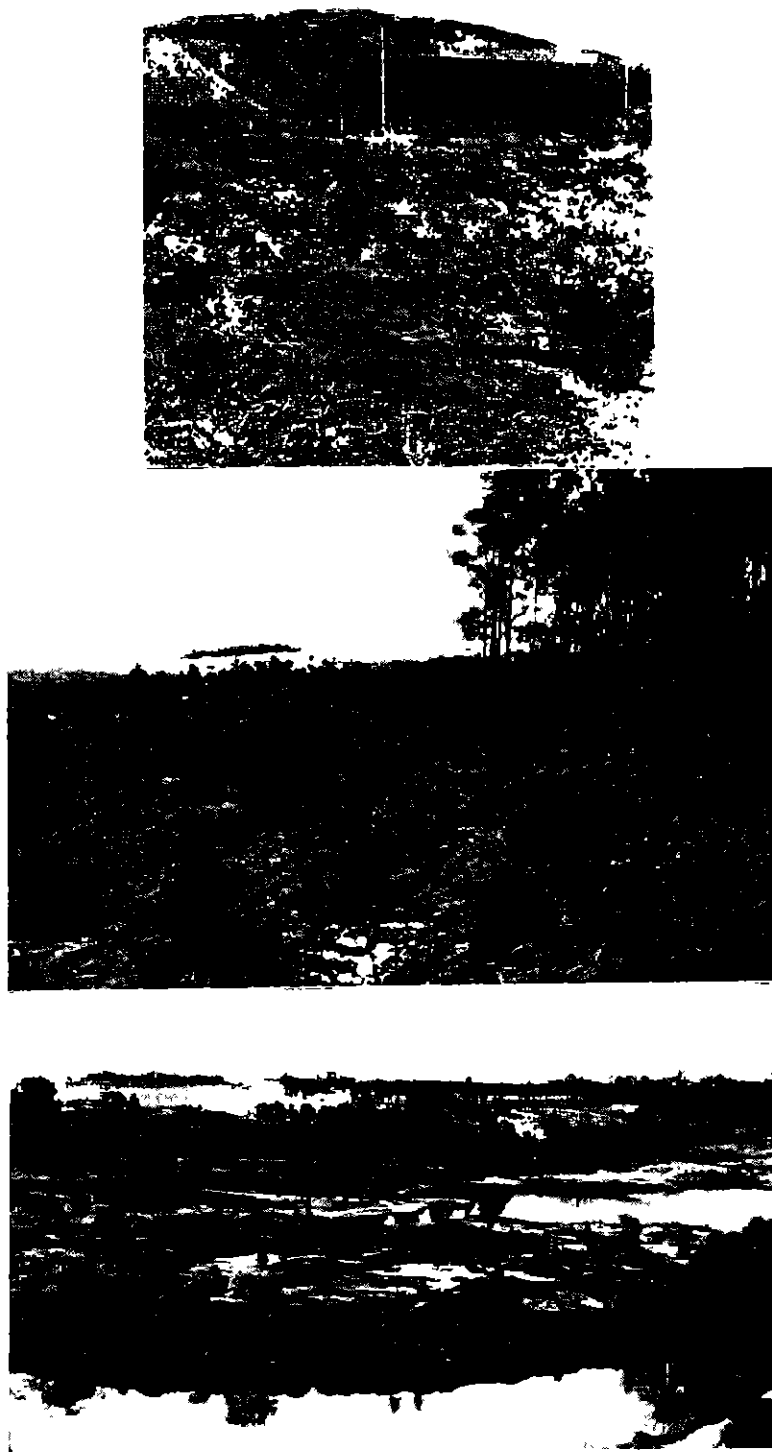


FIGURE 7

REHABILITATED MINING WASTES IN WESTERN AUSTRALIA. (TOP) IRON MINE REHABILITATION, (MIDDLE) BAUXITE MINING REHABILITATION, (BOTTOM) COAL MINE REHABILITATION.

ACKNOWLEDGEMENTS

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THE ROLE OF FAUNA IN MINED LAND REHABILITATION

J.D. Majer*

ABSTRACT

By comparison with flora, the attention paid to fauna when rehabilitating mined lands is disturbingly small. The low priority of fauna research and monitoring is reflected in the fact that mining companies tend to employ agronomists, to a lesser extent botanists, but seldom zoologists, as rehabilitation officers.

Reasons why fauna should be considered in the rehabilitation agenda are discussed in this paper. They include the fact that animals play an important role in nutrient cycling, enhancing soil structure, consumption of plant biomass, promoting plant diversity, pollination of plants and dispersal of seeds. Of course, the conservation aspect of the fauna should also be considered.

The role of fauna in some of these activities is discussed, using examples gathered throughout Australia, and some ways in which rehabilitation may be designed to promote various animal groups are outlined.

Studies performed on ants suggest that the rate of return of fauna, and probably development of the plant biota, are directly related to prevailing climatic factors. A model is proposed which divides Australia into zones of differing potential rehabilitation rates. This model should assist rehabilitation officers, and government agencies overseeing rehabilitation, to realistically gear their expectations to what is theoretically attainable in a particular climatic zone.

INTRODUCTION

In Australia, open-cut mines are usually subjected to some form of rehabilitation following cessation of the mining phase. Rehabilitation may be performed to restore native vegetation or to produce forests, pastures, recreation areas or some other form of land-use. The biological problems associated with each option differ, although many problems are shared.

The comments in this paper mainly apply to the native vegetation option. However, as many of the timber species used in the forestry option are native, they are also relevant to this as well. Many comments also apply to agricultural and other options.

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A mine may be a lacuna in the original vegetation, if the pod-type mining approach is practised (Fig. 1A), or an elongated barrier if strip-type mining takes place (Fig. 1B). In either case, the fauna needs to be considered for the following reasons:

- (1) Their return is necessary if rehabilitation is to be sustained.
- (2) The presence of certain species may pose special problems with regard to the process of rehabilitation.
- (3) The mine needs to be rehabilitated in order to minimise the threat to conservation of animals both within and outside the mined area.

These may all seem to be extremely important reasons for considering fauna but, surprisingly, little attention is paid to them. Nichols (personal communication) recently surveyed the work done on fauna in association with terrestrial mining operations in Australia. He found that, although a number of companies considered fauna in their pre-mining Environmental Impact Statements, few followed up these studies following mining.

I now wish to outline the specific reasons why fauna need to be considered in relation to mining and, where possible, give examples where fauna have been studied in relation to the problem. The reasons are discussed under the three categories mentioned above.

