REHABILITATION OF MINED LANDS IN WESTERN AUSTRALIA

PROCEEDINGS OF A MEETING HELD
IN PERTH ON
11TH OCTOBER 1978

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PREFACE

This publication contains the proceedings of a meeting held to review recent developments in methods and research carried out in the field of rehabilitation of land surfaces disturbed by mining and extractive industries. It grew out of initial discussions within the Biology Department at the Western Australian Institute of Technology early in 1978. Following preliminary discussions with interested individuals regarding the desirability of holding such a meeting, an organising committee was formed. The members of this group were:

J.E.D. Fox	Biology Department W.A.I.T.
W.J. Lorimer	The Chamber of Mines of W.A. (Inc.)
J.K. Marshall	Division of Land Resources Management C.S.I.R.O.
R.M. Nunn	Department of Conservation & Environment
J.R.H. Riches	Resource Management Branch, Department of Agriculture.

It was felt that the type of meeting proposed would do much to bring together biological and mining viewpoints to what has often been seen as an area of controversy. The main uniting themes were seen as being the problems in Western Australia and current progress in meeting rehabilitation objectives in this State.

There is no doubt that the subject is a topical one. In recent months we have seen the publication of three important documents outlining proposed mineral developments. All of these involve a consideration of the consequences of mining to the land surface. At the same time public awareness of many of the issues involved in land management during and after mining has tended to be confused. This confusion is perhaps inevitable as there are different problems inherent in the various types of mining operation. It is hoped that the meeting will serve to lift some of the confusion by its concentration on the real world and by emphasis on tested and proven methods.

Besides the speakers presenting their papers the organising committee felt that the meeting would provide an excellent opportunity for individuals, companies and organisations active in the general area of mining rehabilitation to inform other interested parties of their recent work. To this end brief communications were solicited with the preliminary announcement of the meeting. The communications received are taken as being documents tabled at the meeting and, by virtue of their inclusion in these proceedings, as formally published contributions. Papers and communications together are considered by the organising committee to give an excellent account of the present state of the art of rehabilitation in Western Australia.

JOHN E.D. FOX
BENTLEY, W.A.
OCTOBER 1978.

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Edited: J.E.D. Fox

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PAPERS

Rehabilitation after Mining in the Collie Coalfield

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Abstract

The Collie coalfield is Western Australia's sole commercial coalfield. Current production is approximately 2.5 x 10^6 tonnes with a projected production in excess of 8 x 10^6 tonnes in the year 2000.

Most overburden dumps are unvegetated, acid and suffering from severe erosion. A range of native forest species and agricultural pasture species have been tested on both unamended acid spoil and non-acid spoil.

Possible rehabilitation techniques are outlined.

Introduction

The Collie coalfield is located some 150 km S.E. of Perth on an infilling of Permian sedimentary strata in a small basin in pre-cambrian basement rock. It is W.A's sole commercial coalfield. It has been exploited since 1898 but large-scale development has been restricted by the limited local market and the low calorific value of the coal. Escalation of energy costs and significant new outlets should ensure considerable future expansion. Current production is 2.5 M t *per annum* and it is estimated (Fuel and Power Commission, 1974) that production will rise to 8 M t *per annum* by the year 2000. Current economic reserves are estimated at approximately 390 M t.

The mines are located in sparsely settled areas, the tenure of which is predominantly State forest. Almost no operational rehabilitation work has been carried out by the mining companies in the past, with the exception of the Wallsend mine. A levy of sixpence a ton of coal was imposed on coal won from this open-cut during the early 1950s to provide funds for back-filling, as the open-cut was immediately adjacent to the Collie townsite. The Department of Mines has been carrying out remedial treatment to make some other abandoned mine sites safe, *e.g.* the covering of carbonaceous materials prone to spontaneous combustion.

In this paper we review historical, economic and land use aspects of rehabilitation before focusing on technical problems. The possible resolution of these problems will then be discussed.

Review

Introduction

Historical

Mining commenced in 1898, reached 0.4 M t *per annum* by 1918 and 1 M t in 1954. All early mining was deep, but open-cut operations commenced during the 2nd World War, rose rapidly to 50 per cent of production in the early 1950s but later declined to average 30-40 per cent (Johnston 1957). In the last decade the proportion of open-cut coal has increased to approximately 75 per cent.

The State Government encouraged the development of the Collie coalfields and supported it over many years when coal might have been imported more economically. The State Government has always been the major consumer. Its influence on the industry was so dominant that in the 1934 Award of the Coal Mining Industrial Board, Mr Justice Dwyer stated: "The proper method of regulation of the industry is to view it as a State activity, the companies being nominal employers". (Cited by Johnston, *op. cit.)*.

The traditional approach of regarding mined areas as wasteland still prevails in this industry. Since the advent of open-cut mining, several areas have been converted to wasteland and abandoned (Fuel and Power Commission 1974) as shown in Table 1.

Table 1. Abandoned open-cut areas in the Collie Coalfield

Mine	Last Worked	Area (ha)
Collieburn	1953	10
Western No. 3	1958	22
Centaur	n.a.	8
Ewington	1959	22
Stockton	1957	19
Wallsend	1948	20
Black Diamond	1953	15
Total area		116

They also estimate that current active mine areas cover an additional 93 ha and that a further 490 ha will be disturbed by mining to the year 2000.

Examination of aerial photographs taken in January 1974 (Proj. P20 WA1499(c) Collie Coal Basin Ext to run 3 E), shows that the forested perimeter surrounding the Muja open-cut alone, encloses an area of approximately 360 ha of disturbed ground. It would therefore appear that the Fuel and Power Commission have greatly underestimated the area of disturbed ground.

Economic

Where mining occurs in highly developed regions rehabilitation may be economically profitable. For example, Knabe (1964) quotes German figures where rehabilitation costs are estimated at 60-70 per cent of freehold land values. It is likely that rehabilitation costs at Collie will considerably exceed land value. In this type of situation there is increasing acceptance of the need for reasonable standards of rehabilitation in spite of cost (Tacey *et al* 1977, Report of the Committee of Enquiry 1971).

Where it is an uneconomic practice, miners may not be prepared to voluntarily undertake rehabilitation. In this case, a deliberate political decision is required to set standards and allocate costs. Very few coal mining leases currently being mined have rehabilitation conditions. Fosket (1976) emphasises a further important aspect of the economics of rehabilitation - that rehabilitation methods should be predetermined and integrated with the mineral extraction operation. In this way maximum efficiency in rehabilitation might be realised.

Land Use

The Forests Department, as land managers of State forest which comprises some 85 per cent of the coal basin, have recently completed comprehensive land use policy statements which have been endorsed by Cabinet (Forests Dept. 1977a). A system of multiple use has been embraced to cater for a maximum range of uses (Forests Dept. 1977b). Mining is one such use. Broadly, the objective of multiple use management will be to minimise conflicts with current mining and to direct rehabilitation to best suit future land use.

For the coal basin as a whole, water production is seen as the dominant or priority use. Secondary uses include timber production (hardwoods and pine), flora and fauna conservation and recreation. A management strategy is outlined which states that coal mining should be closely supervised to reduce adverse environmental effects, and rehabilitation undertaken with the objective of aesthetic improvement, recreational development, soil conservation and possibly the creation of wet land habitats for fauna. As yet, the manner in which this strategy will be brought into action has not been determined. Control of mining operations in W.A. is the responsibility of the Mines Department.

Technical Problems

Acidity

In the undisturbed state the bulk of the spoils of open-cut mining are below the water table. These spoils contain significant quantities of pyrites (FeS_2). Following mining and exposure to the atmosphere, rapid oxidation occurs which generates sulphuric acid. This acid-producing potential is reflected in the pH of spoils dumps. The pH of spoil was observed to be spatially very variable; however, of 82 samples taken on six dumps at the Western Collieries No. 5 Mine, pH ranged from 2.2 to 5.6 with a median value of 4.1. Similarly, 51 samples from three dumps at the Muja open-cut ranged from pH 2.3 to pH 4.9 with a median value of pH 3.7.

Natural colonisation of dumps at abandoned mines is extremely sparse even after 25 years of exposure. It is estimated that the proportion of abandoned dump area naturally revegetated is less than 10 per cent.

No colonisation was observed where pH was less than 3.5. Significant cover only occurs where pH is greater than 5.0. *ucalyptus patens* Benth. shows the most impressive acid tolerance of volunteer local species, being able to invade areas with surface pH as low as 4.5. Some species of sedge occur at pH as low as 4.0.

Laboratory neutralisation of sample spoil material showed that the $CaCO_3$ requirement varied depending on strata and depth. Above water table strata had a lower lime requirement than those strata below the water table (Table 2).

Table 2. Typical lime requirement to increase pH of spoils to 6.5

Soil Attribute	Strata depth * in m 0-1	1-5	5-10	10-15	15
pH	5.7	4.1	4.1	3.8	3.0
TSS	.013	.20	.13	.30	.41
Lime requirement in tonnes/ ha/m to bring to pH 6.5	12.5	12.5	129	70	208

* Water table depth approximately 5 m.

These observations conform to the pattern for the so-called acid sulphate soils. The acid release phase is transient but results in permanent degradation of the medium for plant growth (Pons 1972; Brinkman and Pons 1972). Without amendment, therefore, it is likely that acid spoils dumps will remain inhospitable to plant growth.

Slopes

The sides of spoils dumps are typically 37° (the angle of repose) for truck-built dumps. Scraper-built dumps have lesser grades but scrapers are generally only used in the early stages of dump construction, and result in greater overall compaction of the dump than truck-built dumps. The stability of dumps varies according to the proportion of sand and clay in the surface material and the steepness of the side slopes. Greater proportions of sand lead to less stability. Massive water erosion occurs on the more unstable dumps, *e.g.* a 3 m deep gully was observed to form in the dry winter of 1976. All old dumps are deeply fissured with actively eroding gullies.

Revegetation

Some 35 native forest species and 15 agricultural species have been planted in revegetation trials at four locations covering a full range of spoil types. Treatments tested in broad screening trials include topsoil replacement, fertilisation and liming. Observations to date show that all species fail on materials of pH less than 4.0. When amended with 10 tonnes/ha of calcium carbonate, most species were able to survive, though this response lasted only one year. Placement of from 5-25 cm of topsoil material was sufficient to give a marked improvement in growth.

Several species showed some acid tolerance at pH 4.0 - 4.5. These include vetch (*Vicia sativa* L.), rye grass (*Lolium rigidum* Gaud.), *Acacia pulchella* R. Br. and *A. extensa* Lindl. Agricultural legumes were inoculated with root nodule-forming rhizobia bacteria (a standard agricultural practice on virgin soils). This was not done for native legumes (*e.g. Acacia*). Poor nodulation, slow early growth and high mortality was observed in *Acacia* on spoil material where non-leguminous trees performed satisfactorily.

Lake formation

Following cessation of mining, excavations rapidly fill with water to the level of the surrounding water table, thus creating a lake. The pH of some lakes at Collie are shown in Table 3.

Table 3. The area and pH of surface water in three abandoned open-cuts *

Location	pH	Area (ha)
Western No. 3	3.0	7.5
Stockton	4.0	20
Blue Pool	3.7	4.5

* Sampled in August 1978.

Minimal vegetative colonisation of the lake edges is occurring at the present time. The acid content of Stockton and Blue Pool is not sufficient to discourage recreational use. These water bodies are popular swimming and boating venues even in their completely undeveloped state.

It is not known how long these lakes will remain acid under conditions existing at Collie. In the United States, (Campbell and Lind 1969, cited by Doyle 1976), it was noted that acid lakes associated with open-cut coal mines progressively return to neutrality. This is influenced partly by the availability of organic matter within the lake and partly by associated rock strata. In the U.S. a lake returns to a neutral pH in approximately 30-40 years. This time period can be shortened by the addition of organic matter or lime.

The effects of acid generation on underground water quality and riveraine ecosystems at Collie is not well understood. In some parts of the world acid release into streams from mining areas is a considerable problem (Armiger *et al* 1976).

Discussion

From work completed to date no firm prescriptions for optimal solutions can be made. However, with what is known and using experience from elsewhere, some broad conclusions can be drawn.

Acidity

Plant growth cannot be expected to survive on spoils material without amendment or covering with non-toxic material. The amount of lime required in the amendment option is large and would be difficult to apply and incorporate. Assuming an average requirement of 50 t/ha, cost would be of the order of $2 500/ha for the lime alone.

The alternative is to avoid exposure of acid-generating materials on the surface of dumps and backfill areas. For current mining areas this option appears the most attractive and is the most common solution used internationally. Dumping sequences should be pre-planned to best utilise non-toxic spoils (*i.e.* those from above the water table) and in particular, topsoil. An example of the extent of pre-planned use of non-toxic spoils is provided by Knabe (1964). Spoils with particular value are stored to be blended into mixtures to give soils with various desired characteristics. Fresh topsoil is biologically active (Tacey, this meeting) and priority should be given to its placement on the exterior of finished dumps, as a continuing process.

At abandoned sites where non-toxic material is not readily available the amendment option may be favoured.

Slopes

Slopes at the angle of repose will be unstable in the long term, particularly if made of erodible materials. Two improvements in finished dump (and pit) design are possible. Firstly, dumps should be finished to conform to a minimum slope angle constraint and, secondly, drainage off dumps should be planned to minimise erosion.

It is more efficient to include these objectives in overall mine planning and operation so that no clash with the objective of preventing exposure of toxic materials occurs. However, the literature indicates that grading, shaping and landscaping are frequently carried out as final steps. It should be clearly understood, however, that if reshaping is carried out as a terminal operation, rehabilitation costs will be considerably higher because of increased earth moving costs as a result of "double handling'.

On a dump 130 m square, having a height of 20 m, a reduction in the side slopes from 37° to 20° would involve a 9 per cent increase in area of the dump. On all minesites examined the peripheral disturbed area surrounding the dumps is sufficiently large that a reduction in angle of side slope to 20° need involve no increase in the total area to be rehabilitated.

Revegetation

Revegetation of unimproved spoils materials by selection of acid tolerant species is an approach that is not likely to be very successful. Many spoils have properties beyond the tolerance limits of vegetation. Where growth can occur it may not be sufficiently vigorous to fulfil the aesthetic or stabilisation function of vegetation. Well planned rehabilitation with no exposure of acid materials and no steep slopes will open a range of revegetation options that can be met with standard techniques.

Lake Formation

The Muja open-cut mine will ultimately extend over an area of approximately 1.5 km x 0.75 km. The Mines Department currently requires that backfilling to ground level be carried out progressively. If this is done a relatively small lake will result at the conclusion of mining. An alternative approach is to backfill to a depth 4 m below the water table; this would create an inland body of water 1.5 km x 0.75 km of 4 m depth.

This approach of maximising the lake area effectively reduces total disturbed area to be rehabilitated, and thus *reduces* rehabilitation costs. Large fresh water bodies are uncommon in Western Australia and well planned rehabilitation could form the basis for significant recreational development and wetland flora and fauna habitats. Such a trial development is currently being undertaken by the Forests Department at the abandoned Stockton open-cut.

Costs

Three abandoned mines were examined with respect to:

* area of disturbed ground
* area of water body
* total coal production

Calculations were made to determine the amount of money available in dollars/ha of disturbed ground if a levy of 10 cents/ton of coal produced had been applied. Similarly estimates were made for Muja open-cut up to January 1974 (Table 4).

These show that at Muja up to 1974, a 10 cent/ton rehabilitation levy would have generated finance equivalent to $1,944/ha of disturbed ground. Two factors may dramatically increase the finance available in future years when calculated on a per hectare of disturbed land basis, viz:

* If a large lake were incorporated in the rehabilitation proposals, this effectively decreases the area to be rehabilitated and so *increases* finance on a per hectare basis.
* Pre 1974 includes the "starting up" phase of the Muja open-cut. This phase is characterised by a disproportionately high ratio of area of disturbed ground to tonnes of coal mined. In future years the ratio will decrease, thus effectively *increasing* finance on a per hectare of disturbed land basis.

Table 4. Cost calculations for four sites to generate a rehabilitation levy.

Mine	Water area (ha)	Disturbed ground (ha)	Total area (ha)	Coal (x 10^6 tons)	Levy @ 10c/ ton ($ x 10^3)	Levy per ha disturbed ground ($)
Collieburn	4.5	16	21	0.189	18.9	1,180
Western Coll. No. 3	7.5	27	35	0.258	25.8	955
Stockton	20	40	60	1.600	160.0	4,000
Muja (operational)	-	360	360	7.000*	700.0	1,944

* estimated quantity

Conclusion

To continue to generate wasteland is unacceptable in today's political and social climate. Rather than attempt rehabilitation as a terminal operation, the available information suggests that it would be best integrated into the mining process. If this is done it would appear that costs will be of the order of tens of cents/t rather than dollars/t of coal extracted.

To put the problem in perspective, approximately 15 M t of coal have been mined to 1978 out of a total open-cut resource of perhaps 200 M t. This suggests an eventual disturbed area of greater than 7,000 ha.

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Selection of Tree Species for Rehabilitation of Degraded Areas in the Northern Jarrah Forest.

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Abstract

A large proportion of the Northern Jarrah Forest may require rehabilitation over the next several decades because of the combined effect of jarrah dieback and bauxite mining. In the salinity prone eastern forest the major objective of rehabilitation will be to restore the hydrologic balance by restoration of tree cover. The identification of tree species suited to this task is critical. Plant introduction methodology suggests that species selection should initially be based on an understanding of the ecosystems of origin and introduction. To date insufficient work has been put into the search of environments comparable to the Northern Jarrah Forest for potentially adapted species.

Species evaluation must take account of the dynamic nature of tree and stand development. Systematic evaluation of species in new arboreta will take many years to give results. Use of this approach must therefore be complemented by evaluation of performance in existing plantings. Progress in species selection is facilitated by the use of evaluation criteria indicating successful adaptation to the jarrah forest environment. Preliminary studies of these criteria have revealed substantial species differences.

Introduction

The Northern Jarrah *(Eucalyptus marginata* Sm.) Forest is undergoing significant environmental alteration due to the effects of jarrah dieback and bauxite mining. *Phytophthora cinnamomi* Rands, the causal organism for jarrah dieback, is a soil-borne pathogen with the capacity to kill a large proportion of species on most sites in the Jarrah Forest (Podger 1972). The disease is widespread but largely confined to moisture gaining sites (Shea 1975). Open cut bauxite mining is rapidly expanding to exploit the bauxite ore which occurs on the upper slopes. The mining operation is also a vector of *P. cinnamomi*. Mining and dieback together have the potential to degrade or remove vegetation from up to 90 per cent of the landscape, (Bartle 1976).