RELEVANCE OF FAUNA TO THE SUSTAINABILITY OF REHABILITATION

Litter decomposition and nutrient cycling

A native ecosystem is characterised by having an adequate nutrient load in the topsoil and a flux of nutrients from decomposing plant and animal material into the soil. Mining often removes these nutrients by failing to preserve the nutrient-rich topsoil or by leaching nutrients from sub-soil during wet processing.

Rehabilitation usually attempts to ameliorate this problem by applying stored or fresh topsoil, and then applying a broadcast or spot fertilizer treatment. This may work in the short-term, but for long-term sustainability, organisms which can recycle nutrients from the leaf litter back to the soil must colonise the area. Micro-organisms, such as fungi and actinomycetes, play an enormous part in the process. Nevertheless, animals such as worms, millipedes and springtails play an over-riding regulatory role. They break up the litter so that micro-organisms can act on it, redistribute the litter into strata where nutrient release can take place more rapidly, or directly stimulate the activity of micro-organisms. From this, it is clear that their presence is necessary if nutrient cycles are to be established in the restored areas.

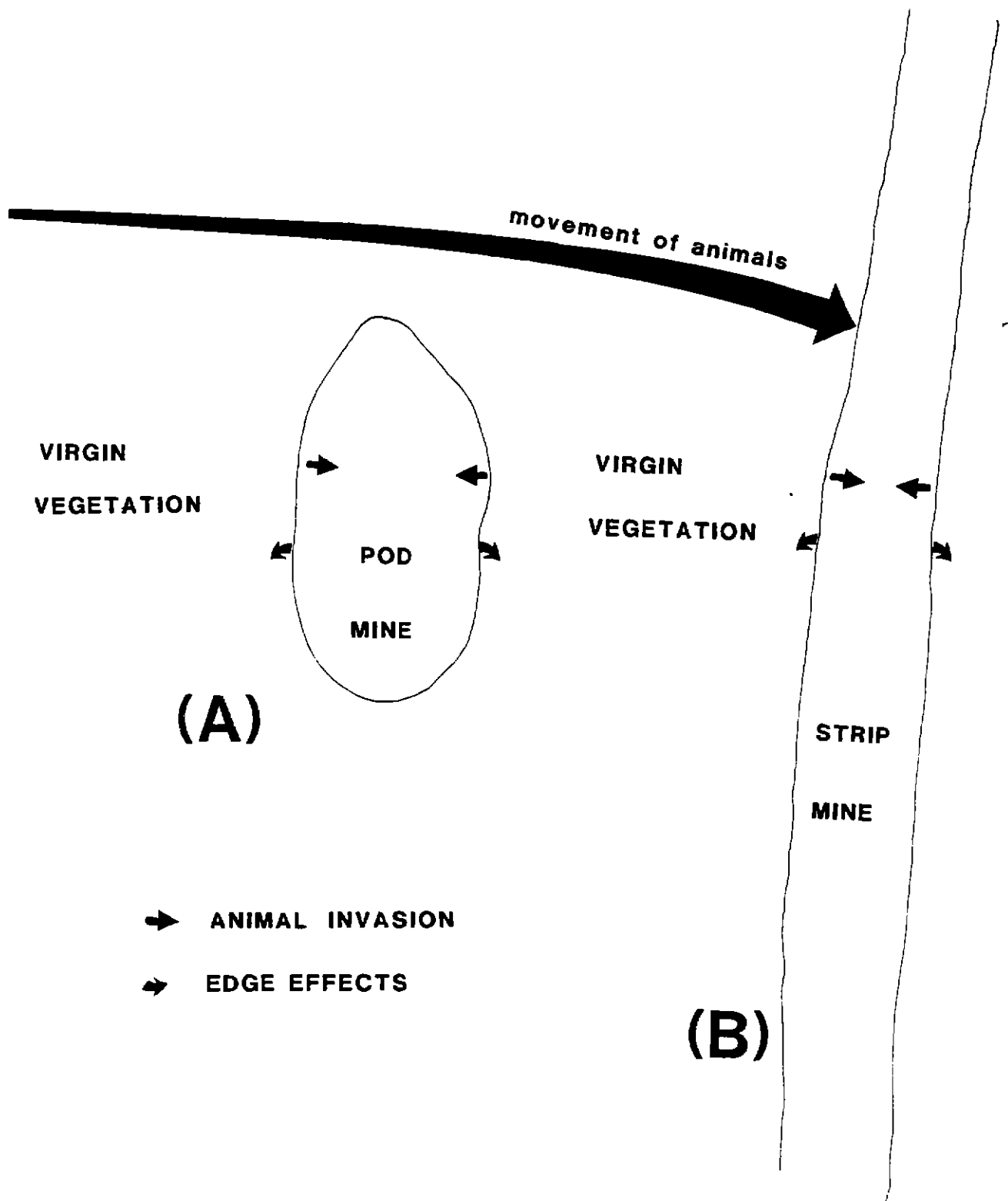


FIGURE 1

RELATIONSHIP BETWEEN POD-TYPE (A) AND STRIP-TYPE (B) MINING, SHOWING THEIR POSSIBLE INFLUENCE ON FAUNA WITHIN AND ADJACENT TO MINED AREA.

Southwell and Majer (1982) recently demonstrated the importance of earthworms when they introduced the worm *Eisenia foetida* into 'mud' residue derived from the bauxite refining process. Worms were fed with sheep pellets and, by comparison with control treatments where pellets were added but worms were absent, large increases in phosphorus, potassium, nitrogen and carbon occurred in the experimental treatment residue (Table 1).

TABLE 1

PERCENTAGE CHANGE IN NUTRIENT CONTENT OF 'MUD' RESIDUE FROM BAUXITE REFINING PROCESS TO WHICH WORMS HAD, OR HAD NOT, BEEN ADDED. THE EXPERIMENT WAS PERFORMED OVER 125 DAYS (ADAPTED FROM SOUTHWELL AND MAJER, 1982).

Nutrient	Percentage change in nutrients	
	Worms absent	Worms present
total phosphorus (%)	+3	+16
available phosphorus (ppm)	-2	+10
available potassium (ppm)	+20	+90
total nitrogen (%)	+1	+17
total carbon (%)	0	+8

Soil structure and turnover

Under the general umbrella of the term 'soil structure', there are various soil attributes that are important to the health of the environment. Included here are the distribution of pores in the soil - important for soil aeration, drainage and root penetration; soil friability - important for root penetration and burrowing by animals; and soil stratification - important for ensuring that nutrients are available at a depth where they are available to plants. Animals play an important role in all three soil structural attributes. Worms, termites, ants and beetles all create cavities in the soil by their burrowing activities and also increase the friability of the soil. Worms, termites and ants also bring lower strata of soil to the surface and hence increase nutrient availability to certain plants. Earthworms have generally been attributed the major role in this activity, although near Sydney it has been found that ants bring $841 \text{ g.m.}^{-2} \text{ yr}^{-1}$ of soil to the surface while worms only turn up $133 \text{ g.m.}^{-2} \text{ yr}^{-1}$ (Humphreys, 1981).