Disturbance of this magnitude has significant impacts on all land use. The major land use in the region is water supply catchment. Secondary uses include wood production, conservation of flora and fauna and recreation (Forests Department 1977a). The objective of rehabilitation research is to determine the effects of ecosystem disturbance on land use and to devise rehabilitation techniques which will restore land use values. In this paper the discussion is restricted to rehabilitation of water supply catchments.

Reduction in vegetative cover as a consequence of either jarrah dieback or bauxite mining has a major effect on the hydrological cycle by causing reduced evapotranspiration (Peck 1975). The effect of this on water quality and quantity is dependent on whether there is significant salt accumulation in the soil profile. There are distinct longitudinal gradients in rainfall, geomorphology and salt accumulation. In most of the western zone of the forest reduced evapotranspiration leads to increased yields of water of acceptable quality. Rehabilitation is directed to capitalize on this effect and it is not an objective to re-establish dense forests (Forests Department 1977b). In the central and eastern zones of the forest, however, reduced evapotranspiration could lead to increased yields of unacceptably saline water. In salt-prone areas of forest the objective of rehabilitation is to revegetate with species able to re-establish the original salt and water balance.

Introduction of trees into new environments is not assured of success. This is particularly so when the introduction is into an environment which is only marginally suitable for forest growth (Shea *et al* 1975). It is unlikely that a single replacement species will be suitable for all site types and hence species selection will be critical. This paper reviews methodology and progress in identification of species suitable for rehabilitation, with emphasis on rehabilitation in salt-prone areas.

Methodology of Identification of Rehabilitation Species

The selection of plants for introduction into new environments can be based upon theoretical predictions of suitability or on empirical 'trial and error' evaluation. A combined approach is desirable as theoretical predictions of suitability will always be limited by inadequate knowledge of the ecosystem and empirical methods by themselves are inefficient (Bartle 1978). The identification procedure should have two steps:

* Theoretical selection based on knowledge of the ecosystems of origin and introduction.

* Evaluation in the new environment.

Theoretical Selection

In the introduction of agricultural plants into new environments, detailed analysis of the natural environments of origin and introduction is not essential since cultural practice does much to eliminate environmental

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differences (Frankel and Bennett 1970). For the introduction of tree species into a difficult new environment where they will be expected to perform a long term task with a minimum of management a comprehensive ecological analysis is necessary. The logical steps in this analysis (Cooper 1970) are:

* Definition of the major characteristics of the environment *e.g.* rainfall distribution, maximum and minimum temperatures.
* Determination of the extent to which some of these characteristics may be modified by management, *e.g.* fertiliser to overcome nutrient deficiencies or ripping to aid root penetration.
* Identification of specific plant adaptations which will effect both survival and performance, *e.g.* survival during drought may be achieved by either restriction of water consumption or the development of a deep root habit, but the latter adaptation may be required to achieve the purpose of introduction.
* Exploration of comparable environments for potentially adapted species.

The benefits of this systematic approach are:

* Species with obvious deficiences which are not likely to meet the objectives of rehabilitation would be excluded from the lengthy process of evaluation.
* Exploration could be directed to particular environmental niches likely to yield useful species, *i.e.* selection could focus on particular provenances or adaptations within a species.
* It may suggest management strategies for the plant in its new environment.
* It would be an aid to evaluation.

Evaluation Criteria

Ideally, evaluation should be carried out on mature stands of all prospective species grown on the same site type and having had identical treatments. However, evaluation is usually attempted before the trees have reached maturity.

Tree growth and response to stress change as trees increase in size. The pattern of tree growth over time may be markedly different between species and within species planted on different site types (Shea 1973). Consequently, measurements of tree growth during early stages of tree development may not accurately indicate future growth rates. Thus, the evaluation of the performance of introduced tree species before they have reached maturity must be approached with caution.

Stands of trees to be used for evaluation can be obtained in two ways. New comprehensive arboreta of all promising species on the most important site types could be established. The advantage of this approach is that it provides a base for systematic evaluation of all species of interest. The disadvantage is that it may take decades before results can be obtained. To complement this long term approach, immediate evaluation could commence on existing plantings. Since such plantings are likely to have been established for a variety of reasons they may have deficiencies in treatments, sites and species. This will complicate comparisons and potentially useful species may be excluded.

The criteria by which to assess performance fall into two categories:

* direct measures of performance in meeting major objectives, *e.g.* tree growth, tree water consumption or catchment salt yield.
* parameters indicating successful adaptation to the new environment, *e.g.* root habit, tolerance of soil water deficits, and resistance to plant pathogens. This type of parameter may have predictive value and enable future growth and development to be anticipated.

Criteria from both categories should be used in evaluation and the dynamic nature of tree and stand development recognized.

Duplication of the functions of the forest being replaced may not be necessary to achieve restoration of land use values but the existing forest provides the only model of a functioning ecosystem. Thus, the ability of the introduced species to duplicate both the performance and adaptive characteristics of the existing forest must form part of the evaluation.

In the Northern Jarrah Forest the major objective of rehabilitation is to restore the hydrological balance. Thus, the most important direct index of performance is tree water consumption. There are two approaches to measuring this parameter. Firstly, the performance of a stand of a given species in a given area could be gauged such as in a micro-catchment study. This approach has problems with scale, replication (or calibration) and time taken to get a result. Secondly, the performance of individual trees could be gauged. Several techniques are available including the recently developed extension of the ventilated chamber method (Greenwood pers. comm.). The individual tree approach is the most practicable for evaluation of large numbers of species.

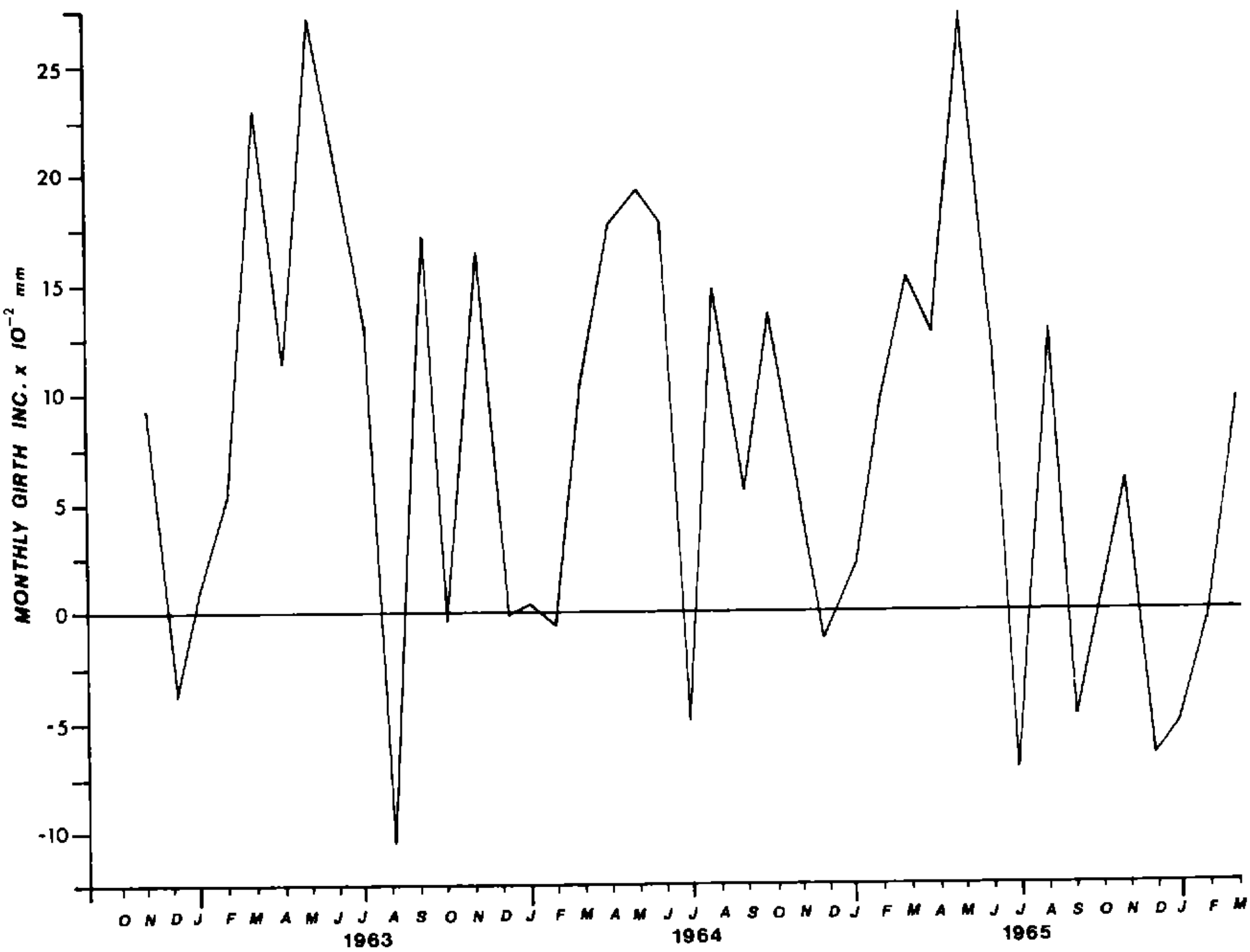
Parameters indicating successful adaptation to the new environment are identified below.

Progress

Analysis of the Jarrah Forest Ecosystem

Kozlowski (1968) presents a broad rationale for the dominant role played by water stress in determining plant adaptation and distribution. In the semi-arid Mediterranean climate of Western Australia, adaptation of forests to water stress is likely to be of particular importance. In addition, the specific problem of salinity arises from water balance disturbance. For this reason we have emphasised plant water relations in this review. Space does not permit discussion of the effect of other major factors of the Jarrah Forest ecosystem such as fire and the presence of *P. cinnamomi* which will affect species selection.

Fig. 1. Monthly girth increment in jarrah



Grieve (1962) and Doley (1967) were first to record that jarrah in its native habitat is able to maintain high levels of water consumption in summer in spite of considerable soil water deficits in the upper profile. In addition, jarrah has the capacity for shoot and cambial growth in summer during periods of maximum drought stress. Shoot extension is active in early summer and girth increment has a late summer maximum (Fig. 1). Kimber (1974) provided evidence of how this may occur. He observed a two-tiered root system in jarrah, a zone of proliferation in the topsoil connected by vertical descending roots to a zone of proliferation at a depth of 14m above the water table.

Rapid responses of groundwater levels and salinity to rainfall have been observed in Jarrah Forest soil profiles (Hurle pers. comm.; Herbert and Shea 1978). This, together with observations of uniform recharge of soil profiles (Whitely pers. comm.), suggests that a significant proportion of rainfall passes rapidly to the water table by preferred channels. This phenomenon together with the existence of a marked excess of rainfall over evapotranspiration in winter would explain the significance of the extensive vertical root development of jarrah.

Havel (1975) observed that jarrah dominates all sites where the soil profile is deep. Apparently, the ability of this species to remain physiologically active in summer due to efficient exploitation of deep soil profiles gives it a competitive advantage over other local species. Havel (*op. cit.*) suggests that the absence of jarrah in the northern dry areas where the soil is shallow and its persistence on shallow soils in moister southern areas provides evidence that water availability is the principal factor determining its distribution.

Further evidence of the extent of jarrah's dependence on efficient exploitation of deep soil profiles is apparent from its performance on marginal sites. The summer of 1978 was the culmination of the driest period for many decades. At a site where several large jarrah trees had died, leaf diffusive resistance and xylem pressure potential of adjoining live jarrah and *Eucalyptus calophylla* R. Br. ex Lindl. (marri) were measured. Leaf diffusive resistance indicated a large degree of stomatal closure throughout the day for all samples. Xylem pressure potential for marri was normal (c. -1100 kPa). Jarrah exhibited extremely low potentials (c. -3400 kPa). It was assumed to be a relatively shallow soil site, due to occurrence of outcropping basement rock, and it is likely that available soil moisture was approaching exhaustion. These data suggest that jarrah has a lower tolerance of water deficits than marri. This is supported by observations of cuticular transpiration by Grieve (1955). It appears that these two species have evolved alternative strategies to manage internal water balance. Jarrah has evolved what is overall the more successful formula of maximising access to supplies rather than regulating losses.

Examination of the soil profiles exploited by jarrah have been reported by Dimmock *et al* (1974) and Herbert and Hatch (1978). Depth of profile was of the order of 20 to 30m, bulk density averaged 1.6 gm/cc and pH averaged 5.3±0.5. Salt concentrations up to 0.37 gm/100 gm soil were observed giving total storage up to 4.4 x 10^5 Kg/ha. Vertical distribution was generally uniform in the absence of a water table but exhibited a marked 'bulge' of concentration above water tables.

Even this limited analysis of the Jarrah Forest ecosystem provides a basis for selection of replacement species. For example, it provides a theoretical framework to structure a search for likely rehabilitation species which, as yet, has not been utilised. This is a serious deficiency in the rehabilitation research programme. For example, salt accumulating ecosystems occur in South Australia and Victoria (Mulcahy 1978), and may well occur elsewhere in the world, even if somewhat modified by man. The basic components of the Jarrah Forest ecosystem, *i.e.* markedly alternating wet and dry seasons over a deep water retaining soil profile, must occur in other parts of the world. Within these situations it will be species with the most mesophytic characters (*i.e.* not drought tolerant) that will be of most interest.

An understanding of the major processes within the ecosystem that the introduced species must occupy, also assists with identification of important plant adaptations. For example, the ability of an introduced species to occupy the inhospitable deep subsoils of the Jarrah Forest profile is likely to be a critical factor. For successful rehabilitation it will be necessary to minimise any rise in water table. This means it will be necessary to re-establish a rooting pattern comparable to jarrah. Any change could throw salt storage into disequilibrium even though total plant water use may be unchanged (Peck 1975).

A more superficial understanding of the ecosystem might suggest selection of vegetation adaptations which maximise interception as a measure to minimise ground water accumulation. However, this analysis shows that it is not plausible to rely on interception as a major factor, since in at least some rainfall events throughfall will be considerable. This will rapidly infiltrate to depth and unless the vegetation has roots established in the deep recharge zone ground water accumulation will occur. Therefore, the success of *Pinus* species with their high interception capacity is still dependent on root habit.

Having identified root habit as an important adaptation for successful introduction it can be used in evaluation. Progress by introduced species in occupying the deep subsoil profile may be a useful indicator of stand development and potential. Species performance in combating particular aspects of the subsoil environment may be amenable to laboratory study. For example, the difficult nutritional and acid characteristics of the Jarrah Forest subsoils are under investigation (Loneragan pers. comm.).

Evaluation of New Arboreta

The most recent phase of the evaluation programme is the establishment of large arboreta on the important site types. The Arboreta establishment programme is shown in Table 1.

Table 1. Northern Jarrah Forest Arboreta

Site	Year of estab.	No. of species	Area (ha)
1200mm rainfall bauxite pit	1976	35	33
1200mm rainfall P.c. infected upland	1978	68	70
800mm rainfall upland	1979	70	70
800mm rainfall valley floor	1979	70	70
800mm rainfall bauxite pit	1980	70	70

Prior to the initiation of this programme of arboreta establishment species selection has been inadequate. Only cursory attempts have been made to identify appropriate habitats or adaptations in the search for useful species. The procedure for species selection for the arboreta which are currently being established, although still not optimum, is based on a rational analysis of the ecosystem. Species selection was restricted to eucalypts and included members of the box and ironbark groups from inland Queensland and New South Wales and Western Australian goldfields and wheatbelt species. It is hoped to carry out more detailed analysis for selection of species for future arboreta.

In siting these arboreta the objective has been to place them at intervals along the major environmental gradients. This permits interpolation rather than extrapolation of tree performance. At present arboreta have been established in the western high rainfall (1200mm p.a.) zone near Dwellingup. Eastern low rainfall (800-900mm p.a.) arboreta will be established on the eastern State Forest boundary. At each rainfall point arboreta will be replicated at upper and lower landscape positions and in bauxite pits.

Establishment and management treatments carried out on these arboreta should be comparable with what might occur on the operational scale in the future. Proper evaluation of alternative treatments within the arboreta is not practical since a minimum plot size of 50m x 150m is considered desirable to overcome edge effects. Therefore, a uniform treatment which anticipates future developments must be selected. Potential treatments such as direct seeding of tree seed (Bartle *et al* 1978) and species mixtures can be excluded since they should not intrinsically alter species performance. However fertilisation, establishment of *Acacia* understorey (Shea and Kitt 1976; Shea and Malajczuk 1977), and caprock blasting are treatments which have the potential to give significant responses which may interact with species. It is intended to apply fertilisation and *Acacia* understorey treatments (total cost approximately $100) but the caprock blasting treatment (total cost approximately $1,500/ha) is excluded from the main arboretum area. Due to its potential significance, the blasting treatment will be applied to several replicated plots of major species on sites where it is relevant (Tacey pers. comm.).

Evaluation of Existing Stands

Many plantings of potential replacement species exist in the Northern Jarrah Forest. These plantings can be categorised as follows:

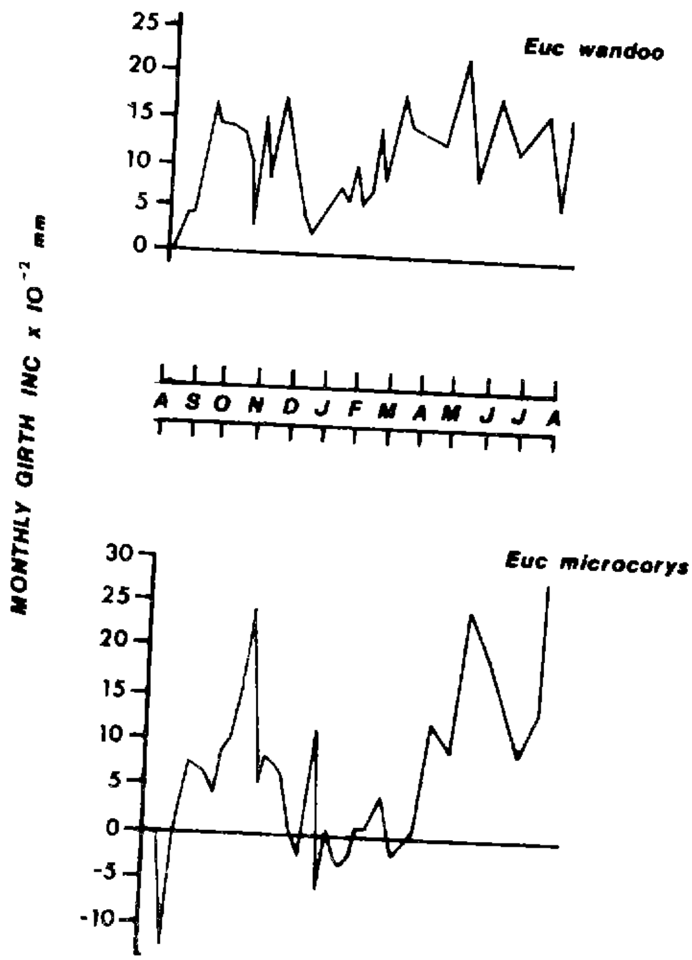
- Existing arboreta
- Plantations on *P. cinnamomi* infected sites
- Bauxite pit plantings
- Pine plantations
- Miscellaneous roadsides, gravel pits, etc.