Abbott, Parker and Sills (1979) performed a study on the role of large soil animals in agricultural soils which was highly relevant to minesite rehabilitation. They found that when ploughing and stocking was suspended for seven years, there was a recovery in the density of large soil animals. This was accompanied by improvements in water permeability, soil compactability and the number of pores within the soil (Table 2).

TABLE 2

SUMMARY OF PHYSICAL AND CHEMICAL CHARACTERISTICS, AND THE DENSITY OF ANIMALS IN VIRGIN, FRESHLY CULTIVATED AND OTHER SOILS CULTIVATED SEVEN YEARS PREVIOUSLY, AT KODJ-KODJIN, WESTERN AUSTRALIA (ADAPTED FROM ABBOTT, et al., 1979).

Attribute	Virgin area	Formerly cultivated area	Cultivated area
pH	5.6	5.2	4.9
% organic matter	14.05	9.49	6.62
Infiltration rate of water (s)	53.1	47.6	150.3
Soil penetrability	239.3	207.6	192.2
Number of soil animals per core	21	15	0

Pollination of plants

Many plants are either pollinated by insects, birds or other vertebrates. If pollen vectors are excluded, or eliminated, plants will not set seed. The ubiquity of most insects and the generalist nature of most bird pollinators suggests that appropriate pollinators are likely to be present in rehabilitated areas. However, if the rehabilitated area is small, vegetated by plants not present in the adjacent vegetation, and pollinated by animals not present their either, the mine may be too small to support a pollen vector population.

In other instances, a mine may be rehabilitated with plants having a very specific pollinator. Included here may be some of the low-growing heath *Dryandra* spp. which are thought to be pollinated by honey possums (*Tarsipes rostratus*) (Hopper, 1981). These animals are unlikely to be early colonisers of the rehabilitated sand mines near Eneabba, and it is therefore in such places that the long-term sustainability of certain *Dryandra* populations is likely to be a potential problem.

Promotion of plant diversity

It is known in other parts of the world that selective grazing by mammals can increase or decrease the species diversity and

abundance of vegetation in different plant associations. More recently, it has been suggested that differential grazing by insects on particular Eucalyptus species may actually increase the diversity of vegetation (Morrow, 1977). The actual reason is that an otherwise dominant Eucalyptus sp. is suppressed by herbivore activity, and this in turn allows other plant species to thrive.

The implications of this are particularly important to minesite rehabilitation, since the early stages are characterised by the abundance of just a few species of plants. Herbivore activity may play an important role in reducing the abundance of these plants, and thus providing opportunities for plants normally less able to compete with the abundant species.

Seed dispersal and survival

The fate of seeds in rehabilitated areas is also influenced by the activities of vertebrates and invertebrates. Birds such as emus, doves, pigeons and even honeyeaters consume plant diaspores, and viable seed may pass intact through the alimentary canal. As a result, they may play an important role in seed dispersal (Noble, 1975). As well as benefiting rehabilitation by dispersing seed within the pit, these birds may enrich the area by carrying seed of new species from the adjacent native vegetation.

Ants are other major vectors of seeds. Seeds of legumes and other genera which possess arils are often gathered by ants which consume the aril but discard the rest of the seed intact. By doing this, the seed becomes buried beneath the soil and benefits by being protected from desiccation, fire and predators. Majer (1980, 1984 a) has demonstrated that this beneficial ant/seed relationship has been restored in areas that were rehabilitated at last three years previously (Fig. 2).

DETRIMENTAL EFFECT OF FAUNA

Consumption of plant material

Rehabilitated mines are often characterised in their early stages by a dominance of a few plant species, some of which may not be native to the area. Both attributes may be conducive to herbivore outbreaks; dominant plants providing abundant resources for the build up of herbivores; exotic plants having poorly adapted defences against herbivores with which there is no history of coevolution.

I know of no published reports of pest outbreaks in rehabilitated areas, although my observations indicate that they are widespread. In the rehabilitated bauxite mines of Western Australia, psyllids have been noticed defoliating Albizia sp. and the common longicorn, Phoracantha sp., has attacked drought-affected Eucalyptus microcorys. More recently, densely growing