With the exception of existing arboreta these plantings have not been established with a view to comparing species performance. Hence, in plantings other than arboreta species comparisons are difficult because of site, age and treatment differences, and are restricted to the limited range of species occurring in these plantings. The arboreta are numerous but have two significant deficiences. Firstly, they are generally located on low topographic positions where tree growth is enhanced by favourable water supply. Secondly, plot size is too small for valid evaluation of water relations. Arboreta established at Dryandra and Inglehope suffer less from these deficiencies.

One other planting is worthy of special mention. An extensive *Pinus radiata* D. Don. plantation has been established north of Boddington. This is the only planting of an introduced species over whole micro-catchments in the saline zone in Western Australia. If, in addition to its timber potential, this species can maintain desirable salt and water balances it could put the economics of rehabilitation in saline catchments onto a much more favourable basis. A stream sampling programme has commenced in this plantation but much more work could be justified.

Comprehensive and systematic species evaluation is not possible in existing plantings. They can be used, however, to obtain estimates of water consumption for different species and to assess their capacity to adapt to the environment. Precedence has been given to studies of parameters indicating successful adaptation to the Jarrah Forest environment as the existing plantings are too young to provide a reliable measure of absolute water consumption rates.

Fig. 2. Monthly girth increment in *E. wandoo* and *E. microcorys*



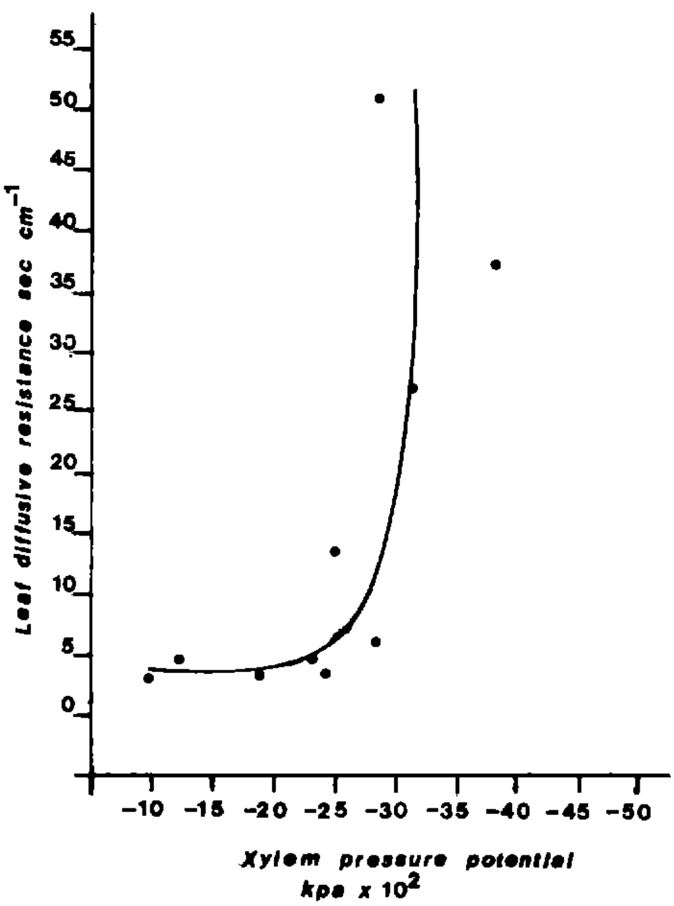
The pattern of diameter increment of 60 species of *Eucalyptus* and *Pinus* is being monitored. Contrasting growth patterns of two 5 year old bauxite pit plantings are shown in Fig. 2. Both species had similar establishment and management treatments and both have similar canopy density. *E.wandoo* Blakely shows a marked mid-summer re-commencement of diameter increment comparable to jarrah (Fig. 1). This is in contrast to *E.microcorys* F. Muell. which remains inactive until rainfall commences in autumn. The initiation of growth in summer suggests adequate access to stored subsoil moisture.

It has been hypothesized that deep root development will be a critical ingredient of success in rehabilitation, and that progress in occupation of deep subsoils may be a useful indicator of likely future performance. Forty seven trees of nine species have been excavated on rehabilitated bauxite pits for the examination of root systems. Excavations were made at 16 locations to an average of 4m depth in stands of four to seven years of age, which had experienced a variety of establishment treatments. All of the trees excavated had moderate to rapid growth rates.

Interpretation, complicated by differing establishment treatments, was further confounded by variability in subsoil material between locations. Conclusions from the small sample size are therefore of doubtful statistical validity. However, some observations are of value.

Penetration into subsoils of granitic origin (the predominant parent material) was rarely extensive but did occur in all species. Penetration nearly always followed zones of structural discontinuity or, more commonly, old root channels. The availability of such access lines determined the form of root systems. The greatest number of penetrating roots was observed in *E.wandoo* and the least in *E.agglomerata* Maiden and *E.resinifera* Sm. Jarrah grown under bauxite pit conditions was not obviously superior to other species. No root systems were comparable to jarrah in the undisturbed forest.

Fig. 3. Leaf diffusive resistance *vs* xylem pressure potential in jarrah



Monitoring of root growth and development involves substantial logistical and sampling problems as evidenced by this study. Nonetheless, the study has shown that root exploitation of the subsoil, during the early stage of tree growth on bauxite pits, is relatively poor. Further monitoring of root systems is required as the stands develop before any definite statement can be made on the ultimate root form of different species on bauxite pits.

During 1977 a programme of monitoring the diurnal and seasonal fluctuations in two important water relations parameters for 30 species of eucalypts was commenced. These parameters are xylem pressure potential, an indicator of the balance between leaf water uptake and loss; and leaf diffusive resistance, a measure of the resistance to loss of water vapour from leaves. These two interrelated parameters control leaf water balance (Burrows and Milthorpe 1976). For example, for jarrah (Fig. 3) at xylem pressure potentials in excess of approximately -3000 kPA there is marked increase in diffusive resistance. For this species, once xylem potential exceeds -3000 kPA, water consumption is markedly reduced. Information on the relationship between leaf diffusive resistance and xylem potential for different species provides basic data on the water relations of the species and can be used as one of the criteria for selection of species for rehabilitation of salt-prone areas of forest. For example, it is reasonable to infer that a species which maintains xylem potential at levels which maintain low diffusive resistances will have higher water consumption rates than species which cannot.

Diffusive resistance and xylem potential levels recorded during a period of maximum water stress for three species of eucalypts which were growing in an arboreta near Dwellingup illustrate how these parameters can be used to show species differences.

Table 2. Leaf Diffusive Resistance (r) and Xylem Pressure Potential (P)

	a.m.		p.m.	
	r (sec cm^{-1})	P (kPa)	r (sec cm^{-1})	P (kPa)
E.cladocalyx	8	-2100	20	-3300
E.saligna	26	-2100	96	-1600
E.microcorys	17	-2700	144	-2100

Eucalyptus cladocalyx F. Muell, does not exceed the threshold xylem pressure potential level which triggers a steep increase in the resistance to water vapour loss. In contrast, *Eucalyptus saligna* Sm. and *Eucalyptus microcorys* increased resistance to water vapour loss during the day so that the water balance was improved and water potentials increased during the afternoon.

The major problem with this method of evaluation is to account for differences in canopy density. This is common to all methods of water relations measurement that use leaves, twigs or branches rather than whole trees. To overcome this problem it is intended to measure water consumption of whole trees. A scaled-up version of the ventilated chamber method has been successfully developed and applied on trees up to 16m in height (Greenwood pers. comm.). The whole tree is enclosed in a clear plastic tent and release of water vapour into a forced air stream is monitored with an infra-red gas analyzer. This method is rapid and accurate and could be used on trees up to 25 m. It will become an important tool in species evaluation because, in addition to giving a direct estimate of water consumption per unit area, it can be used to calibrate other less direct methods of evaluation.

Conclusions

There is insufficient long term data to permit selection of the most suitable tree species for rehabilitation of salt prone areas in the Northern Jarrah Forest.

Existing plantings of trees are too young to permit conclusive evaluation. Initial assessments of the plantings have therefore focused on parameters which reflect adaptation to the environment rather than direct measurements of performance. Preliminary results from these assessments have shown substantial differences between species.

Acknowlegements

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Rehabilitation of Areas Affected by Mining at Greenbushes, W.A.

S. Bennison

Greenbushes Tin N.L., Greenbushes, W.A.

Abstract

Recent mining activities in the Greenbushes district have resulted in the creation of deep open-cut pits, overburden dumps and tailing ponds. These areas are now undergoing progressive rehabilitation with the ultimate purpose of rendering the sites aesthetically acceptable. Particular emphasis is placed on the rehabilitation of weathered greenstone clays characteristic of overburden dumps and open-cut pits. Kaolin clays collected in tailing ponds are mentioned with reference to future alternative land use development. Present rehabilitation sites are small in area and the techniques used are those which have been under trial since 1975. These are based on their success and efficiency in controlling erosion and improving vegetation establishment. Indigenous plant species have been selected on their ability as pioneers in re-establishing themselves on mined areas and their role in forming the necessary stages of succession until a climax ecosystem is reached.

Introduction

The Greenbushes Tin N.L. mineral field is located approximately 80km south-east of Bunbury on the South West Highway. The Greenbushes townsite is situated within the mineral field at latitude 33° 40' south and longitude 116° east.

Climatic conditions are temperate with December mean maximum and minimum temperatures of 27.9 and 10.2°C respectively. The July mean maximum and minimum temperatures are 15.4 and 4.2°C respectively. The field lies between the 763 and 1017 mm isohyets with most of the average annual rainfall of 1009 mm falling in winter.

The mineral field is situated in hardwood forest comprising mainly jarrah (*Eucalyptus marginata* Sm.), marri or red-gum (*E. calophylla* R.Br.), blackbutt (*E. patens* Benth.) and bullich (*E. megacarpa* F. Muell.) The understorey to these forests comprises sheoak (*Casuarine fraseriana* Miq.), *Banksia grandis* Willd., *Dryandra floribunda* R.Br. with *Persoonia elliptica* R.Br. and *P. longifolia* R.Br. forming a still lower intermediary storey. Below these again are many shrub species including prickly moses (*Acacia pulchella* R.Br.), *Hibbertia* spp., *Hakea* spp., *Mirbelia* spp., *Leucopogon* spp., blackboy (*Xanthorrhoea preissii* Endl.), zamia palm (*Macrozamia reidlei* ((Gaud) C.A. Gardn.) and many other members of the Proteaceae, Myrtaceae, and Epacridaceae families.

A high percentage of jarrah has been cut from the field to supply local timber mills and the cutting of such timber is controlled by the Forests Department. The soil type over the field is fairly uniform being lateritic podzol. Tin mining has occurred in the area since 1880 with early operations being confined to small open-cut or shaft workings. Most of these areas are now overgrown and covered by natural regeneration. During the 1960s dredging was used to mine alluvial deposits and with the depletion of these reserves mining operations were transferred to the use of open-cut methods.

The minerals sought occur in weathered pegmatite and this is processed through two stationary plants located at elevated positions on hillsides. Tailings are collecting in a series of terraced holding dams (slime bunds) which allow the fine silt and clay (slimes) to settle with the water being decanted into the processing plants' water supply dams. The coarse sand tailings are collected in the upper terraced areas while the slimes are transported by the water to the lower regions. Often it is necessary to remove weathered greenstone clays (overburden) to obtain access to the mineral-bearing weathered pegmatite (kaolin) clays and these may be used to backfill completed open-cut pits, dumped in old alluvial workings or a similar strategic topographic landform which allows machinery to blend in the shape of the dump with the surrounding landscape during rehabilitation work.

Apart from the overburden dumps the main areas of concern with regard to rehabilitation are deep open-cut pits, tailing ponds, slime bund retaining walls and alluvial workings including those worked by previous companies and then abandoned.

Sites Requiring Rehabilitation

Open-cut Pits and Overburden Dumps

The primary deposit is a strongly metamorphosed and structurally complex pegmatite intrusive body running for 3 km south of the townsite. Its width across strike may vary from 60 to 200 m and both the pegmatite and greenstone country rocks are weathered down to at least 50 m. The open-cut pits are left for a period of one to two years following the completion of mining to allow for any subsidence to take place. The pit walls are then graded to a 30° incline. Blasting is usually necessary prior to these works. The area is then contoured and shaped to blend in with the surrounding landform and render the site aesthetically acceptable.

The resulting clay surface is of a weathered greenstone nature and this is also characteristic of the overburden which is removed from the pit to gain access to the kaolin clays. Overburden removed from a pit during mining operations may be used to backfill another where excavation has been completed. Once the pit has been backfilled or the walls battered to a 30° incline, landform restoration commences.

Topsoil that has been stockpiled adjacent to the pit prior to mining is spread over the clay surface using a scraper or Hough 400. Contouring of embankments is necessary to prevent erosion. Areas inaccessible to machinery are mulched with hay. Trees are then planted randomly over the area with the spacing varying between 2.5 and 4 m. Slow release fertilizer is placed around every planting. Random planting is used to obtain a more natural appearance in revegetation though certain trees are planted in areas to which they are better adapted. Fertilizer requirements of plants are estimated using the soil analysis shown in Table 1 along with plant type and the mechanical structure of the soil.

Table 1. Typical chemical analysis of greenstone clays, tailings and naturally occurring topsoil at Greenbushes

Analysis	Greenstone clay %	Tailings %	Topsoil %
Fe O	0.55	0.40	1.61
Al_2O_3	24.23	9.50	21.6
SiO_2	53.17	82.40	26.6
TiO_2	2.33	0.46	2.9
Fe_2O_3	8.58	2.63	39.4
Mn O	0.02	0.04	0.04
Ca O	0.04	0.02	0.06
K_2O	0.07	0.88	0.04
Mg O	0.06	0.08	0.04
Na_2O	0.07	0.64	0.02
Total Soluble Salts	0.10	0.01	0.03
Organic carbon	0.6	0.6	0.7
Na (me/100g)	1.00	0.01	0.03
K (me/100g)	0.01	0.01	0.06
Ca (me/100g)	0.06	0.05	2.09
Mg (me/100g)	0.70	0.06	0.78
Cation Exchange Capacity	4.00	0.6	6.1
pH	4.4	6.8	6.25
Conductivity umho cm	300	55	82
Cu p.p.m.	0.10	0.15	0.4
Zn p.p.m.	0.10	0.10	0.4
P p.p.m.	26.0	8.0	4.0
K p.p.m.	15.0	17.0	50.0

Overburden dumps are treated in the same manner. The general practice adopted has been to contour the dump using graders and dozers in an effort to produce a landform which will blend in with the surrounding topography to give maximum aesthetic appearance. The dumps are formed using elevator scrapers and care is taken to avoid forming flat tops or a shape which results in a large catchment area, as erosion becomes a severe problem. Where batters are too steep to allow access of machinery for contouring, the area is mulched. Deposition of overburden using scrapers results in an acceptable standard of compaction which freely allows root penetration and a certain degree of water permeability. Many areas of overburden dumps show natural regeneration of *Eucalyptus* spp. of up to five and six years growth.

Where the clay is not covered with topsoil, perennial rye grass (*Lolium perenne* L.) is seeded at a rate of 23 kg/ha. Following the establishment of grass species, native trees, shrubs and ground cover are planted. Those plants used in rehabilitating these sites are listed in Table 2. In some instances overburden is dumped adjacent to forest areas and rehabilitation is assisted by natural regeneration from seeds dispersed by surrounding trees. Overburden is also used in the construction of dam walls.

Table 2. Indigenous and introduced species used in the rehabilitation of mined areas at Greenbushes

Locations are 1 open-cut pit, 2 overburden dumps, 3 alluvial pits, 4 bund walls, 5 coarse sand tailings.

Species	Location *	Comments
Acacia decurrens (J.Wendl.) Willd.	1, 2, 3, 4	Well suited to lateritic soils.
A. cyclops A.Cunn. ex G.Don.	1, 2, 3, 4	Very common in lateritic country.
A. pulchella R.Br.	1, 2, 3, 4	Good pioneer species, first to establish.
A. baileyana F v M	1, 2, 3, 4	Very attractive and well adapted to laterite.
Albizia lophantha (Willd.) Benth.	1, 2, 3, 4	Prefers wet areas. Grows well on clays
Chamaecytisus proliferus (L.f.) Link	1, 2, 3	Introduced. Very hardy. Sets numerous seeds
Eucalyptus globulus Labill.	5	Possible future use. Needs further trials.
E.cladocalyx F. Muell.	3, 5	No longer used though show reasonable growth
E. camaldulensis Dehn.	1	Recently used. Future unknown.
E. calophylla R. Br.	1, 2, 3, 4, 5	Very common. Grows under all conditions.
E. fasciculosa F. Muell.	1, 2, 3	Only recently tried. Appears hardy on laterite.
E. lehmannii (Schau.) Benth.	1, 2, 3	Recently used and growing very well in clays.
E. marginata Sm.	1, 2	Recently used. Troubled by frost. Slow to establish.
Hardenbergia comptoniana Benth.	1, 2, 4	Ground cover. Prolific growth on clays.
Kennedia coccinea Vent.	1, 2, 3, 4	Ground cover. Very hardy and colourful.
K. prostrata R. Br.	1, 2, 3, 4	Ground cover. Very hardy.
K. nigricans Lindl.	1, 2, 3, 4	Ground cover. Recently used.
Lolium perenne L.	1, 2, 4, 5	Rye grass used in stabilization.
L. rigidum Gaud.	1, 2, 4, 5	Rye grass used in stabilization.
Oxylobium lanceolatum (Vent.) Druce.	1, 2, 3, 4, 5	Very hardy though prefers wet areas.
Pennisietum clandestinum Hochst. ex Chiov.	4, 5	No longer used. Too competitive.
Pinus radiata D. Don	3, 5	No longer used. Natives preferred.
Populus nigra L.	3, 5	No longer used. Showing hardiness on tailings.

Alluvial Areas

Alluvial areas are those resulting from the accumulation of gritty material and some clays, eroded and deposited in topographically low features from the main elevated pegmatite body. The deposits are rarely more than 10 m in depth. There are two types of alluvial deposits mined, Recent and Tertiary.