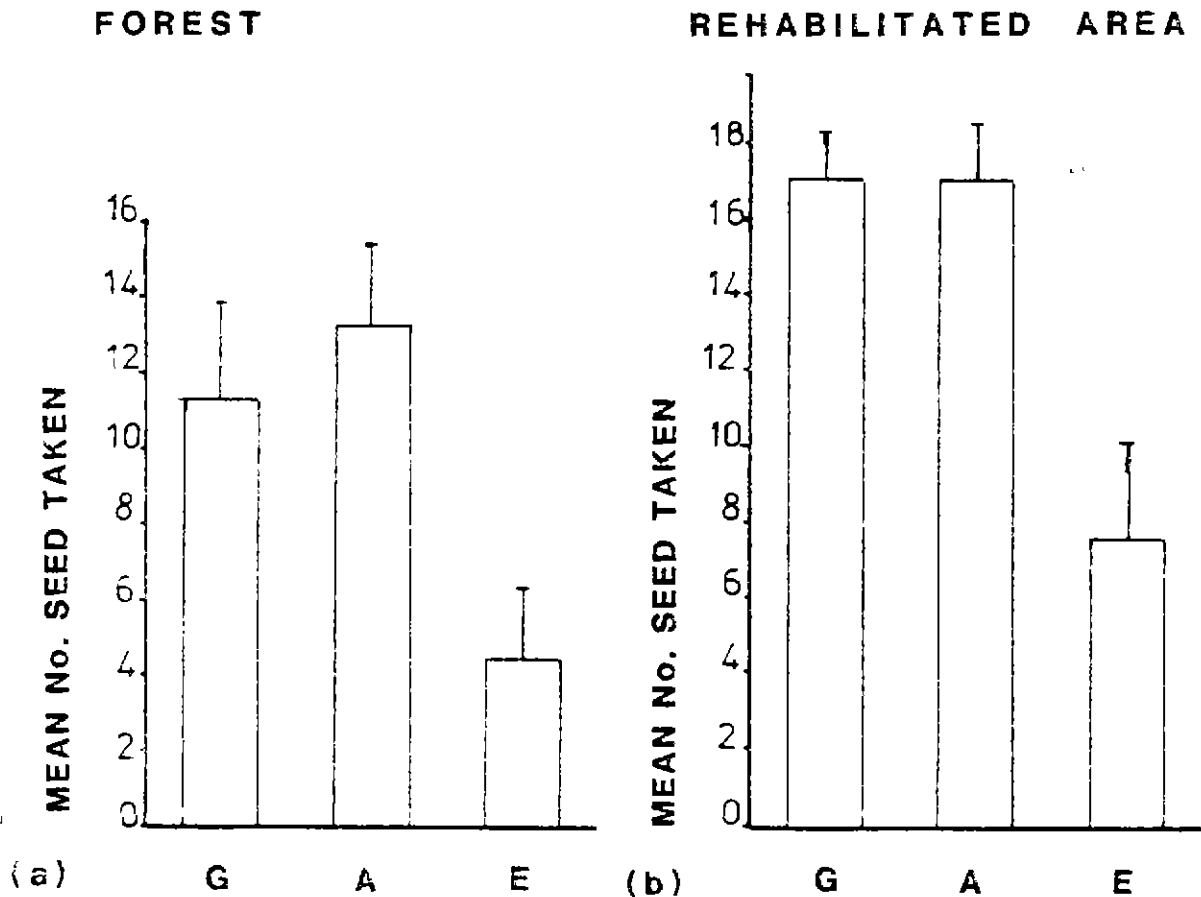


FIGURE 2

MEAN NUMBER OF GREVILLEA PTERIDIFOLIA (G), ACACIA LEPTOCARPA (A) AND EUCALYPTUS TETRODONTA (E) SEEDS REMOVED PER DEPOT (MAX = 20) IN VIRGIN FOREST AND AN AREA WHICH HAD BEEN REHABILITATED 3.5 YEARS PREVIOUSLY AT GOVE, NORTHERN TERRITORY (ADAPTED FROM MAJER, 1984 a).

Acacia sp. have been dying back as a result of attack by Buprestidae larva borers (Curry, personal communication).

Consumption of seeds

Although, as mentioned earlier, many ant species play a beneficial role in seed survival, other types harvest and eat the entire seed. These are clearly a threat to the success of broadcast-seeding operations in areas being rehabilitated.

Investigations have shown that although ants are rare in newly topsoiled areas (Majer 1980, 1984 a), they may forage from adjacent forest or rehabilitation and remove seeds. In the north of Australia ants spread up to 80 m from previously rehabilitated areas into the freshly topsoiled area and remove up to 100% of

seeds. Some of the ants may be beneficial but others certainly reduce the success of seeding operations.

Encouragement of feral animals

The early stages of rehabilitation are often characterised by the growth of lush vegetation, particularly if grasses are used. This may provide conditions suitable for feral animals, such as rabbits, which may be unable to colonise the adjacent native vegetation. By colonising the rehabilitated area, rabbits may forage into the normally hostile native vegetation and damage seedlings. In addition, the growth of vegetation in the rehabilitated mine may also be jeopardised. Although no cases of this happening are reported in the Australian mine rehabilitation literature, there are known instances where rabbits have colonised agricultural enclosures within the, normally hostile, jarrah forest environment (King et al., in press).

I have recently investigated the return of ants in rehabilitated sand mines on North Stradbroke Island (Majer, 1984 b). The return of ant species followed a linear pattern up to 7 years (Fig. 3), although thereafter there was a sharp decline in the number of ant species per plot. This coincided with the introduced pan-tropical pest species of ant, *Pheidole magacephala*, colonising the mine and attaining massive densities. This ant was absent in the adjacent native vegetation and the competitive effect which it had on the native fauna is a matter for concern.

CONSERVATION CONSIDERATIONS

I assume that all readers of this paper are familiar with the reasons for conservation of fauna, and will hence not present the arguments here. Readers wishing to know more about the subject should consult Tyler (1979).

A mine may influence the conservation status of animals in a number of ways. Firstly, all animals are temporarily eliminated, or frightened away from the area. This may not be important if the proportion of a particular vegetation association which is mined is small and isolated (Fig. 1A). However, in many cases large proportions of vegetation associations are affected. One example is the coastal dune vegetation of eastern Australia, where extensive mineral sand mining takes place. Strip mining (Fig. 1B) may have a greater influence than pod-mining (Fig. 1A) on the fauna of adjacent undisturbed vegetation, since it provides a broad obstacle to the normal movement of animals. Both types of mining may influence the fauna of adjacent areas to some extent, due to the downgrading of native vegetation by processes which may collectively be referred to as edge effects.

Clearly, it is desirable to rehabilitate mined areas rapidly following mining, and with suitable vegetation, if the threat to native fauna is to be minimised.