Following the removal of Recent alluvials the lateritic caprock is usually exposed and this is ripped to a depth of 1.2 m before topsoil is spread over the area. Native trees and shrubs are planted in the topsoil to create a plant regime similar to that of the overburden dumps. Burnt windrowed material is then dispersed over the ripped area.

Tertiary alluvials lie under the caprock and the resulting landform following mining is a small open-cut pit. Present rehabilitation methods involve the backfilling of the pit with the caprock which has been stockpiled adjacent to the area during mining The depression which remains is backfilled with overburden, covered with topsoil and planted out. Clay depressions are avoided as much as possible due to their water holding capacity during winter which limits the type of plant to those adapted to wet winters and very dry, hard summer conditions.

Tailing Dams and their Retaining Walls

Tailings from the processing plants are separated into two categories depending upon the particle size of material filling the dams. Silt and clay (slimes) are collected in one area and coarse tailings in another. A representative mechanical analysis of the coarse tailings gave the following percentages of particle size fractions: clay 13.8, silt 2.0, fine sand 27.3, coarse sand 34.5, gravel 22.2. The texture is sandy loam and the slimes are a small proportion. The slimes are collected in large dams (bunds) which are rehabilitated by two methods at present. The clay type present in the slimes is Kaolin.

First Method:- The slime bunds which have contained water all year round for the past five years have been naturally revegetated by the invasion of rushes and sedges (listed in Table 3). This has resulted in the creation of a wetlands environment which offers refuge for coastal aquatic birds for several months of the year. However these areas are still being used for mining purposes and will be in the future, leaving the wetlands method of rehabilitation a solution on a short term basis.

Second Method:- At the end of summer when the surface of the slimes has dried and is reasonably firm, coarse tailings are dispersed over the area. This results in a medium containing a mixture of coarse and fine sand as well as a percentage of slimes and is classified by a texture triangle (Marshall 1947) as sandy loam. The depth of this material varies from 1.5 to 2 m. Reclamation of slime dams using this method has only recently taken place and is still at an experimental stage. Greenbushes Tin is beginning plant trials on the reclaimed area towards the end of this year with the assistance of the Western Australian Department of Agriculture. Food crops to be tested include corn, sunflower, pasture grasses and various cereals.

Several plant species have already established themselves on the tailings to be trialled. Their seeds probably passed through the processing plant and this may have aided germination. *Lotus corniculatus* is doing exceptionally well as are *Oxylobium lanceolatum*, *Tetragonia* sp. *Kennedia prostrata* and *Chamaecytisus proliferus*. Though their density is very sparse and their growth quite slow, they do not show any signs of nutrient deficiency. Return of this area to its natural state does not have priority at this stage unless the trials at cultivating agricultural crops are unsuccessful. The problems and expense involved in returning the dams to their original landform would be immense. The area at present being reclaimed is 11.6 ha and the remaining area still in use totals 194.8 ha.

The retaining walls of the tailings and slime dams are rehabilitated in an effort to reduce erosion and improve their aesthetic appearance. The walls are fertilized, mulched and native trees, shrubs and ground cover are planted along the face of the wall. The walls are basically constructed of overburden clay, covered with lateritic podzol.

Table 3. Pioneer plant species on areas presently undergoing rehabilitation in the Greenbushes area.

Species	Location	Comments
Acacia extensa Lindl.	Pisolitic gravels, bund walls and alluvials	A dominant shrub species. Shows liking for gravels not clays.
A. pulchella	Everywhere.	Very hardy. Grows under the most severe soil types, with little or no attention.
Banksia grandis	Alluvial gravel areas.	Slow growing. Very sparse.
Bossiaea ornata (Lindl.) Benth.	Bund walls.	Loose gravel areas. Very prominent.
Daviesia preissii Meissn.	Bund walls.	Prefers loose gravels.
Conyza canadensis (L.) Cronq.	Bund walls.	A weed. Mainly growing at base of walls.
Grevillea glabrata (Lindl.) Meissn.	Bund walls. Alluvials.	Shrub occurring in wet areas at base of walls.
Hakea prostrata R. Br.	Bund walls, general lateritic areas.	Shrub. Good coverage.
Hardenbergia comptoniana	Lateritic, clay and tailings.	Climber and creeper. Fast growing.
Inula graveolens (L.) Desf.	Laterite and clays.	Local noxious weed, though adds a small amount of organic matter.
Juncus spp.	Slime dams.	Aquatic reeds. Prefer wet slime areas.
Lotus corniculatus L.	Coarse sandy tailings.	Sparse, though showing good growth.
Macrozamia reidlei	Alluvials, laterite.	Sparse, slow growing.
Oxylobium lanceolatum	Everywhere.	Grows under most severe conditions.
Persoonia longifolia	Hard laterite, alluvials.	Very early pioneer.
Scirpus prolifer Rottb.	Slime dams.	Grows densely on edges of dams.
Sollya heterophylla Lindl.	Bund walls.	Early pioneer of bund walls.
Typha angustifolia Linn.	Slime dams.	Bullrush growing densely in dams.
Tetragonia sp.	Coarse sandy tailings.	Very sparse. Showing good growth.

Rehabilitation Techniques

One of the problems associated with rehabilitation of the Greenbushes mining area is the variation in soil types resulting from the mining process. Different techniques are involved in rehabilitating these soils due to the contrasting chemical compositions, friabilities and textures.

Trials using similar fertilizer applications on plants in different soil types (clay and tailings), highlighted the need for specialized nutrient requirements of these soils. Trials are still in progress and work is being concentrated on the sandy loam tailings covering reclaimed slime bunds. Plants, including different vegetable seeds, are grown in the various soil types in specially constructed sunhouses. To date, trees and grasses have readily survived on clay overburden, however coarse sand tailings, having been through a thorough washing process, are nearly void of any nutrients. Soil analysis (as seen in Table 1) helps in the understanding of variations in plant growth from one area to another.

Ideally topsoil is placed over the area to be rehabilitated, only in some cases this is not possible and we therefore require knowledge of the properties and structure of each soil type to ensure success. A mechanical analysis is therefore also very helpful in deciding fertilizer needs and any possible inhibitors to plant growth.

Fertilizers

Trials have been carried out using rates from 120 kg/ha to 298 kg/ha., the heaviest rate having given the best results. Higher rates are avoided where possible so as not to cause eutrophication of the water supplies, where most of the runoff in present operations area is directed. Low fertilizer levels also ensure pasture grasses will not become too dense and suppress the growth of endemic ground cover species. High fertilizer levels have also been observed inhibiting the growth of many native plants in a particular area. The actual physiological explanation for this is not definite, however root development definitely seems to be retarded.

As can be seen from the analysis of overburden clay in Table 1 very little fertilizer is required to reach the levels contained in natural topsoil. Fertilizer used varies from 22 per cent superphosphate to superphosphate with copper, zinc and molybdenum trace elements added. Native plants are also being planted with slow release fertilizer pellets, this is hoped to reduce after-care attention. The pellets contain a nitrogen, phosphorous, potassium mix with trace elements.

Various types of N:P:K mixes will be used in the future.

Mulching

Stabilization techniques using hay mulch have proven to be most successful. The method of mulching employed involves the spreading of bales of hay by hand over areas susceptible to erosion. This method is cheaper than those incorporating automated hydromulches and the resulting effect and efficiency is most satisfactory. Costs shown in Table 4 include the cost of hay, labour, fertilizer and any other expenses.

Table 4. Summary of rehabilitation costs at Greenbushes

Area	Method	Objective	Cost ($ ha)
Open-Cut Pit	Dozer and Grader	Landform restoration	2,500
	Scraper	Topsoil replacement	1,000
	Seeding, mulch, fertilizers, plants	Stabilization, revegetation	2,000
Overburden Stockpile	Dozer and Grader	Contouring, landform restoration	1,500
	Scraper	Topsoil replacement	1,000
	Seeding, mulch, fertilizers, plants	Stabilization, revegetation	2,000
Bund Walls	Mulch, seeding, fertilizers, plants	Stabilization, revegetation	2,000
Alluvials	Scraper	Topsoil replacement	1,000
	Dozer	Dispersion of windrow material	500
	Seeding, fertilizing, plants	Revegetation	1,300

The mulch improves the general aesthetic appearance of the area, especially bund walls. Spreading of hay by hand allows the covering of areas populated with native species, without damaging or inhibiting the growth of the plants. Areas to be mulched are often small and therefore do not justify the cost of hydromulching machinery. Access to areas is often difficult, either by vehicle or on foot. Bund walls have a 30° incline and are usually surrounded by wetlands. Clay areas not covered by topsoil, are boggy in winter making access with earth moving machinery almost impossible, consequently there is little alternative than broadcasting of seed and hay by hand.

Wind and lack of rain have proven to be the greatest problems for the hay due to the absence of a chemical binder. Rain is required to settle the hay and assist in forming a mat. Strong winds before settling can disperse the hay. Thus, timing of application is important. Rain is also required to germinate grass seeds within the hay bales.

A lucerne hay mix is used for mulching material and it is harvested prior to flowering, consequently containing little seed apart from that of some pasture grasses. The ability of the hay to retain water has been vital in seed germination and continued growth during dry periods.

Application rates of hay mulch have varied from 100 bales/ha to 594 bales/ha. The heaviest rate provides a better, uniform, mulch 5 to 10 cm thick. Application is carried out during the wet winter months.

Pasture Grasses

Perennial rye grasses (including Wimmera) are most efficient in preventing the erosion of clay surfaces. To attain this they must be sown at fairly heavy rates. Seeding rates have been tested from 10 to 23 kg/ha and the heaviest rate was needed to produce an intertwining root system which would efficiently prevent erosion. Rye grass has been found to improve the aesthetic appearance of overburden dumps and reclaimed pits. It also adds to the organic matter of the clay, assisting the establishment of native plants. Perennial ryes are generally poor competitors with native species.

Dinninup clover has also been used on tailings though not with the success of rye grass. Both types require far heavier fertilizer applications than 298 kg/ha to grow successfully. *Lotus corniculatus* and *Tetragonia* sp. have been observed growing on coarse tailings. How they were introduced is unknown, though their future use in rehabilitation of tailings looks promising. Their root system is very fibrous and lateral, providing a strong binding effect of the soil. The prostrate foliage is extremely dense and would assist in the build up of organic matter.

Propagation and Planting

Seedlings are propagated in a nursery on the mineral field and transferred to the rehabilitation site a week prior to planting so they may undergo a hardening-off period. Native seed is hand broadcast in mulched areas and where topsoil lies, with successful germination. Planting occurs during the wet winter months. Planting is deferred if frosts appear imminent and jarrah seedlings are scheduled to be planted out, as past experience has shown them to be susceptible to frost damage.

In some cases native seedlings have been transplanted from areas to be mined to those requiring rehabilitation. Plants are located in areas to which they are best adapted. Ground cover plants such as the *Kennedia* spp. are planted on embankments and bundwalls in such a position as to take advantage of prevailing winds which train the plants up the face of the slope.

Rehabilitated areas are closely attended following revegetation. Trees often require weeding, staking and supplementary trace element fertilizer applications. Watering may be required for trees planted late in the season. Areas are continually photographed and the growth of the vegetation is monitored.

Costs

The costs incurred in rehabilitation as listed in Table 4 vary from one area to another depending on the type of terrain, haulage distance of topsoil and differing size and shape of pits. The cost of labour is included. Seedlings are planted at 1,720 per ha and costed at 30 cents each.

Other cost factors included are:-

Labour @ $4.00/hr	160 hrs/ha
Hay	594 bales/ha
Seed	23 kg/ha
Fertilizer	300 kg/ha

Conclusion

The method used in rehabilitating overburden dumps and open-cut pits is presently designed to aesthetically satisfy those who wish to see mined areas returned to their natural state. To date the efforts have been most successful. The reclamation of slime dams with coarse sand tailings has provided an alternative land use development which could prove most rewarding for the people of the Greenbushes district and the knowledge gained beneficial to similar future developments.

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Problems With Restoring Native Flora

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Abstract

Changing land use patterns are mentioned and early work at Broken Hill, N.S.W., briefly described for historical perspective. A comparative presentation is made of the different restoration approaches that are required for eremean regions and the sclerophyllous vegetation of the south-west. Rehabilitation techniques are considered in relation to the land management disciplines in which they are found. Techniques used at Eneabba are briefly described with emphasis on the established practices of topsoil spreading and the use of cereal rye as a cover crop. The relevance of vegetation mapping and classification systems to rehabilitation programmes is discussed.

Social factors and future land use should be considered when planning restoration work. The accessibility of rehabilitation blocks by road increases human pressure on the developing ecosystem. Some protection from fire damage is necessary at early stages, even though controlled burning may produce benefits at a later stage of the succession. Some popular attitudes to native flora revegetation are discussed. Some benefits to botanical science and commercial horticulture are predicted.

Historical Introduction

In recent years changing economic conditions, cultural aims and land-use priorities have stimulated motivation towards the restoration of native flora and natural ecosystems. Thus we read of the abandonment of many northern pastoral enterprises, and in the south of much higher priorities being allotted to the protection of water catchments and large scale wilderness areas.

Of course the agricultural industries have by far the major role to play in these matters. However, recorded priorities required of landholders are slow to change and it is probably still true to say that taxation laws and statistical returns favour those who are clearing land of native flora, even when they have no clear aim of putting the land to productive use.

The extractive mining industry operates on much smaller areas where land may be denuded because of related activities such as exploration, transport and mining community activities, or directly in the case of open-cut mining. Because of the greater concentration of rehabilitation effort and a higher level of local motivation (particularly in arid areas), mining companies have usually led the way in the accumulation of "ways and means" knowledge on the restoration of native flora.

The first large scale Australian project began at Broken Hill, N.S.W., in 1936. The aim was to combat soil erosion and dust problems which had developed to the extent of threatening homes and mining sites. The motivation was entirely local and involved the co-operative activities of several mining companies and local government. The work was made possible by the study and experiments of Albert Morris, a local botanist and field naturalist. The use of large fenced enclosures in a semi-arid environment to keep out domestic, feral and native grazing animals was a pioneering step in rehabilitation which has since found many applications and has also become a standard method of range management assessment. Some 250 species of both indigenous and introduced plants became established in the Broken Hill regeneration areas. This is about the same number as the native species that occurred on the Allied Eneabba minesite (Lamont 1976) which we hope to regenerate in our rehabilitiation projects.

Eremean and Sclerophyllous Vegetation

There are actually three vegetation types in Australia that require separate consideration for regeneration methods. These are eremean (arid or semi-arid), sclerophyllous (predominantly hard leaved) and rainforest. The last can be ignored for most practical purposes in Western Australia.

Eremean communities contain a large proportion of pioneer species. Even those species that would not normally be considered as pioneers, are generally capable of establishment on fairly bare soils and are resistant to exposure factors such as wind and high temperatures. In spite of this, the seral stages of the particular vegetation to be regenerated is well worth study and application in the programme. Soil fertility considerations are generally minimal except where toxicity factors exist. Even where a high yielding introduced pasture species is to be used as a cover crop, work at Newman (Dames and Moore 1977) on iron ore waste dumps showed only very small response to added phosphate fertiliser.

As mentioned in the introduction, the exclusion of all herbivores may be critical for success in arid and semi-arid environments. By far the most important factor is water, but the season when this is applied is often not important.

Sclerophyllous communities contain a much smaller proportion of pioneer species, particularly those capable of establishment in the open cut situation where the whole soil profile has been disturbed. For this situation, successional studies carried out on roadsides or other cleared areas have little relevance. These communities are much more highly developed and integrated; thus seral stages, if known, are more of academic interest and rarely play an important part in rehabilitiation practices. An exception is the *Acacia* dominated subclimax often found in forest country. Generally, one has to aim much more directly at re-creating the climax community.

In spite of their hard leaves, many sclerophytes are very sensitive to exposure and sand blasting, particularly as young plants. They often require virtual field nursery conditions for successful establishment and their seed are generally incapable of emergence from a deep setting on the soil. Thus mulch treatments become much more important.

Soil fertility is a difficult problem on which it is impossible to generalise. Each desired sclerophyllous community must be separately assessed; agricultural experience, where augmented fertility may be an important factor in getting rid of the same community, can be of great assistance if the principles learned can be applied in reverse. Some families, such as the Myrtaceae, may respond very well to added phosphates, while others, such as the Proteaceae, may do best in the most sterile medium. Added to this is the problem of applying fertiliser to establish a grass cover crop where this may be essential to prevent soil erosion and sand blasting, as in mineral sand tailings.

The exclusion of at least native herbivores is not necessary. In fact at Eneabba we are hopeful they will perform positive functions. Large numbers of kangaroos move into the rehabilitation areas each evening to crop the cereal rye (*Secale cereale* L.) cover crop. Possibly their droppings will bring in much needed native seed from the surrounding virgin areas. They also neatly crop almost to ground level competing grass adjacent to nursery raised and fertilised *Eucalyptus* spp.

Rehabilitation Techniques

It is not possible to produce a brief list of rehabilitation techniques of use in all situations where the restoration of native flora is desired. Rather, it is more profitable to group techniques in the various categories in which we find them for a wide range of land management disciplines. In theory this makes the native flora restoration specialist a "jack of all trades". In practice, it means that he, or she, must recognise the relevance to the problem of particular disciplines and then seek help from advisory institutions that happen to have the desired discipline represented on their staff.

The principal disciplines involved from the most extensive to the most intensive can be listed as follows:

> Range management specialists,
> Ecologists,
> Agronomists or agrostologists,
> Soil conservationists, and
> Horticulturists.

This explains why many companies face a trivial dilemma when deciding what to call their land restoration specialist, particularly when only one person is involved. Ecologist, agronomist or horticulturist appear to be the general choice. Of course there are other disciplines whose activity spreads over the whole range and whose help to a programme may be vital. Chief among these are the botanist, plant pathologist and biometrician. To round off a programme the fauna and/or livestock factors cannot be ignored; this brings in disciplines such as zoology, animal production, entomology, microbiology, etc.

As pointed out above, effective rehabilitation techniques differ widely according to whether the vegetation is eremean or sclerophyll. A discussion on techniques suitable for arid enviroments was presented in the paper by Black and Trudinger (1976). Many publications exist on the development of suitable techniques for jarrah (*Eucalyptus marginata* SM.) forest areas where bauxite mining has occurred. These have been summarised in Alcoa of Aust. (1978 sections 6 and 7). Techniques found most useful to date in stabilising sand mining tailings at Eneabba are the spreading of topsoil and the use of cereal rye as a cover crop. The raising of native plants in a nursery and the spreading of native vegetation mulch are under trial at present and appear promising. Techniques to be investigated in the future including irrigation and the broadscale collection of large quantities of native seed.