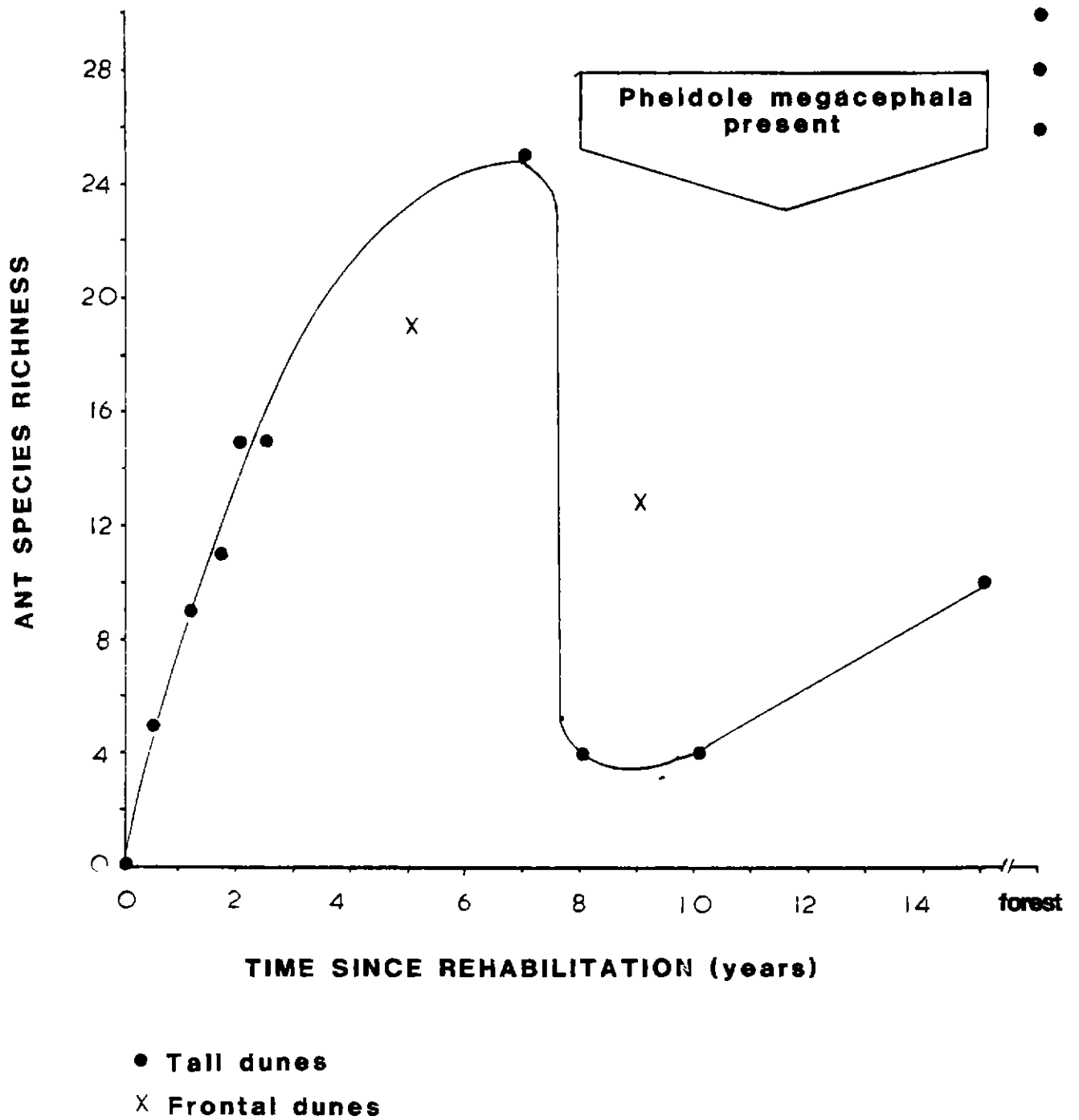


FIGURE 3

RELATIONSHIP BETWEEN RETURN OF ANT SPECIES PER MINE AND INCIDENCE OF THE INTRODUCED ANT, *PHEIDOLE MEGACEPHALA*, IN SAND MINED AREAS ON NORTH STRADBROKE ISLAND, QUEENSLAND (ADAPTED FROM MAJER, 1984 b)

Considerable work has been performed on this topic in the Western Australian bauxite mines. Two examples of this research effort are briefly described here, one involving insects and the other, birds. Majer (1978, 1981) has continuously monitored the epigaeic invertebrate fauna of three bauxite mined areas for a three year period following initial rehabilitation in mid-1976. One mined area had no vegetation returned, one was planted with marri (*Eucalyptus calophylla*), and the other was seeded with mixed native plants. Ants were scored as species, while other invertebrates were recorded at the order or family level. The study revealed that there was a graduation in the order of unplanted, planted to seeded plot in terms of increased plant area cover, plant species richness, total invertebrate numbers, total ant individuals, and ant species richness. A calculated index of similarity of ant composition showed that the seeded plot supported a fauna most similar to that of the original forest. The implication of this study is that mines rehabilitated by seeding with mixed native plants provide more opportunities for the return of native insects than does planting single *Eucalyptus* sp. trees. Subsequent studies (Majer et al., 1983) indicated that a species-rich, forest-like ant fauna could be encouraged if the rehabilitated area had a high plant species richness, high plant cover, particularly in the lower strata, a thick but patchy litter layer and an abundance of large logs.

Wykes (1984) has recently completed a study of the potential for bauxite mines to support the original jarrah forest bird community. The approach used was to elucidate the habitat requirements of the birds in the virgin forest and then see whether these requirements were provided by the bauxite mine rehabilitation. He concluded that the majority of forest birds were insectivores, likely to have foraging habits that required vegetation of particular structural characteristics rather than floristic composition. Following from this, he predicted that birds would readily colonise rehabilitated bauxite mines as soon as the appropriate vegetation structuring had developed. The first species to colonise should be shrub layer foragers, then sub-canopy/shrub layer foraging species, and finally species of the tree strata and open-litter layers. Species likely to be absent or in exceptionally low densities for an extended period might be hollow-timber nesting species which may require mature tree growth.

These predictions were tested by monitoring bird density and species composition in a seven year old rehabilitated plot in which a mixed shrub layer had been seeded and marri (*E. calophylla*) had been planted. Bird species richness was almost as great as in virgin forest, and bird densities were identical in both vegetation types. A break-down of bird species into guild composition supported the predictions quoted above. There was little difference in abundance of large and small insectivores between jarrah forest and rehabilitated plot. The latter was, however, characterised by a paucity of bark foragers and an abundance of nectarivores.

ENCOURAGEMENT OF FAUNA RETURN

Table 3 has been compiled to outline the ways in which mines may be rehabilitated to maximise the return of fauna and restore the ecological processes that are necessary for sustainability of the developing ecosystem. The reasons for the various suggestions are not discussed here, so the reader is advised to consult the bibliography at the end of this paper. The specific case of wetland formation in mined areas is not discussed here, as the subject has already been covered by Kabay and Nichols (1981).

Zones of potentially different land rehabilitation rate in Australia

The final part of this paper concerns my studies on ant return in rehabilitated minesites. I have found that the various members of the ant community may serve as good bio-indicators of the condition of the environment (Majer, 1983).

Studies on rehabilitated bauxite and sand mines in Western Australia indicate that ant species richness builds up at a rate that is related to the rapidity of plant growth. It is also related to the type and variety of vegetation that is applied. This finding is important, because ant species richness is positively correlated with the abundance and species richness of many other invertebrate groups. Thus, high ant species return indicates a more satisfactory buildup of other organisms associated with nutrient cycling (e.g. springtails), soil aeration (e.g. termites) and plant grazing (e.g. grasshoppers). In short, ants provide us with information on many aspects of ecosystem recovery.

I have recently extended these studies on ant return to mined areas in Queensland and the Northern Territory (Majer, 1984 c). In all cases, the sampling methods closely followed those used in Western Australia, so the results are comparable. The return of ant species was generally linear over the first 3-5 years (Fig. 4), although the trends became less clear after this time due to interspecific competition within the ant community or poorer rehabilitation technology being encountered in the older plots.

After taking these facts into account, I was struck by the highly characteristic patterns and rates of ant return associated with the different climatic zones. These rates could not be explained in terms of variations in species richness of native vegetation at each locality. Table 4 shows the numbers of ant species associated with 3 year old plots in mined areas throughout Australia. Some of the figures are estimates since plots of exactly 3 years of age were not always studied.

These figures indicate that there is a cline in ant return rate, from lowest in the drier Mediterranean climate areas, through the warm temperate, sub-tropical to the tropical monsoonal climate areas. It follows from the earlier statement that there is probably also a cline in ecosystem recovery rates.

TABLE 3

SUGGESTED WAYS IN WHICH MINES MAY BE REHABILITATED IN ORDER TO MAXIMISE THE RETURN OF FAUNA AND ENCOURAGE RE-ESTABLISHMENT OF IMPORTANT ECOLOGICAL PROCESSES.

Rehabilitation option	Effect on fauna
Rehabilitate as soon as possible after mining.	. Minimises chances of local animal populations becoming extinct.
Provide fresh topsoil, preferably using the double stripping technique to conserve stratification.	. May introduce micro-arthropods and micro-organisms.
Rip mine floor.	. Assists tunnelling activities of large soil animals.
Avoid excessive rip-lines.	. Reduces likelihood of puddles forming which may drown animals or waterlog their habitats.
Add mulch to topsoiled areas.	. Encourages litter fauna and therefore re-establishment of nutrient cycling.
Avoid tracks around entire circumference of plot.	. Minimises edge effect in virgin vegetation. . Reduces barrier to colonizing animals.
Dump large logs in rehabilitated areas.	. Provide nesting sites for birds, mammals and reptiles.
Provide nest boxes.	. Provide bird nesting sites.
Select plants to provide high structural floristic diversity.	. Provides feeding and nesting opportunities for a wider range of species.
Provide at least a few fast growing trees.	. Accelerates availability of tree trunk nest sites and bark foraging areas. . Provide tree canopy foraging strata for birds at a relatively early stage.
Provide a patchy rather than uniform environment.	. Provides greater range of habitats for animals.

TABLE 3 (CONT.)

Rehabilitation option	Effect on fauna
Provide plants with high nectar output and/or which support high insect numbers.	. Encourages nectarivores and insectivores.
Rehabilitate virgin vegetation surrounding mines if necessary.	. Reverses down-grading edge effects and encourages abundant fauna adjacent to, and within, rehabilitated areas.
Leave tree thinnings within rehabilitated areas.	. Leaves encourage build-up of litter layer. . Trunks provide habitats for invertebrates and small vertebrates.
Explore possibility of introducing less mobile animals.	. Encourages early return of fauna which would otherwise not colonize area.
Employ zoologists or ecologists as rehabilitation officers.	. Increase understanding of complexities involved in rehabilitation processes.

When the influence of differing revegetation technique is also considered, it becomes apparent that climate has the over-riding influence in these study sites. Revegetation method is of secondary importance. The amount of rainfall, and seasonal spread and time of rainfall all appear to be important, as is the influence of temperature. The role of these variables is probably in part direct, through their influence on micro-climate, and partly through their influence on plant growth and plant species richness. At present I know of no comparative studies on plant growth in rehabilitated areas throughout Australia so the latter statement may only be supported by qualitative observations.

I am reporting these observations because I am aware that some rehabilitation officers, and some members of committees that are established to monitor the success of rehabilitation, base their expectations on what has been seen elsewhere in Australia. From what has been said, it seems quite unreasonable to expect, say, Queensland sandmine rehabilitation rates to occur in sand-mines in the drier parts of Western Australia.

I suggest that it is possible, once the relevant data are collected, to divide Australia into zones, with each zone having a certain potential rehabilitation rate. To create such a scheme

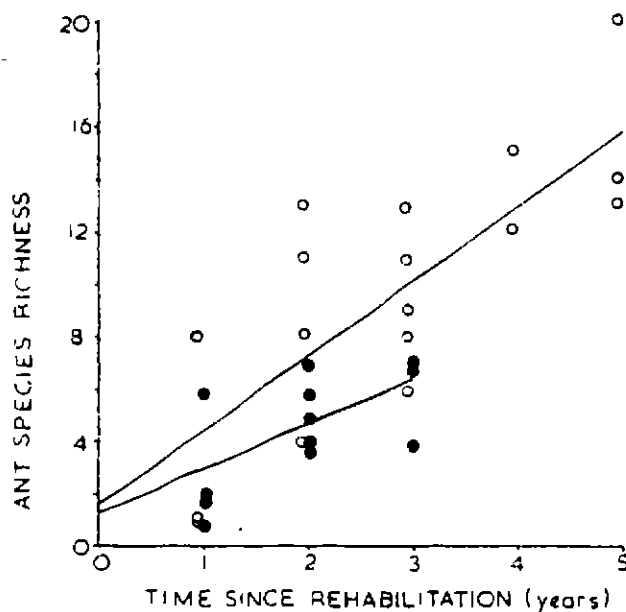


FIGURE 4

RELATIONSHIP BETWEEN NUMBER OF ANT SPECIES (RICHNESS) PER REHABILITATED PLOT AND TIME SINCE REHABILITATION IN THE ENEABBA, WESTERN AUSTRALIAN SAND MINES (●) AND THE JARRAHDAL/ENEABBA, WESTERN AUSTRALIAN SAND MINES (○). SIMPLE REGRESSION LINES HAVE BEEN FITTED TO BOTH SETS OF DATA (FROM MAJER, et al., 1982).

TABLE 4

ESTIMATED NUMBER OF ANTS FOUND IN 3 YEAR OLD PLOTS WITHIN MINES SITUATED IN DIFFERENT CLIMATIC ZONES OF AUSTRALIA.

Location	Mine type	Climate type	Annual rainfall (mm)	Number of ant species
Eneabba, W.A.	Sand	Mediterranean	550	6
Jarrahdale/Del Park, W.A.	Bauxite	Mediterranean	1155-1287	10
* Myall Lakes, N.S.W.	Sand	Warm-temperate	1205-1362	11
Nth Stradbroke Island, Qld	Sand	Sub-tropical	1645	18
Gove, N.T. Groote Eylandt, NT Weipa, Qld	Bauxite or Manganese	Tropical monsoonal	1277-2083	22

* data from Fox and Fox (1982).

would enable more sensible judgement to be made on rehabilitation success, and would also enable guidelines to be established on what rehabilitation officers can expect to achieve after specified periods of time following commencement of rehabilitation.

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MINED LAND REHABILITATION - IS IT SUSTAINABLE? A SYNTHESIS

J.R. Bartle

ABSTRACT

The character of the environment in which rehabilitation is to be undertaken determines what objectives, are appropriate. In the process of choosing an objective, the social environment is equally as important as the natural environment and the type of disturbance to it. The many factors of this wider environment are analyzed to indicate the sometimes conflicting contributions they make to the selection of an objective, and the consequent opening of potential for problems of sustainability.