The use of topsoil is an interesting example of the one technique used for differing reasons in both eremean and sclerophyll programmes. In arid environments topsoil often has very poor physical characteristics and may be difficult to collect and stockpile. However, it usually contains a valuable store of viable native seeds and, when collected with all vegetation material, can be used as an effective source of organic mulch (Black and Trudinger 1976). On the other hand in sclerophyll regions, the physical characteristics of topsoil is its most valuable asset, when used to cover the clay floor of bauxite pits, or sand mining tailings. Work at Eneabba has further shown that native plant establishment from seed stored even in fresh topsoil is extremely poor and that vegetation mulch, to be effective, must be collected separately from, and prior to, topsoil scraping.

Vegetation Classification

When restoring native flora some clear aims are required on the type of vegetation that should be attained at the completion of the programme. This information should include a species list, percentage ground cover, life form of the more common individual species and the general structure of the community. A survey of the vegetation prior to mining is very useful (*e.g.* Lamont 1976 for the Allied Eneabba minesite), though surveys of neighbouring areas of vegetation carried out during the programme may well suffice. However, it is important that such aims should not be inflexible, because of unavoidable changes to the soil profile and landform.

For work in the arid and semi-arid regions of Western Australia, the vegetation survey maps of J.S. Beard are very useful (for example Beard 1975 covers the Pilbara area). Greater detail than shown on these maps is usually required for work on a particular locality; thus the preparation of a local vegetation map based on a field survey and aerial photographs is usually worthwhile.

Such a survey may include locations some distance from the work area if it is considered that these more closely match the landform and soils created by the mining disturbance. In this way a more effective approach to the restoration of native flora may include the use of species and the creation of seral communities that do not occur in the actual work locality. If a number of options are available, a field trial may be set up to compare the effectiveness of different plant communities that will develop from topsoil and mulch samples collected from the differing habitats. This approach works well in the eremean environment.

In sclerophyll climax plant communities, structure, life form and the dominant plant species tend to remain constant over larger areas. In forested areas, this constancy may spread across differing plant habitats, for example exposed ridges and certain valley floors can both be jarrah dominant. Thus vegetation maps based on the usual criteria are of little use for rehabilitation work in these situations.

A recent classification of the vegetation in the Northern Jarrah Forest into site-vegetation types (Havel 1975) should be useful for restoring native flora. The selection of this method was done with land use studies in mind and the classification is based on the floristic composition of the understorey. Using principal component analysis and applied criteria, the recorded species were reduced to some 70 indicator species from which the site-vegetation types could be defined. Further, from within and between these types, species groups were selected which showed an almost identical ecological behaviour. Thus an assessment of indicator species presence or absence allows a deduction to be made on the habitat properties of the site.

The habitat properties of a rehabilitation site may not match any natural site very closely and there could be successional factors affecting the development of indicator species on a disturbed site. However, the latter possibility would be common throughout many parts of the Northern Jarrah Forest. Thus this classification system does offer some hope for a planned approach to restoring native flora and a background of known vegetation types on which the monitoring of progress could be based.

Social and Land Management Factors

Future Land Use Potentials

In restoring native flora we hope to create a natural ecosystem which will have sufficient buffering capacity for natural regeneration to be able to maintain itself after the first three to four years of intensive effort. This is the main distinction between this work and the creation of agricultural or horticultural ecosystems. Future successional development will lead to vegetation forms of which we cannot be certain.

Nevertheless, in practically all cases there will be one or more future land uses which should be taken into account during the intensive period of land formation and vegetation encouragement. Some future land uses for the same area may be quite compatible, for instance water catchment and the conservation of flora, while others could bring some degree of conflict, such as use for pastoral rangeland and the conservation of fauna. Such conflicts should be resolved during the planning stages of the work.

One economic advantage of restoring native flora is that surface levelling and grading requirements are rudimentary compared with the requirements for an agricultural ecosystem to be produced. If the new surface is a water catchment close to streams feeding a reservoir, special attention would be required for erosion control and the construction of silt traps.

In most southern locations, transport access to the mine and the rehabilitation tracks that are required for the early intensive work, tend to leave the rehabilitation areas more open to visitors than adjacent unmined areas. This can produce a "no win situation" in which the more visitors arrive to assess the success of the programme, the less favourably the rehabilitation areas will compare with adjacent untouched areas. This factor also lends strong weight to the future use of such rehabilitation sites as recreation areas. If this land use appears inevitable, it should be planned for by providing such amenities as a circuit sealed road, a camping area, toilets and perhaps an artificial lake.

Fire Protection

Developing rehabilitation areas are fairly resistant to fire damage because of incomplete vegetation cover and a network of access tracks. The most important danger at an early stage would be the burning of a cover crop. The burning of a mulch layer could also greatly set back progress.

Those fortunate enough to be working within the jurisdiction of the Forests Department fire control organisation can plan operations within fairly stable parameters.

However, outside these areas fire control has no such expertise to guide it and a rehabilitation programme may risk as much damage from officially lit fires as from those accidentally lit. Some organisation and preparation to counter this threat is necessary with every rehabilitation team.

The careful firing of limited areas should bring some benefits in a sclerophyll community containing an appreciable proportion of *Acacia* species and members of the family Proteaceae. Such activity should be restricted to advanced stages of the succession when *Eucalyptus* trees are mature enough to resist fire damage and there are sufficient mature seed plants of the types that require fire to multiply their numbers.

Practical Problems and Influences at the Minesite

The traditional Australian land clearing complex is alive at minesites as in all other population groups. The only exceptions are certain well established groups in arid environments where dust and erosion are ever-present hazards. Thus many people become cynical and find incongruous a deliberate programme for the re-creation of areas of native flora. Commonly with these people, the inconsistency of requiring unspoiled areas for their recreation goes unrecognised.

Thus one must expect to find at least some tacit disapproval when working on the restoration of native flora. This may express itself on and off the minesite in a variety of ways. On the positive side, the average mine worker at Broken Hill probably has a vocabulary many times larger than the average Australian when words are required for the naming of trees. Botanical plant names would be more widely used on minesites than in any other population group outside the plant professions. The level of local motivation is generally high, particularly in arid regions, and responds well to public relations efforts.

Firm government directives on rehabilitation such as we have at our Eneabba site are probably the most important contribution towards overcoming social problems. On the contrary, in my view, official notices prohibiting the non-commercial picking of wildflowers are probably counter-productive.

All rehabilitation programmes require an in-service education and public relations component to explain what is going on and to ask for co-operation. Mine traffic is heavy footed and usually in a hurry to get to its destination. Poorly constructed roads often mean an ever widening strip of flattened virgin vegetation which may appreciably add to the rehabilitation bill. Unmarked rehabilitation tracks may lead slow tracked vehicles to a blind end where the inevitable way out is a cross country hike through what may be a carefully planted rehabilitation block or trial.

Benefits to Botany and Horticulture

To avoid too much emphasis on the problems of restoring native flora, some mention should be made of potential benefits other than the obvious ones brought about through land stabilisation and revegetation.

Premining surveys, the collection of seed for nursery propagation and the monitoring of the progress of the programme inevitably produces much data on the species and varieties of plants present on or near the site. Mining is quite frequently carried out in remote areas inadequately surveyed and collected for botanical specimens. Provided the work is done in liaison with professional botanists, a great deal of knowledge concerning new species, new varieties and their distribution may be gained. Close observations on the growth of plants in a range of new soil media may also produce valuable information on their ecology and reproductive systems.

The commercial horticulture of native plants has progressed considerably in recent years as home owners and park supervisors look for plants requiring less attention and less water. Native flora restoration programmes should produce new horticultural types, particularly where nursery activities are involved.

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Rehabilitation of Mined Land - the Involvement of the Mines Department

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Abstract

The paper deals with the question of responsibility for the rehabilitation of mined land. The objective is to enable interested persons to understand more clearly where responsibility lies for ensuring that mined land is rehabilitated. An endeavour has been made to indicate those areas in which the decisions on final rehabilitation are the responsibility of the Mines Department and those areas where other authorities prevail.

Introduction

My contribution to the meeting has been prepared with the object of presenting a reasonably clear picture of where and with whom lies the responsibility to ensure that the rehabilitation of mined land is carried out. To achieve this it will be necessary to attempt to deal with the rather complex implications of mining rights and land titles within the space allocated. I will therefore devote my discussion to the responsibilities associated with the rehabilitation of those mining activities which appear to incur most public dissension. These are: sand; hard-rock; gravel; brick-clay; limestone; bauxite; mineral sands; tin and coal.

Other papers presented at this meeting deal with specific problems and activities related to the task of rehabilitating mined land and my discussion should enable a better perspective to be gained as to which authority the particular type of mining activity is responsible. In dealing with each activity in turn I intend firstly to qualify just why the particular activity is necessary, secondly, I will illustrate how the finished mining area can become a desirable community asset; and finally I will explain the legal responsibilities of the mine operator for the rehabilitation of the ground.

Sand-Pits

The majority of sand-pits are being excavated for sand used for filling low lying areas in land development, and for concrete and mortar, and sand for gardening purposes. Some high grade deposits of silica sand and lime sand are used in the glass manufacturing industry. A sandy hill can be reduced in elevation to produce material for the uses mentioned and then provide recreational or housing development needs for the expanding suburban area.

The majority of sand-pits are on private land and the requirement for a sand-pit operator to rehabilitate the area at the completion of mining - or in some instances to rehabilitate progressively - is written into a license to excavate issued by a shire council under the provisions of the Draft Model By-laws for Extractive Industries under the Local Government Act. Such licenses are usually issued for twelve months and are renewable but they may be cancelled by the respective council for non-compliance of the conditions imposed when the license was issued. The usual type of conditions applied to a license to excavate require that topsoil to a certain depth must be retained and limits the depth (reduced level) to which the excavation must be returned after the sides have been sloped to a stipulated angle and the topsoil respread over the area.

The reason for the license being issued by the Local Government Authority (L.G.A.) instead of the Mines Department is because sand, gravel, and rock, as such on private land are not regarded as minerals for the purposes of the Mining Act.

To amplify this statement, I draw your attention to the different requirements between mining for sand, gravel or rock on private property or Crown land.

Anyone desirous of mining sand, gravel, or rock, on private property has to purchase the land or successfully negotiate with the owner for the right to mine. Should the owner refuse, then his decision is final. If a satisfactory arrangement can be negotiated the applicant must then seek the approval of the L.G.A. concerned, if that Authority has adopted excavation licensing. The L.G.A. may or may not issue him with a license. The license would normally contain appropriate conditions of mining relative to safety, finished contours, and rehabilitation and may require the lodgement of an amount of cash by way of security in the event of default of conditions.

In the case of Crown land the holder of a Miners Right may peg and apply for a Quarrying Area or Quarrying Areas not exceeding 24 acres (9.7 ha) each. Conditions relating to safe working, finished contours and rehabilitation are imposed by the Mines Department.

Hard-Rock Quarries

Three hard-rock quarries are currently operating in the Perth metropolitan area. Their principal products are aggregate for concrete work, road metal and roadbase for roads and driveways, lump rock for groynes, and ballast for railways.

Criticism directed at these operations is usually based upon the proximity of the quarries to developed areas and because of the so-called 'scars' which are being created on the western profile of the Darling

Scarp. At the time when each of these quarries was first mined, they were relatively distant from developed areas but they are now becoming engulfed in the metropolitan expansion.

There is no immediate shortage of the types of material won from these quarries and for the opponents of their continued operation may I point out that their closure must only transfer the objections to another area. Since transport costs represent such a large proportion of the delivered products of quarrying, the shifting of the quarries away from the metropolitan area would significantly increase roadmaking and building costs and probably create additional traffic hazards on major roads into the Darling Range.

Quarry usage after mining may present some problems. Because no local hard-rock quarry has been phased out during the past twenty years there is little background from which to quote although an old quarry at Boya has been used for the training of service and civil defence units in ascent/descent and rescue manoeuvres. Hang gliding enthusiasts would certainly show interest and possibly an enclosed bird park similar to the 'Jurong' Bird Park in Singapore may eventuate.

Permission to mine for hard-rock has to be sought in a similar manner to that involving sand or gravel. If the area concerned is private property then the land has to be purchased, or an agreement negotiated with the owner, and a license to quarry has to be sought from the respective L.G.A.

If a quarry is applied for over an area of Crown land, rehabilitation conditions are imposed by the Department of Mines. Quarrying on private property is conditional on the requirements of the L.G.A. concerned.

Gravel Pits

Numerous quarry reserves for gravel appear on our Lands Department maps. These reserves were created so as to ensure that supplies of gravel for roadmaking would be available as the inland areas became settled. The Local Government Act and the Main Roads Act enable the various L.G.A's and the Main Roads Department to utilise the quarry reserves for their own requirements.

Some areas from which the gravel has been removed have been turned into barbecue or picnic areas, but in most cases the excavation has been relatively shallow and some degree of natural revegetation has taken place.

The Shires are responsible for the rehabilitation of their own gravel reserves and the Main Roads Department carry out rehabilitation work on readily visible gravel pits as areas become worked out.

Brick-Clay

The majority of brick dwellings constructed in the metropolitan area are constructed of clay bricks and use clay tiles and clay sewerage pipes. This clay is excavated from river flats and from the foothills and gullies of the Darling Scarp.

Few protests have been recorded in relation to the mining of brick-clay, probably because of the general acceptance that housing has to be durable and the double-brick dwelling has a fairly wide acceptance in this State.

Two examples of local rehabilitation are: an old clay pit at West Swan which has been filled and resurfaced to form a recreational playing field; and Queens Gardens, which was initially a brickworks clay pit.

Brick-clay is classified as a mineral so the brick manufacturers in the metropolitan area must apply for a mineral claim or mineral lease over any land they desire to excavate even if they have purchased the land concerned. The process of acquiring the right to excavate brick-clay is further complicated if private property is involved because the applicant must buy the land or negotiate with the owner regarding a right to mine, before he can gain title to a mining tenement. He must then comply with mining conditions laid down by the Mines Department, and finally he must obtain a license to excavate from the Local Government Authority and comply with their requirements as well.

Rehabilitation of clay pits is usually in accordance with the property owner's wishes and in keeping with the respective council policy. Here again, criteria for rehabilitation rest with the L.G.A. concerned.

Limestone Quarries

Limestone is classified as a rock or a mineral depending upon the percentage of calcium carbonate it contains. This implies that areas to mine low grade limestone should be sought as Quarrying Areas if Crown land is involved or as a Mineral Claim or Mineral Lease if any high grade limestone is known to exist and is to be disposed of as such.

Again limestone for agricultural usage or for roadmaking or groyne purposes can be mined from private property without a mining tenement under the Mining Act, but approval to excavate must be obtained from the L.G.A. by way of a License to Extract where appropriate By-laws apply.

Some old quarries have been landscaped into residential sites and at Fremantle some quarries which were subsequently filled as rubbish disposal sites are now recreational areas.

Rehabilitation of limestone quarries rests with the respective L.G.A. in some cases, and with the Mines Department in others, while there may also be a few old licenses under the Land Act, 1933.

Bauxite

Apart from the operations of Alcoa there has been a small scale operation in the Bedfordale area from which bauxite has been mined for cement manufacture. The operations and rehabilitation work being undertaken are subject to the quarrying and rehabilitation conditions of the Shire of Armadale-Kelmscott.

The bauxite mining being carried out by Alcoa of Australia (W.A.) Ltd. has been the centre of controversy for many years principally because of the fears of various groups which relate to the destruction of native forests and to the possibility of an increase in the salinity of run-off water and recharge water following rain.

I do not intend to comment on these aspects since the discussion is concerned with the rehabilitation of mined land. Likewise it is difficult for me to comment on the finished product from rehabilitation after mining for bauxite because the type and quality of rehabilitation is designated by the Conservator of Forests.

Because of the immensity of the project; both in areas involved, period of operation, and the need for refineries and railways, the entire project was dealt with under a Special Agreement Act of Parliament and all mining areas held by Alcoa are encompassed by M.L. $1^{S.A.}$.

Under this agreement the rehabilitation of mined areas has to be done to the satisfaction of the Conservator of Forests.

Mineral Sands Mining

The bulk of the world's recent production of titanium minerals has come from Australia. The first of the Western Australian deposits to be worked lie along an old coastline which stretches from Bunbury to Busselton.

The demand for ilmenite and rutile and the associated heavy minerals zircon, leucoxine, monazite and xenotime, fluctuates with the periodic surges and recessions of the world economy. Although the current demand for ilmenite and associated minerals is low, there will no doubt be periods of resurgence followed by recession again in the future.

The operations north and south of Capel have either been on private property, or Forest, Road, or Railway Reserves. With private property, a permit must be gained from the Mines Department in the first place in order to gain access to peg a particular area. Most of the tenements were applied for as Mineral Claims but in this area, because the Shire of Capel had not adopted the Extractive Industries Act - Model By-laws, the Mines Department applied rehabilitation conditions at the time of processing each application.

Applications for the mining rights on Road and Railway Reserves were considered only after the applicant had agreed upon the amount of compensation to be paid for the re-alignment of the particular road or railway and in the case of Forestry Reserves the mining company has to pay a set royalty to the Forests Department for every ha of forest which is removed and also has to rehabilitate the area to the satisfaction of the Conservator of Forests.

It is worth mentioning that the cost of rehabilitating much of the mined areas is considerably more per ha than the ruling cost of prime land in this locality. However, the economics of mining the contained minerals was sufficient to enable the mining and rehabilitation to be completed with an overall operating profit. Mining has therefore resulted in some uncleared areas of poor quality sandy soil being turned into valuable grazing areas after mining and rehabilitation.

Operations within the Eneabba area vary somewhat from those near Capel, principally because two of the operating companies will mine on a Flora Reserve. Their rights to mine are covered by Special Agreements and the mining and rehabilitation programmes are monitored by a committee of Government officers which is known as the Rehabilitation Co-ordinating Committee Mineral Sands Mining. The programmes are approved or altered by the Minister for Industrial Development subject to reports from the Co-ordinating Committee.

Tin Mining

Tin was first discovered at Greenbushes in 1886 and that centre is currently the scene of the major tin production in Western Australia.

During the past three years practically the entire area of the Greenbushes Mineral Field has become the mining entitlement of one company and to enable that company to operate with greater safety and efficiency an agreement was reached whereby the South West Highway was rerouted so as to by-pass Greenbushes townsite and the principal mining areas.

As part of the agreement to reroute the highway the mining company had to pay for the cost of the new alignment as well as the cost of new power and telephone lines. Additionally the company had to lodge $50,000 as a bond for rehabilitation to be paid for in the event of company failure and to expand annually a sum of at least $50,000 on the rehabilitation of current and past mining activity.

While the early diggers and the smaller syndicates who followed left the area with the general appearance of it being a hotch-potch of excavations, shafts, and dumps, the current method of mining will ensure that the economically mineable mineral will be extracted and the area will be left with a safe and aesthetically pleasing appearance.