The objectives of rehabilitation can be diverse. However, questions of sustainability only arise where little on-going management is to be provided, where an attempt is to be made to quickly establish a complex ecosystem and where a high standard of performance is prescribed.

INTRODUCTION

Rehabilitation may be attempted after a variety of types of mining, in a diversity of environments. The objective of earlier papers in the publication has been to extract from this diversity some common principles and practices that have a bearing on the issue of 'sustainability'. Previous papers have considered general problems (Carbon), soils (Marshall), flora (Bell) and fauna (Majer) associated with rehabilitated ecosystems. This paper puts these components into a broader perspective, so that all of the influences on sustainability can be considered as a whole.

A rehabilitation programme will generally have an objective, probably defined in terms of the use or value of the rehabilitated land. The objective will be partly determined by factors in the social environment. It will also be influenced by the potential of the natural environment, both by its undisturbed elements (climate, topography) and the disturbed elements (soil, flora, fauna). These factors determine the difficulty that is likely to be experienced in achieving successful rehabilitation. As indicated earlier by Marshall, some objectives in some environments are just not attainable. An ambitious objective in an adverse environment can present some doubts as to sustainability, while a modest objective in a favourable environment may be readily achieved.

In this paper, elements of the environment and objectives are analyzed. Our ability to synthesize these elements into whole, dynamic ecosystems is discussed and areas where sustainability is in doubt are identified.

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THE REHABILITATION ENVIRONMENT

Social, political and economic setting

Most discussion of rehabilitation focuses on the physical and biological aspects. In reviewing a recent symposium, Thorhaug (1980) identified political and legal aspects as frequently dominant factors in the success of rehabilitation. Likewise, Pearce (1982) asserted that the politics of land restoration is clearly as important as the science.

A well informed population with high expectations in close proximity to a profitable mining operation will demand high standards of rehabilitation. More binding legal obligations will be imposed on miners. It will not only be expected that rehabilitated land is aesthetically presentable, but also that it is returned to productive use. A mining company's liability for rehabilitation of the land may not be lifted until exacting ecological criteria are met. Within this scenario rehabilitation would be difficult and expensive, and questions of sustainability would need thorough resolution. However, this could be balanced by the priority of rehabilitation attracting more commitment. Rehabilitation would be efficiently integrated into mine planning and operation, and would attract an adequate level of research support, possibly with funds subsidized by governments.

Alternative, less demanding scenarios can be imagined: mining operations distant from population centres; less sophisticated populations; old established mines now part of the local 'scenery'; marginally viable mines. These could all expect less social and political pressure, with more easily achieved rehabilitation goals being set.

Some of these points are well illustrated by examples from the mining of public land in the south-west of Western Australia. Political and social forces succeeded in imposing increased control and rehabilitation standards over bauxite mining, a relatively new and profitable operation close to Perth (Anon, 1978; Alcoa, 1978a,b). The standards of rehabilitation in this operation have recently been described as extravagant (Anon, 1983). In contrast, an older, intermittently viable tin mining operation more distant from Perth has until recently had no apparent rehabilitation programme (Anon, 1983). There is, presumably, no question of the sustainability of wasteland!

Climate and topographic setting

The climatic and topographic setting of a mining and rehabilitation operation is substantially fixed and undisturbed by mining, and has a major influence on rehabilitation methods and potential.

The climatic environment influences all the physical, chemical and biological processes on the land surface, both on a macro and micro scale. The major climatic factors are rainfall, radiation,

temperature and wind. Their amount, distribution, intensity, variability and, especially, their extremes set basic ecologic constraints.

In the short term, specific establishment procedures are available to modify microclimate in order to protect the soil surface from erosion, and to help plants through their juvenile stage. These procedures include seedbed preparation, hydro-seeding, mulching, nurse crops, wind breaks and irrigation (Bradshaw and Chadwick, 1980). In the long term, rehabilitated soil and its vegetation will generally have to tolerate the extremes of the climate.

Though topography can be locally modified during mining and rehabilitation, the effect of the regional topographic setting cannot be eliminated. Steep and broken terrain will present greater difficulty for rehabilitation than gentle topography. However, run-off control and slope stabilization techniques appropriate to such terrain are well established.

The importance of climate and topography can be inferred from agricultural experience. In environments with moist moderate climate and gentle topography, agriculture flourishes. In other environments, stable, sustainable agriculture is not so readily achieved. For example, mediterranean climates combine intense winter rainfall with summer drought. Both rainfall and length of growing season have a high variability, leading to high risk of crop failure, overgrazing, exposed soils and erosion. Even with a high level of technical competence, and over a period of less than 100 years, two thirds of all West Australian agricultural land in the mediterranean climate belt is unstable and in need of conservation treatment (Carder and Humphrey 1983). In the Mediterranean Basin itself, with the additional adverse factor of steep terrain, extreme land degradation is widespread (Naveh and Dan, 1973, Paskoff, 1973).

These problems of sustainability in agriculture indicate an inherent 'fragility' in some types of climate and landscape. The vulnerability of such fragile lands arises much more from incompetent management, economic duress or social dislocation than from lack of technique (Thirgood, 1981). This suggests that any laxity in commitment to rehabilitation or in the regulation of standards could have most severe consequences in such fragile environments.

As a side issue, it is difficult to reconcile a concern for sustainability of rehabilitation in small areas affected by mining while our agriculture over vast areas is clearly not sustainable. Graetz, in his recent television series 'Heartlands', lamented the fact that the conservation movement has yet to discover our arid wilderness.

The nature and intensity of disturbance

The specific purpose of mined land rehabilitation is to minimize

or reverse the adverse impact of the mining operation itself. This includes the following components:

- (1) Retention or regeneration of favourable physical, chemical and biological properties in the overburden or wastes destined to become the soil of the post-mining landscape. This aspect has been dealt with by Marshall in an earlier chapter.
- (2) Restocking of the land with an array of plants and animals that is matched to the soil and other features of the environment, and is able to meet the objectives of land use. This aspect was dealt with by Bell and Majer.
- (3) Restoration of the dynamic functions of the ecosystem and landscape. Such processes as the flow of the water through the system (the hydrologic cycle), the cycling of nutrients and energy, succession in plant communities and soil formation, may operate on time spans of hundreds of years and effect the whole landscape. These processes are rarely well understood. It is only usually possible to push them in the right direction, not to prescribe the eventual outcome.