At the completion of mining the edges of deep pits are to be sloped, topsoiled and planted with grasses and trees. Wetland areas have already been established and have attracted numerous forms of aquatic birdlife and tests are being conducted with the establishment of crops on the tailings areas. Marron and trout are being raised in hatcheries at the mine with the aim of stocking the waterways with them.

The rehabilitation of Greenbushes is in accordance with conditions approved by the Minister for Mines and the yearly programmes are submitted in advance for Ministerial approval. Quarterly progress reports are submitted by the company and these are checked in detail prior to their acceptance.

Coal

Coal mining commenced in Western Australia during 1898 at the Wallsend colliery near Collie and during the subsequent eighty years a total of twenty two underground and nine open-cut operations have produced a total of almost 53 Mt of coal.

Of this total approximately 21 Mt (40 per cent) has been produced from the two open-cut and one underground mines now operating. Although some 70 per cent of the total production has come from underground mining operations the recent trend has shown that production for 1977 was 77 per cent to 23 in favour of open-cut production. Indications are for this trend to continue for several years but a return to a much greater production of underground coal appears to be inevitable.

Mining of coal by underground methods can result in the creation of large dumps of waste material in the form of shales and slates. It can also lead to subsidence which may pipe through to the surface.

Rehabilitation of surface dumps from underground mining was not considered at the time the coal mine leases were originally approved. There is, however, a study being carried out in connection with this problem (Bartle and Riches 1978).

With reference to open-cut mining the Minister for Mines has the power to apply conditions for the rehabilitation of mined land and he can alter, delete, or add to such conditions as he deems necessary. As most of the land outside of the townsite areas of Collie and its adjacent settlements is part of a State Forest, rehabilitation is usually required to be done to the satisfaction of the Conservator of Forests and the District Mining Engineer (Senior Inspector of Coal Mines).

Discussion and Conclusions

I have omitted to comment on the Goldfields areas with respect to underground mining. The thousands of shafts which now dot the West Australian landscape may represent a form of visual pollution to some people. However to a miner or geologist a hole with a shaft head dump of material which has been brought to the surface through it is an asset which gives a ready indication of rock types and mineral occurrence and also may provide access for underground investigation.

Although it has seldom been considered to be an economic possibility to refill the excavations which result from open-cut mining, the type of research which is being undertaken in respect of rehabilitation in the iron-ore areas suggests that improvements are possible (*e.g.* Burt *et al* 1978, Riches *et al* 1978).

My discussion hopefully has indicated that the responsibility to ensure that mined land is rehabilitated after mining can rest with authorities other than the Mines Department. However, I must point out that with every mining operation the Mines Department does have responsibility to ensure that safe working is maintained. The operators must comply with the provisions of the Mines Regulation Act 1946-1974, the Coal Mines Regulation Act, the Inspection of Machinery Act, 1921-1958, and the Explosives and Dangerous Goods Act 1961 (where applicable) and regular inspections are made of these operations.

To conclude may I leave you with these thoughts on which to ponder.

During the period from 1966 to 1976 the value of mining production in Western Australia rose from approximately $76 M to $1,438 M or by 18.92 times. During the period from 1966 to mid 1975 the value of all other primary production which encompasses wool, meat, cereal crops, poultry products, dairy produce, forestry, and fishing has risen from $419 M to $893 M or about 2.13 times. Currently the value of mineral production compared with other primary production is of the order of 5 to 4 in favour of mining, yet these primary industries employ approximately 4 per cent and 8 per cent of this State's work-force. In addition, mining royalties rose from $0.72 M in 1966 to $46.65 M in 1976. One wonders if, in the absence of mineral exports, we may be faced with the prospect of exporting unemployed people.

Finally, after having been closely associated with the mining industry since I commenced working underground on the Golden Mile at the age of seventeen, some 38 years ago, it saddens me to hear and read of so much intense antagonism being directed against mining. It was mining which was responsible for our early expansion and without mining today our economy would be extremely weak.

Perhaps the reason lies in the fact that the mining centres have been remote and many of them were of fairly temporary duration, but it is my opinion that because the School of Mines in Kalgoorlie was, until W.A.I.T. recently came into being, the only centre for tertiary education in mining in this State, the mining industry has suffered because of this. Isolation has tended to eliminate dialogue between students of the various faculties of learning and has resulted in so many graduates in professions other than mining from gaining a basic knowledge of mining and the problems with which the mining industry is confronted.

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Biophysical Constraints to the Rehabilitation of Mine Wastes

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Abstract

Mine wastes are likened to the Sahara Desert, but may be saline and phytotoxic as well. Successful plants must have remarkable, often incompatible, properties, or the dump environment must be altered before colonization is possible. Careful consideration to the ease of propagation, tolerance and growth requirements of each species in relation to the location and physicochemical properties of the waste is advocated as a basis for species selection before field trials begin. A flow diagram is used to demonstrate the complex relationships between and within the abiotic (physical, chemical and meteorological) and biotic (propagule, plant, human and 'soil') constraints controlling eventual establishment of a plant cover. Nutrition is used to illustrate some of these relationships. The limitations of various multivariate methods for identifying the critical constraints controlling plant growth are discussed, with most favour going to canonical correlation analysis using coordinates obtained from non-linear techniques of multidimensional scaling *and* direct comparisons of the known range of environmental tolerances with the prevailing conditions. Some options for deciding when a site can be regarded as rehabilitated are noted.

Introduction

Historically, mine sites and their associated piles of earth, whether processed (tailings) or untreated (over-burden), have been regarded as 'sacrifice areas in the national interest'. This must have been viewed with considerable relief by the mining industry, as the geographical location and the physicochemical properties of many mine wastes places them on a par with the Sahara Desert as the world's most inhospitable sites for plant growth! For example, of 200 species tested, Plummer (1966) considered at most two were suitable for reclamation of saline soil in an arid part of Utah (open-cut coal), even in the absence of mining. Despite this, legislation now requires all barren areas resulting from mining activities to be revegetated. Clearly a knowledge of the biophysical constraints operating must be an essential first step in ensuring that such attempts are not met by continual failure.

Abiotic Constraints

Slime (tailing) dumps are the most difficult to rehabilitate and experience in Canada, the U.S.A., South Africa and Australia indicates the common problems are:

* adverse physical properties leading to inadequate aeration, low permeability to water and surface crusting
* extreme deficiency of plant nutrients
* toxic levels of heavy metals and/or salts
* sandblasting
* high temperatures
* low water supply
* low (sometimes high) pH
* surface instability and high rates of erosion.

Partial solutions to such problems have included application of lime, use of open windbreaks, sowing and planting of selected grasses and legumes, irrigation, fertilising, mulch amendment - especially sewage, ploughing and control of animal grazing. There can be no universal solution, however, as the properties of the waste and growing conditions are never the same, even within the same dump, and the agronomic possibilities and relative costs vary from location to location.

Biotic Constraints

Species suitable for rehabilitation will clearly require environmental tolerances which overlap the constraints listed above *or* the properties of the waste (at least at the surface) will need to be changed, so that less tolerant species can survive. The latter may be a much more expensive, but often the only, solution. Other desirable plant characteristics include:

* rapid growth rate (productivity)
* effective as a soil binder or windbreak
* easily propagated
* readily regenerates following death or a major setback in growth
* ability to fix atmospheric nitrogen.

In the interests of economy, then, some initial process of species selection is necessary with respect to the plants' ease of propagation and ability to grow satisfactorily on the mine waste under consideration. Table 1 is an example of the propagation potential of a group of native species under consideration for rehabilitation of tailings following open-cut mining for heavy minerals. The results clearly suggest that supply of propagules would be a problem, that field germination would be a waste of effort, and that nursery raising of stock would be necessary.

Table 1. Propagation characteristics of 204 species occurring in sand-heath near Eneabba which were under consideration for re-planting on the site following processing for heavy minerals. (Lamont and Newbey, unpublished).

Characteristic	Percent of all species
High seed set	37
Mature seed retained most of the year	25
High seed viability	96
High field germination after fire/earth disturbance	11
High nursery germination	74
Can be propagated by lignotubers or roots	2
Propagated by sub-divisions, rhizomes or tubers	9
Propagated by cuttings	46

If enough is known about the properties and growing conditions of the mine waste on the one hand, and the environmental tolerances and growth characteristics of a large number of candidates for rehabilitation on the other, then a short list of the species most likely to succeed can be prepared. This may be formalized as in Table 2, where the various levels of each attribute for a given species are rated according to their desirability for rehabilitation, each value hopefully reflecting the importance of that level in relation to other levels of that attribute, and of the attribute itself in relation to other attributes. The values for each species are summed, and the species ranked from best (lowest sum) to worst (highest sum). This two-dimensional approach is an attempt to be objective in a subject fraught with subjective judgments, but is compatible with what is done anyway, however crudely, when an agronomist/horticulturalist is asked to recommend species for a particular purpose. Of 178 species already considered the most suitable shrubs and trees for the dry region of Australia, on grounds of their rainfall requirements and salt tolerance, only 22 appeared worth using in field trials on the slime dumps in the Eastern Goldfields, Kalgoorlie. The best ten were derived as shown in Table 3.

Table 2. Ratings of various levels of nine attributes relevant to growth and dust control on slime dumps in the Kalgoorlie area. Based on a list of 178 species suitable for the 'dry country' of Australia (Lamont, unpublished data).

Variable *	Level	Rating
Rainfall (cm)	⩾ 15	1
	⩾ 18	2
	⋮	⋮
	⩾ 25	5
	> 25	†
Height (m)	⩾ 12.2	0
	⩾ 11	1
	⩾ 9.8	2
	⋮	⋮
	⩾ 1.2	9
Occurrence	W.A.	2
	East. States	4
	overseas	6
Growing season	winter	1
	all year	2
	summer	4
Salt-tolerance	'high'	0
	slight	10
	nil	†
Nitrogen-fixer	yes	0
	no	4
Windbreak	good	0
	moderate	5
	poor	10
Shade value	good	0
	moderate	2.5
	poor	5
Honey source	nectar and pollen	0
	nectar/pollen	0.5
	neither	1

* Rainfall requirement is considered a measure of drought tolerance, height a measure of minimal planting density required, occurrence an indicator of availability of seed and suitable eco-types, and shade value as an indicator of dust reduction.

† Excluded from list.

Table 3. Ranking of the ten most suitable shrubs and trees for rehabilitating slime dumps in the Kalgoorlie area, derived from Table 2. (Lamont, unpublished data).

Species	Salt	Height	Wind break	Shade	Season	Rain fall	N_2 fix-ation	Distrib-ution	Honey	Sum	Rank
Eucalyptus salubris F.Muell.	0	0	0	0	1	3	4	2	0	10	1
E. salmonophloia F. Muell.	0	0	0	0	1	3	4	2	0	10	2
E. brockwayii C.A. Gardn.	0	0	0	0	1	4	4	2	1	12	3
E. camaldulensis Dehn.	0	2.5	0	0	1	3	4	2	0	12.5	4
Acacia stenophylla A. Cunn.	0	1.2	0	2.5	1	3	0	4	1	12.7	5
Eucalyptus longicornis F. Muell.	0	2.5	0	0	1	5	4	2	0	14.5	6
Acacia sowdenii Maiden	0	7.5	0	2.5	1	2	0	2	1	16	7
Eucalyptus torquata Luehm.	0	5	0	0	1	4	4	2	0	16	8
Casuarina cristata Miq.	0	5	0	2.5	2	4	0	2	1	16.5	9
Schinus molle L.	0	3.7	0	0	1	7	4	6	1	22.7	10

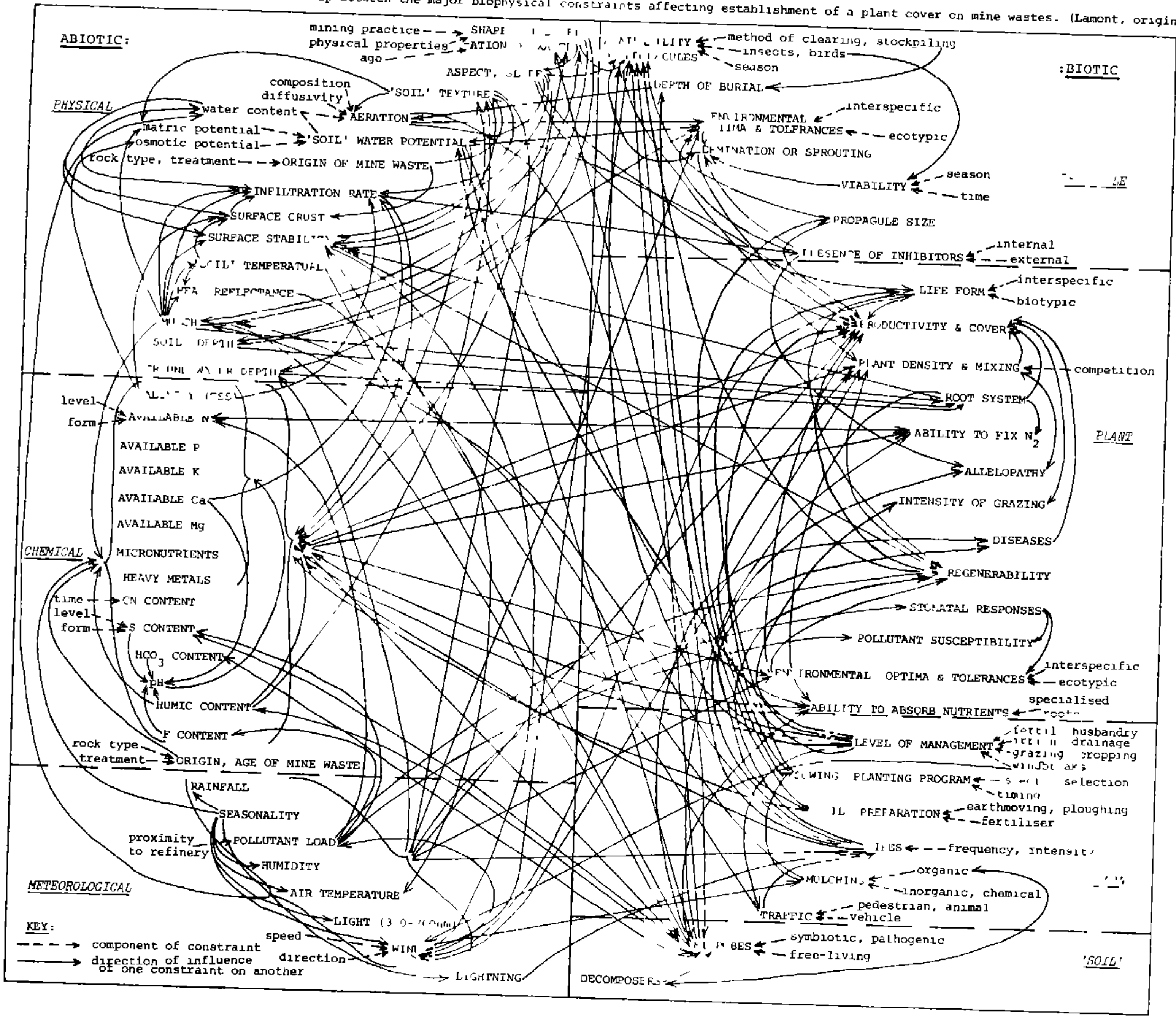
Interestingly, six of these species have already colonized some dumps and/or are present in the surrounding vegetation.

The advantages of ranking all candidates, rather than producing a short list, is that one can choose species for testing as far down the rankings as finance and nursery facilities will allow. Of course, the more is known about the growing conditions and physicochemical properties of the waste (abiotic constraints) and growth requirements and characteristics of the candidate species (biotic constraints) the better the rankings. This is a particular problem with native species as so much is yet to be learnt about them, particularly what range of ecotypes and biotypes exist. As another limitation, the response of a species to the novel attributes of mine waste, especially pollutants, can rarely be predicted in the absence of field trials.

Abiotic *versus* Biotic Constraints

Fig. 1 has been prepared to show the many biophysical constraints operating, any one or small number of which may determine whether or not satisfactory rehabilitation is achieved. The left half of the diagram deals with abiotic factors and shows the relationship (solid arrows) between 14 physical, 15 chemical and 8 meteorological attributes and various biotic attributes. The broken arrows indicate components of an attribute or independent factors affecting its level. The right half deals with biotic factors and shows the relationship between 7 propagule, 13 plant, 6 human and 2 'soil' attributes and the abiotic attributes. The number of arrows departing from or directed at a given attribute is an indication of the number of interrelationships in which it is involved, though this is partly dependent on how I have chosen to lump or split certain attributes.

Fig. 1. Flow diagram of the relationship between the major biophysical constraints affecting establishment of a plant cover on mine wastes. (Lamont, original)



Typical of any problem in applied ecology, the number of variables involved is enormous, and the interrelationships (wheels within wheels) extremely complex. This is not the place for a detailed consideration of such a flow diagram, but it may prove helpful to refer to it at the start of a rehabilitation programme or when interpreting data or monitoring progress of the programme.

Nutritional Relationships

I would like to refer to one aspect of Fig. 1, that of nutrition, to illustrate the issues involved. While mine wastes are invariably chronically deficient in the major and at least some minor plant nutrients, there may be toxic levels of other minor nutrients, salts and heavy metals. Fertilising will almost certainly increase salinity and may increase the availability of the toxic substances *(e.g.* through a decrease in pH). Fig. 2 is ample demonstration of how merely leaching the material may actually produce a marked increase in growth. With this in mind, some tailings in South Africa are continually mist sprayed, though the gains are considered by critics as short-term and very expensive (Hill 1978). Such critics would prefer to search for ecotypes resistant to the toxins. On the other hand, if the chemical properties of the material are known, appropriate fertilisers may be devised. For example, NO_3^- or $SO_4^=$ can be incorporated to compete with uptake of Cl^- in saline 'soil'. Organic mulches, while a source of nutrients in themselves, have been shown to chelate and hence detoxify undesirable cations via their humic acids, but considerable irrigation is required. On the other hand, sewage sludge may itself contain numerous heavy metals, which may eventually be released (Davis *et al* 1978).

To minimise transport, tailings are often deposited close to smelters, refineries and other processing plants. These are an additional source of airborne heavy metals and also of gaseous pollutants, such as NO_x, O_3, SO_2 and HF.

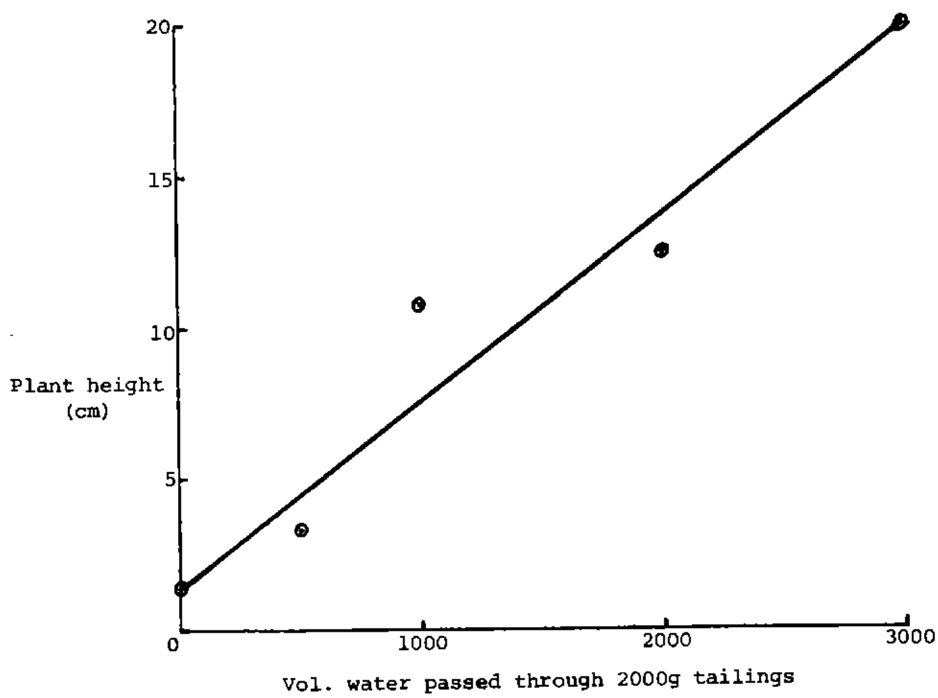


Fig. 2. Pot trial showing the effect of increasing volumes of leaching water on height of phasey bean (*Macroptilium lathyroides)* in mine tailings at Mt. Isa. (adapted from a plate in Hunter and Whiteman, 1974).

Not only are plants in nutritionally-impoverished waste more sensitive to gaseous pollutants, these gases also decrease the pH and hence increase the rate at which nutrients are leached from the root zone. Resistance can be increased by adding moderate levels of N, P, K and Ca (Guderian 1977). The B in superphosphate can increase uptake of HF however. On top of this is the variation in genetic resistance to air pollutants; legumes for example are more sensitive than non-legumes, with a consequent reduction of N incorporation into the waste.

Not all root systems are equally effective in absorbing nutrients. Halophytes for example absorb Cl preferentially to other cations and, via their salt bladders, gradually build up saline islands beneath their canopies. Many plants have specialized roots superimposed on the normal root system which enable them to thrive in soils too impoverished for survival by other species. The greatly increased absorptive area is achieved by means of root hairs in the family Proteaceae (proteoid roots), and Cyperaceae (dauciform roots) and by the external threads of symbiotic fungi in the Myrtaceae and Pinaceae (ectomycorrhizas) and Poaceae and Fabaceae (endomycorrhizas). Successful colonizers of mine wastes are increasingly being shown to be heavily infected with endomycorrhizas in particular (Table 4).

As a bonus, mycorrhizas tend to detoxify heavy minerals (again by chelation) and increase the host plant's resistance to drought. In regard to the latter point, it is interesting to note current research is demonstrating that many species are able to continue absorption of nutrients from the dry surface layer, where specialized roots are concentrated, provided plenty of water is available to the root system at depth - the water is exuded from the surface roots and then reabsorbed carrying nutrients with it.

Table 4. Percentage endomycorrhizal infection of root systems of representative species colonizing the coal tips (overburden) of the Illawarra region of New South Wales (adapted from Khan 1978).

Species	Mycorrhizal Infection (per cent)
Prostanthera sieberi Benth.	10
Eucalyptus pilularis Sm.	31
Persoonia linearis Andrews	0
Banksia paludosa R. Br.	0
Leucopogon lanceolatus R. Br.	6
Hibbertia dentata R. Br.	19
Casuarina distyla Vent.	30
Lantana camara L.	21
Indigofera australis Willd.	37
Oxylobium ilicifolium Domin	27
Erythrina sp.	29
Acacia myrtifolia Willd.	88
Helichrysum bracteatum (Vent.) Andr.	21
Senecio linearifolius A. Richard	29
Agrostis avenacea Gmel.	49
Cynodon dactylon (L.) Pers.	57
Danthonia pallida R. Br.	61
Poa sieberiana Spreng.	44
Tripogon loliiformis (F. Muell.) C.E. Hubb.	31

Identification of biophysical constraints to plant growth

It is helpful to know the range and possible relationships of attributes that may help to explain the rate of regeneration; it is even more helpful to know which of these *are* the *most critical* attributes at a given site. If there was one plant (dependent) attribute of interest and one known critical independent attribute from Table 1, then a simple linear regression analysis could relate the two. However, such an attribute would be unknown, unless it was the basis of a field trial or glasshouse experiment with only one variable. Further, this attribute is certain to be under the influence of, or affect, other variables - *i.e.* there is no such thing as an independent (orthogonal) attribute. We could then measure many 'independent' attributes and relate them to plant growth by multiple regression analysis. A 'stepwise' approach has the advantage of examining the contribution of the attribute with the largest variance first, the next second, until perfect correlation is achieved. Where curvilinear relationships are suspected, or the frequency pattern of the data is very skewed, there is a strong case for adopting a non-parametric (ranking) version of the regression coefficient, such as Spearman's.

Using the above approach, natural colonization (on the basis of biovolume) of slime dumps in the Eastern Goldfields was shown to be high if the sites had natural soil mixed with them (low available water capacity) and were close to the source of propagules (low elevation). These two attributes, of the 23 measured, accounted for 84 per cent of the variance. Biovolume (an estimate of biomass) is not concerned with species composition. Halophytes colonize saline sites; glycophytes colonize non-saline sites. When a glycophyte (sunflower) is used throughout in pot experiments with the same 'soil') the critical attributes were quite different (Table 5) - salinity (TSS and Cl) and hydraulic resistance (largely an expression of salinity in the natural soils). Such constraints then are largely overcome by using halophytes throughout (Table 3) or at least in the saline sites.

Table 5. Plant growth in the field and glasshouse in relation to physiographic, physical and chemical properties of mine waste (slimes) and natural soils in the Kalgoorlie area.

Variables are given according to their % contribution to the index of growth on the basis of stepwise multiple linear regression analysis*. (Lamont, unpublished).

Field Observations

Vegetated mine waste

Plant Biovolume (non-parametric) = f [- available water capacity (49%), - site elevation (35%), - hydraulic resistance (5%), - water content (5%),.....]

Undisturbed (control) sites

Plant Biovolume (non-parametric) = f [- sand (92%), pH (8%)]

Glasshouse Pot Experiment

Non-vegetated mine waste

log (sunflower weight) (parametric) = f [- TSS (61%), - Cl (9%), + silt (5%), - site elevation (5%)]

Vegetated mine waste

log (sunflower weight) (parametric) = f [- TSS (93%), ...]

Undisturbed (control) soil

log (sunflower weight) (parametric) = f [- hydraulic resistance (99%), ...]

* *Variables measured at 42 sites in Oct. 1974:*

Age of surface material, elevation, slope, % gravel/sand/silt/clay, bulk density, field capacity, permanent wilting %, available water capacity, water content Oct., hydraulic resistance, soluble $CaSO_4$, total soluble salts (TSS), pH, Cl, soluble N/P, available K/Fe/Zn.

But even non-parametric, stepwise multiple linear regression analysis is falling into disrepute (*e.g.* Hedges 1976). The objections are that:

* the solutions are not unique
* the predictor attributes are not orthogonal so that their contributions are overestimated
* small errors in estimation of the attributes may give quite misleading solutions
* usually many species and a number of growth parameters are measured giving many dependent variables to be analysed separately on the same independent data set.

All these problems are overcome by using a technique called canonical correlation analysis, in which a matrix of species responses is compared against the matrix of environmental attributes. The method produces orthogonal vectors that define which species attributes are most closely associated with which environmental attributes, which species-environmental vector pairs contribute most to variation in the data, and which attributes are most highly correlated with each other.

Neither canonical correlation analysis nor other linear multivariate methods however recognize a very basic biological phenomenon: plant-environment response curves are not linear, but roughly bell-shaped - each species has a minimal, optimal and maximal level (cardinal values) for each constraint (within the context of the levels of other constraints) which determine both survival and rate of growth. For example, the salinity may be too low for optimal growth of halophytes on some mine wastes, but too high on others. Analysis of such phenomena would be impossible but for the recent implementation of techniques, such as Kruskal's multidimensional scaling, which aim to show graphically the relationship between sites or species without making assumptions about the nature of their response curves. Changes in time (important in monitoring a rehabilitation programme) may be included in such an ordination. The coordinates for each axis may now be treated as input vectors to the species matrix and subjected to canonical correlation analysis as before: each axis should be found to correspond to a gradient of one or small number of correlated biophysical constraints. The relative values of the 'critical' constraints of those measured for each species or site at a given point in time can now be stated.

On the basis of the above results, the rehabilitation officer will be keen to correct deficiencies and try to reduce excesses or to give preference to some species rather than others in the planting programme. These are still problems of interpretation however: the 'critical' constraints to growth are not necessarily causally related - they could be indirectly related to growth (*e.g.* poor growth in calcareous material actually due to low Fe uptake), merely highly correlated with the real constraint (*e.g.* humus content with N availability) or actually a dependent rather than an independent attribute (*e.g.* surface stability and plant cover). Where there are a number of correlated 'critical' attributes, the causal ones must be distinguished (*e.g.* via Wright's path analysis). Further, the analyses described above operate on gradients of environmental change, where the constraints really holding down productivity may be uniformly high or low at all sites and for all species - *e.g.* sandblasting, P deficiency, low water availability. Here, knowledge of the range of environmental tolerances and requirements of each species throughout its life cycle is needed so that these can be compared against the levels of each biophysical constraint in the dump environment and agronomic adjustments made where possible. In the absence of such knowledge (the outcome of exhaustive distribution studies and experiments), careful field observations, backed by an awareness of the constraints that may be operating (Fig. 1), can go a long way to arriving at the same critical constraints.

Field trials or (less satisfactorily) pot experiments of a multifactorial nature should indicate the likely success of attempts to reduce the impact of these constraints.

At what point is a site rehabilitated?

Presumably a mining company cannot be required to maintain a rehabilitation programme at a given site indefinitely. What options are available then for deciding when formal management can be regarded as completed? The answer partly depends on the aims of the programme - is it merely to stabilize the material? Is it to both stabilize and have aesthetic and utilitarian value (sight-seeing, honey, forestry, grazing, annual cropping)? Is it to merge finally with the surrounding present or original ecosystem? Some of the appropriate options are:

* sufficient ground has been covered to prevent soil erosion
* productivity equals results for the best treatment in field trials after a certain number of years
* one or more 'critical' species has returned or established, or reached a certain abundance or stage of maturity
* a particular seral stage in the succession sequence required to return the original or other vegetation type has been achieved.

There are certain to be others - we need to think about the issue more, bearing in mind the limiting biophysical constraints.

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The Importance of Invertebrates in Successful Land Reclamation with particular reference to Bauxite Mine Rehabilitation

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Abstract

The need to monitor invertebrates during attempts at land reclamation is discussed. This is considered in relation to the sheer abundance of invertebrates, the paucity of ecological and taxonomic information on the group, the possibility of habitat instability, pest outbreaks and seed theft (in direct seeded areas), and their role in soil drainage, aeration, nutrient cycling and as sources of food for vertebrates. The possibility of using invertebrates as indicators of the success of rehabilitation is also explored.

These factors are illustrated using the result of a two year continuous monitoring programme of invertebrates in bauxite mine pits which have been rehabilitated by planting *Eucalyptus* spp., by direct seeding of native plants or which have not been subject to any form of revegetation. These results are then related to the world literature on invertebrates in reclaimed lands.

Introduction

There is now a realisation that biological aspects should be considered when planning and carrying out mining operations. The influence of mining on flora and the importance of flora in mine site rehabilitation generally receive the most attention in biological components of mining studies. This is exhibited by the fact that a number of Western Australian mining companies employ botanists from time to time. There has been a considerable research effort invested in the revegetation of bauxite mines (Tacey 1974; Shea and Herbert 1977).

Studies on fauna in relation to mining are less common and, if performed, usually superficial. In such cases, studies have generally concentrated on the vertebrates. For instance, Recher (1975) has looked at the succession of birds while Fox and Fox (1978) have investigated mammal incidence in sand mining areas at Myall Lakes, N.S.W. Although there are exceptions such as the Alligator Rivers Region environmental fact-finding study (Anon 1973), invertebrate studies are generally not performed.

This paper is divided into two sections. The first part discusses the need for considering invertebrates in relation to mining operations, with particular reference to rehabilitation. Secondly, data are presented on invertebrate succession in bauxite mine pits which have been subjected to two different types of rehabilitation in order to illustrate the foregoing discussion and also to assess the ecological desirability of the different rehabilitation approaches.

Importance of Studying Invertebrates

Invertebrate Abundance

Invertebrates, particularly insects, are amongst the most abundant and successful of terrestrial animals (Anon 1970). In its submission to the Senate Standing Committee on Science and the Environment (Anon 1977), the Australian Entomological Society (1976) state that insects contribute a considerably greater biomass than vertebrates to forest faunas and include more species, usually by several orders of magnitude. These facts suggest that invertebrates are an important influence in forest ecosystems.

Paucity of Information on Invertebrates

It is a recognised fact that one reason for nature conservation is that particular species may be currently, or potentially, of use to man. Until recently invertebrates were all but absent from the international wildlife conservation agenda. However in 1976 the Survival Service Commission of the International Union for the Conservation of Nature and Natural Resources set up a Lepidoptera Specialist Group (Pyle 1978). This also acts as an umbrella for other arthropod conservation issues and similar groups have been set up for molluscs and coral reefs.

Ecological information on Australian terrestrial invertebrates is inadequate to say the least. Taxonomic information is also incomplete. The importance of invertebrates was so recognized by the Senate Standing Committee on Science and the Environment (Woodchips) that their research recommendation number 75 stated that ... 'taxonomic studies on Australian flora and fauna, the invertebrates in particular, appear to be absolutely basic to research progress in many biological fields of importance to forestry' (Anon 1977). It is the authors' opinion that an evaluation of certain parts of the invertebrate fauna in areas prior to mining is highly desirable. If rehabilitation is performed following mining it is also important to know which methods encourage the return of the original fauna.

Problems of Pest Outbreaks in Rehabilitated Areas

Mines are often rehabilitated by planting out single species of trees. It has often been suggested that, by growing monocultures, or reducing the species diversity of vegetation, the stability of an ecosystem is reduced, leading to an increased vulnerability to pest outbreaks. This has certainly occurred in tropical tree crop situations although May (1976), using theoretical models for his analysis, suggests the opposite, that increasing complexity makes for dynamic fragility rather than robustness. May also suggests that the instability of many agricultural monocultures stems from a lack of history of co-evolution amongst the agro-ecosystem components rather than to the simplicity of the ecosystem.

The woodchip report (Anon 1977) contains extensive discussion on the likelihood of pest outbreaks in relation to post-clearfelling regeneration although no meaningful conclusions are presented. There are no reports of serious pest outbreaks in the replanted or seeded bauxite pits at Jarrahdale, Del Park or Huntly. However, the author has noted an incidence of leaf galls, leaf miners and other damage on *Eucalyptus* spp. leaves and S.J. Curry (personal communication) has recorded psyllids causing defoliation of *Albizia* sp. and the common longicorn attacking drought affected *Eucalyptus microcorys* F.Muell. in rehabilitated mine pits.

It is considered that rehabilitation attempts should be monitored for pest occurrence if successful long-term regeneration is to be assured.

Seed Theft in Seeded Mine Pits

One approach to minesite rehabilitation is to direct seed the pits with native or introduced species of plants. This method is now being investigated in bauxite mine pits and, since seed taking by ants is a widespread occurrence in Australia (Berg 1975), there has been a concern that ants and other insects might reduce the success of these operations. Majer (1978a) has assessed the magnitude of seed theft by ants in reseeded bauxite mine pits and found that seed theft is only significant along the forest margins. It is necessary to maintain observations on seed theft in seeded mine pits since seed theft might occur in mines in other parts of this State. In addition, the regrowth will ultimately be subject to prescribed burns or wildfires. It is important to know whether seeds are deposited in ant nests or beneath the soil surface and hence protected from the extreme heat of the fire - in effect, planted.

Soil Rejuvenation and Nutrient Cycling

Invertebrates are of crucial importance in relation to soil formation, turnover, aeration, drainage and also litter decomposition and nutrient cycling (Springett 1978). Their importance is illustrated by the fact that most studies performed on invertebrates in reclaimed lands (Table 1) have been on soil, or soil surface, living animals. Neumann (1973) reviews the importance of invertebrates in *new* forest sites and comments that 'soil fauna and soil micro-organisms in a stand are exclusively responsible for the formation of a fertile soil'.

For these reasons it is clearly desirable to monitor soil and litter invertebrate succession in rehabilitated mine pits in relation to litter decomposition, availability of nutrients, and soil structure.

Invertebrates as Vertebrate Food Sources

Most reptiles, many birds and some mammals are partly or totally insectivorous. Their occurrence is therefore dependent on the availability of suitable food. Recolonisation of rehabilitated mine pits by invertebrates is therefore important in order to encourage the return of certain native vertebrates.

Invertebrates as Indicators of Rehabilitation Success

Although it is a contentious issue, one aim of mine pit rehabilitation is to produce an ecosystem which resembles the original one. The mine pit vegetation structure and species diversity may be compared with that of the original vegetation in order to assess the success of such attempts. Since long-term survival of plants cannot always be predicted, vegetation may not be an effective indicator of regrowth. In view of the specialised niches which many invertebrates occupy, it may be that the species present can be used as indicators of the type of mine pit rehabilitation and of its success in terms of ecological similarity to the original vegetation. The possibility of using invertebrates as indicators of various factors has been explored by a number of workers. For instance, Murphy (1953) used invertebrates as indicators of soil conditions, Franz (1949) related invertebrates to productivity and Mahoney (1974) attempted to use the Collembola fauna as indicators of land recreation use. Majer (1977, 1978c) has also explored the possibility of using ants as indicators of vegetation type and land use in Western Australia.

The preceding points are now considered in relation to a two year monitoring programme of invertebrate succession in rehabilitated bauxite mines.