In some cases, disturbance to some processes may be inherently irreversible. For example, 'thermokarsting' (heat pitting) in tundra plant communities is an irreversible decline initiated by alteration to the surface energy balance following vegetation disturbance (Thorhaug, 1980). A local example may be the mobilization of salt stored in soil. The salt storage phenomenon coevolved with vegetation and is maintained in a stable equilibrium. Once this equilibrium is disrupted, and the salt is mobilized, it may not be readily restabilized. There has not yet been any example of the successful restabilization of stored salt in southern Australia. Irreversibility may also arise from the introduction of a virulent primary pathogen. The contamination of bauxite mining operations in the southwest of Western Australia by pre-existing infection of *Phytophthora cinnamomi*, and its further spread into uninfected areas, is an example of this.

Some mining operations have relatively low impact on the environment, and present no particular barrier to successful rehabilitation. For example, shallow open cut mining such as for bauxite and mineral sands, and exploitation of alluvial deposits of gold or tin, may fall into this category. Physical modification of the profile and landscape may be minimal. Soil chemical problems are unlikely when dealing with a weathered profile, and a constant supply of topsoil from freshly opened ground is available to respread on previously mined areas. After such modest disturbance, revegetation and restoration of balanced dynamic properties to the ecosystem may be readily achieved. It may even be possible to create new ecosystems that are superior in some ways to those that preceded mining.

At the other extreme, represented most commonly by deep open cut mining of coal or metal ores, rehabilitation can present considerable difficulty and expense (Bradshaw and Chadwick, 1980). Such mines may expose spoils that are physically difficult to convert into soil, and chemically hostile to life. Even if tolerant plants can be established in places, there remains the problem of restoring acceptable dynamic properties to the ecosystem. For example, the water balance established must not leave a water surplus available to percolate through deeply buried toxic spoils, where it could mobilize acid or heavy metals and join a ground water system that may emerge to contaminate streams nearby.

THE REHABILITATION OBJECTIVE

The general objective of rehabilitation that is most widely supported is exemplified by the U.S. National Research Council (1981) statement that says that rehabilitation should "...ensure that society does not lose important land use opportunities that were available prior to disturbance, or that can be generated in the reclamation process". This objective stops well short of advocating restoration of original landscapes and ecosystems, but requires minimal loss of potential as well as directing attention to the possibility of enhancing potential. It should be stressed that this may be the current consensus for new mining operations, although it cannot be presumed to apply to established mines operating under conventions from the past.

Within this general objective, there remains considerable choice for any specific mining operation in terms of what precisely should be done, and over what term. The problem of how society may choose a particular objective is very complex, and will usually have to be solved without adequate information. The U.S. National Research Council (1981) identifies two decision making mechanisms. Firstly, various tools, models and criteria, e.g. cost-benefit analysis, can be used to rationally identify the best of available alternatives. These methods are usually employed by 'professionals', but suffer the deficiency that it is often difficult to convincingly weigh up costs and benefits. Some of the reasons for this problem are: important ecological relationships may be poorly understood; intangibles are difficult to price; costs and benefits may be unevenly dispersed through the population; and current values reflecting the preferences of society systematically undervalue the claims of future generations. Secondly, the systems of politics and law offer the citizen the opportunity to contribute to decision making. Access to the decision making process in Western nations has expanded greatly in recent years, and has contributed to a lifting of rehabilitation standards imposed on miners.

It is usually some consensus of the rational and political elements of the decision making process that sets the overall objective of rehabilitation. This consensus may sometimes tend to set objectives that try to reach too far. On the rational side, the direct benefits may be well documented, although

indirect costs and the technology for rehabilitation may be poorly defined or assumed to be acceptable. On the political side, there may be pressure to be progressive in applying the loftiest ideals of conservation, as well as a determination to proceed with mining and realize its economic benefits. For these reasons, unattainable or naive objectives may sometimes be set and therefore the sustainability of the proposed rehabilitation could be in doubt.

The history of bauxite mining in West Australia provides a good example of the setting, or at least suggesting, of an unattainable objective for political purposes. In parliamentary debate on the issue of expanding mining, the proponents asserted that rehabilitation would generate a forest that was better than the original native forest. This was a rather wild assertion, particularly given the level of knowledge at the time.

Perhaps the more important issue is that of setting objectives which initially appear to be technically within easy reach, but which in practice are not sustainable. This problem is exacerbated by the fact that a commitment to the mining operation must usually be made before research and development for rehabilitation can be supported.

The difficulty inherent in rehabilitating disturbed areas, and therefore the likelihood of problems arising with regard to sustainability, depends upon three major factors. These are discussed below.

The level of on-going management

Rehabilitation to regenerate agricultural, plantation forestry or amenity (sporting fields) ecosystems need not be designed to be self-sustaining. Management practices are an essential part of such systems. Few plant species are used, and they rely on man to regulate their establishment, protection and nutrition. Such ecosystems can be successful in a wide range of environments, little being left to the vagaries of natural processes. Management would also detect and correct any shortcomings in the system as they became apparent. The sustainability of these systems can therefore be ensured by careful management.

In contrast, regeneration of ecosystems that are expected to be self-sustaining would need much more careful design in order to minimize the need for on-going inputs. Since our knowledge of ecology is far from perfect, the development of rehabilitation ecosystems, particularly the more complex ones, must be partly empirical, and therefore require at least some follow-up management commitment.

The level of ecological complexity

Simple ecosystems consisting of a few short-lived species (grasslands), are characterized by relatively low biomass productivity and site exploitation. Such systems might be

relatively easy to create, may meet the major short-term objectives of attaining soil stability and initiating ecosystem processes, and may be open to invasion by more competitive species by the process of succession.

More complex ecosystems (woodlands and forests) may exhibit great species diversity in size, form and longevity, may have a high order of biomass productivity, and may fully tax the potential of the site. To create such systems directly, by-passing the normal processes of succession, requires considerable knowledge. In reviewing his U.S. experience, Cook (1976) found that natural successional processes could be greatly hastened by such tactics as direct planting of climax species. However, aiming directly to establish a complex ecosystem in rehabilitation must raise the risk of problems of sustainability. Failure to sustain at a high level of complexity will usually mean regression to some lower level.

The performance level to be attained

In some situations, it may be obligatory to attain a particular standard of performance from the rehabilitation ecosystem. In such situations, there is limited scope for empirical development of methods and little can be left to chance. Intensive research must precede such mining, so that methods with a high probability of producing a sustainable ecosystem with the required performance can be prescribed.

Some good examples of this occur in mining areas where there is a risk of contamination of water resources. To devise ways to prevent mobilization of salt, heavy metals, acid or radio-active wastes, a detailed understanding of the hydrology is required. A specific example is rehabilitation after possible future bauxite mining in the saline areas of the jarrah forest. In order to prevent mobilization of salt, the water balance of rehabilitated areas must be rigidly prescribed. To do this, hydrologic processes and plant water relations must be well understood.

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