Table 1. Review of invertebrate studies on reclaimed lands

Reclaimed substrate	Locality	Taxonomic groups studied	Comments	Reference
Heat sterilized soil.	Rothamsted, England.	Relevant soil inverts.	Field trial.	Baweja (1939), Buahin & Edwards (1963).
Irradiated soil.	Glamorgan, Wales.	Acarina, Collembola.	Field experiment.	Coleman & MacFadyen (1966).
Ironstone Open-cast quarry.	Northants, England.	Acarina, Collembola.	Plots mostly reclaimed for pasture.	Davis & Murphy (1961), Davis (1963).
Spoil heap of disused lead mine.	Co.Durham, England.	Relevant soil inverts.	Observations primarily to observe influence of lead.	Williamson & Evans (1973).
Reclaimed polder.	E. Flevoland, Holland.	Annelida-Oligochaeta.	Earthworms deliberately introduced into grassed areas.	Rhee[illegible] (1969).
Reclaimed polder.	Lauwerszee, Holland.	Coleoptera-Carabidae.	Study primarily concerned with theory of migration.	Meijer (1974).
Brown-coal spoil heaps.	Böhlen and Berzdorf, Germany.	Relevant soil and epigaeic inverts.	Compares fauna on reforested heaps and ones used for agriculture.	Dunger (1964, 1967, 1968a) Brünning, Unger & Dunger (1965).
Brown-coal spoil heaps.	Berzdorf, Germany.	Collembola.	Reforested land.	Dunger (1968b).
Brown-coal spoil heaps.	Böhlen and Berzdorf, Germany.	Annelida-Oligochaeta.	Reforested land.	Dunger (1969).
Brown-coal spoil heaps.	Helmstedt, Germany.	Collembola.	Reforested land.	Bode (1975).
Brown-coal spoil heaps.	Cologne District, Germany.	Diplopoda, Isopoda, Coleoptera-Carabidae.	Reforested land.	Neumann (1971, 1973).
Brown-coal spoil heaps.	Ville, Germany.	Relevant soil inverts.	Reclaimed for agriculture.	Hermosilla (1976).
Coal spoil heaps.	Grangetown, England.	Coleoptera.	Natural regeneration.	Walsh (1910) .
Industrial waste pit heap.	Co.Durham , England.	Relevant soil and epigaeic inverts.	Sown with grass.	Hutson (1972) .
Coal surface mines.	Tennessee Valley, U.S.A.	Relevant inverts.	Reforested land.	Holland (1973).
Strip-mined spoil banks.	Ohio, U.S.A.	Annelida-Oligochaeta.		Vimmerstedt & Finney (1973).
Mineral sand mined area.	Myall Lakes, N.S.W., Australia.	Hymenoptera-Formicidae.	Coastal heath revegetation.	Fox (1978).
Bauxite mines.	Jarrahdale, W. Australia.	Relevant epigaeic inverts, particularly Formicidae.	Forest plantings.	Scott (1974).
Bauxite mines.	Jarrahdale and Pinjarra, W. Australia.	Hymenoptera-Formicidae.	Planted and seeded reforested areas.	Majer (1978b).

Invertebrate Monitoring in Rehabilitated Bauxite Mine Pits

The methods of bauxite mine rehabilitation have been discussed by other contributors to this meeting. Broadly speaking, the approaches can be categorised into planting and direct seeding of mine pits.

The results of these two rehabilitation approaches are quite different. The planted mine pits have the appearance of a monoculture whereas direct seeding produces a regrowth of rich structural and species diversity looking much like coastal heath in the early stages. It is not possible to describe the mature seeded areas since this approach has only recently been adopted.

The succession of epigaeic invertebrates has been monitored in examples of both types of rehabilitation and in a mine pit in which no revegetation has been performed. Most of this work has been carried out in the Del Park minesite.

An area which was planted with marri *Eucalyptus calophylla* R.Br.) in June 1976 was selected as an example of the planting approach. This is referred to as the 'planted plot'. A 100 x 100 m plot situated 55 m north-east of the planted plot was also marked out. With the exception of topsoil replacement and ripping, no rehabilitation was performed. The centre of this area, referred to as the 'unplanted plot', was used for invertebrate monitoring. It was not possible to select a seeded area in this minesite so one was chosen at Jarrahdale. This is referred to as the 'seeded plot'; the species used here are listed in Table 2.

Simultaneous samples were obtained from a forest control plot situated approximately 1 km south-east of the Del Park mine pit plots.

A description of the four invertebrate monitoring plots and the timing of the sampling programme is given in Table 3.

Table 2. Rehabilitation Procedure used in the Jarrahdale seeded plot

Species used Broadcast native shrubs	Seeding rate kg/ha	seeds m^2
Acacia extensa Lindl.	2.5	20
A. saligna Wendl.	0.75	5
A. strigosa Link.	0.5	10
A. decurrens (J.Wendl.) Willd.	2.0	10
Albizia lophantha (Willd.) Benth.	1.0	2
Bossiaea aquifolium Benth.	0.5	3
Broadcast trees (northern end)		
Eucalyptus patens Benth.	1.3	
E. megacarpa F.Muell.	1.3	
E. marginata Sm.	0.3	
E. calophylla R.Br.	2.7	
E. accedens W.V. Fitzg.	0.7	
E. wandoo Blakely	0.7	
E. laeliae Podger and Chippendale	0.1	
E. robusta Sm.	1.3	
Planted tree seedlings (understorey)		
E. cornuta Labill.		
E. megacornuta C.A.Gardn.		
E. erythronema Turc3		
E. nutans F.Muell.		
E. transcontinentalis Maiden.		
E. sargentii Maiden.		
E. brachycorys Blakely.		
Planted tree seedlings (overstorey)		
E. resinifera Sm. (two thirds)		
E. calophylla R.Br. (one third)		

A mixture of native tree and shrub seed was hand broadcast at 7.75 kg/ha on 10th July 1976. A broadcast dressing of 250 kg/ha of No. 1 mix superphosphate was applied in late winter. Further spot dressings will later be applied to encourage maximum development. Tree seedlings were planted randomly at approx. 550 trees/ha of overstorey and 60 trees/ha of understorey species. These trees were spot fertilized with a dressing of 100gm AGRAS 12:52 at 3 and 9 weeks after planting.

Table 3. Description of Four Plots used for Invertebrate Succession Study.

Plot Description	Location	Date area cleared	Date topsoil replaced	Topsoil stockpiled	Date planted or seeded	Distance from forest border (m)	First invertebrate sampling date
Forest control	Del Park	n.a. *	n.a.	n.a.	n.a.	n.a.	March 1976
Unplanted	Del Park (DP9)	early 1972	October 1975	Yes	n.a.	225	March 1976
Planted with *Eucalyptus calophylla* (marri) only	Del Park (DP9)	early 1972	October 1975	Yes	June 1976	170	June 1976
Seeded with mixed native species	Jarrahdale (JW 402/406)	early 1974	April 1974	No	July 1976	35	June 1976

* n.a. not applicable

Sampling Methods

A single grid of six by six traps, spaced at three metre intervals, was established in a representative region of each plot. Traps consisted of 'Pyrex' tubes set in plastic cylinders in order to facilitate ease of changing. Traps contained three millilitres of alcohol/glycerol preservative.

After leaving the traps in the ground for a one week period, in order to minimise digging-in effects, the traps were uncorked for a seven-day period commencing on the dates shown in Table 3. The seven-day samples were repeated at monthly intervals until June 1977 after which sampling intensity was gradually reduced to four times per year. Traps were returned to the laboratory for hand sorting of the contents. Invertebrates were recorded at the level of Class, Order, Superfamily, Family or Subfamily depending on which level was adequate to describe a particular feeding habit and also on taxonomic expertise. Ants were recorded to the level of species.

The vegetation structure and density was recorded using a two metre rod divided into 25cm intervals. The immediate sample area plus a two metre surround was gridded out and 50 stratified recordings were made with the rod. All vegetation touching the rod at each level was counted and identified. The tree canopy situated vertically above the rod was also recorded (Levy and Madden 1933). The resulting data were used to calculate percentage area cover of vegetation, plant cover density and also to construct profiles of the vegetation. Surveys were performed in October 1975, January 1977 and September 1977. No forest recordings were made on the first date.

Data analysis

The results of this work will be reported in detail in a subsequent publication (Majer, in preparation).

Numbers of each taxonomic group were compared between each of the three mine pit samples for the periods July 1976-February 1977 and March 1977-April 1978. Wilcoxon's matched-pairs signed-ranks test (Siegel 1956) was used for the comparison since it compares samples from each particular month and hence allows for the large seasonal trends of the data. For statistical reasons it was only possible to use the test when a taxonomic group occurred in at least six monthly samples.

The ant species data were subject to more detailed analysis. The total ants figure was obtained by summing individuals of all species for the two eight-sample periods. An index of ant biomass was obtained by multiplying species totals by size weightings (1, < 2.5 mm; 2, 2.5-6 mm and 3, > 6 mm) as described by Greenslade (1976). Ant species richness (S) was obtained by summing the number of species collected in a particular time and plot. The diversity of ants was further investigated using Shannon's (1948) H' index. This is calculated by the following formula:

$$H' \text{ (decits)} = \frac{N \log N - \Sigma n_i \log n_i}{N}$$

Where N = total number of individuals and n_i the importance value of the ith species. Room (1975) has found this to be of only limited value for describing the diversity of ant faunas. However, it is useful for deriving the equitability index. The equitability of the apportionment values among species (J') was obtained by the following formula:

$$J' = \frac{H' \text{ (decits)}}{\log S}$$

The similarity of the ant fauna in terms of species composition was compared for the four sample sites for certain sample periods using Mountford's (1962) index of similarity (I). This is calculated by the following formula:

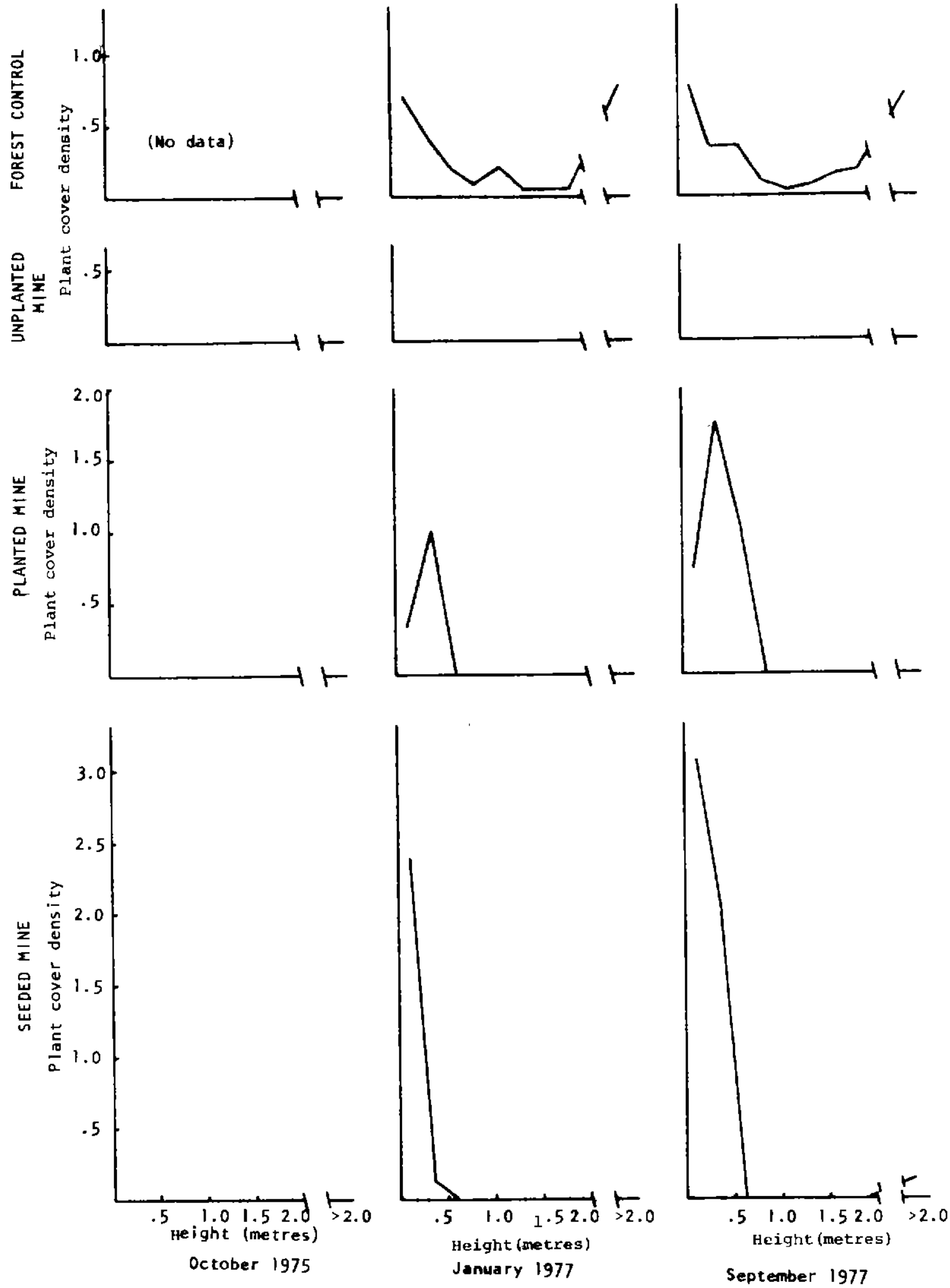
$$I = \frac{2j}{2ab - (a + b)j}$$

where a is the number of species in site A, b is the same for site B and j is the number of species in common to both sites. A comparison of mine pits with the forest plot by this method is considered to be valid as species presence/absence is used rather than quantitative data. A direct comparison of total ants and biomass index between forest and mine plots should be viewed with more caution due to differences in trapping efficiency between forest and mine plots.

Results

Fig. 1 shows that the plant cover density profiles of the four study plots on the three survey dates. The percentage plant area cover and plant cover density values are given in Table 4. No colonization of vegetation in the unplanted plot was detected using the point quadrat method although a few small *Kennedia prostrata* R.Br. have been noted in the plot. Both planted and seeded plots showed increases in plant percentage area cover and cover density following revegetation. The seeded plot values always exceeded those of the planted plot, and by September 1977 both seeded plot parameters exceeded those of the original forest. The cover density profiles (Fig. 1) reveal that

Figure 1. Plant cover density profiles for the four study plots in October 1975, January 1977 and September 1977



with the exception of the last recording from the seeded plot, vegetation was confined to the 0-75 cm height range. A small amount of vegetation exceeded 2 m in the last seeded plot recording. The point quadrat recording method generally underestimates the number of species present in an area although the number of species touched by the rod can serve as an index of plant species richness. The figures are zero, three, seven and 15 for the unplanted, planted, seeded and forest plots respectively.

Table 4. Percentage area cover and plant cover density for the four study plots

Study Plot	Date October 1975		January 1977		September 1977	
	Percentage area cover	Plant cover density	Percentage area cover	Plant cover density	Percentage area cover	Plant cover density
Forest control	-	-	82	2.5	70	2.6
Unplanted	0	0	0	0	0	0
Planted	0	0	6	1.3	14	4
Seeded	0	0	16	2.5	73	14

Table 5 lists the taxa sampled during the study. It also describes the feeding habits of each group and its main period of occurrence in the pit traps; a measure of its activity and, to a lesser extent, seasonal abundance. The taxa which are thought to be attracted to the trap preservative, and therefore not necessarily active in the area, are also shown.

Table 6 compares the presence/absence and mine plot ranks of total abundance for each taxon for the periods July 1976 - February 1977 and March 1977 - April 1978. The forest plot numerical ranges and frequency out of sixteen sequential samples are given for each taxon as a guide to their abundance in the forest. It should be noted that infrequently occurring taxa stand a chance of being missed by the mine pit sampling programme.

The pairs of plots in which significantly different quantities of particular taxa are found are labelled. For statistical reasons it was not possible to compare certain taxa between plots and in such cases no statement is made on the significance of inter-plot differences. Table 6 is summarised in three ways. The ranks in each column are summed and the best rank obtained for the early and later sampling periods. The individual ranks showed a significant degree of concordance ($W = 0.15$, $p = 0.05$ for the early sample period; $W = 0.26$, $p = 0.02$ for the later sampling period) using Kendall's coefficient of concordance (Siegel 1956). The data suggest that the seeded plot supports the most invertebrates while the unplanted plot supports the least in the initial sampling period. The situation is changed in the later sampling period in that the unplanted plot exceeds the planted plot. It is not certain how much importance should be attached to the last point since, if only taxa which show significant differences between plots are compared, the earlier rank is obtained. The number of taxa present in each plot for the two sampling periods is also shown in Table 6. The mine values are always less than those of the forest although there is an increase between the two sampling periods. This may partly result from the longer time-span covered by the second sampling period. In each period the unplanted plot supported fewer taxa than the other two mine plots.

Forest epigaeic invertebrates which are initially absent from the mine plots include Scorpionida, Pseudoscorpionida, Opiliones, Isopoda, Isoptera and Acrididae. Scorpionida, Isoptera and Acrididae are found in certain mine plots in the second sampling period. Dermaptera were absent in the seeded plot.

The ant faunas of the four plots are compared in Table 7. As already indicated, ant totals and biomass indices are not necessarily directly comparable between forest and mine plots. It is, however, appropriate to compare species presence/absence, richness, diversity and equitability values between all four plots.

Table 5. Principal groups of invertebrates collected in the sampling programme showing main periods of activity and feeding habits

Class	Taxon*	Main period of occurence in pitfall traps in forest control plot	Feeding habits	Other comments
Arachnida	O.Scorpionida	Autumn and spring	Predators	
"	O.Pseudoscorpionida	Autumn-winter	Predators	
"	O.Opiliones	High in spring & autumn	Predators	
"	O.Araneae	All year	Predators	
"	O.Acarina	Summer-autumn	Predator families only	
Crustacea	O.Isopoda	Autumn-winter-spring	Dead plant material & other detritus	
Diplopoda		Autumn-winter-spring	Dead plant material & other detritus	
Chilopoda		Spring-summer	Predators of other invertebrates	
Collembola		Autumn-winter-spring	Decaying plant material	Decomposition of bodies in traps obscures trend
Insecta	O.Blattodea	Autumn-winter	Probably omnivorous scavengers	
"	O.Isoptera	Autumn-winter	Decaying wood	
"	O.Dermaptera	Spring-summer-autumn	Omnivores	Probably attracted to alcohol
"	O.Orthoptera, SF.Gryllacridoidea	Autumn-winter-spring	Probably omnivorous scavengers	
"	O.Orthoptera, F.Gryllidae	Autumn, spring and early summer	Omnivores	
"	O.Orthoptera, F.Acrididae	Late winter-spring	Herbivores	
"	O.Hemiptera, SO.Homoptera	Autumn-winter-spring	Plant sap suckers	
"	O.Hemiptera, SO.Heteroptera	Spring-summer	Mainly seed or fungus feeders or predators	
"	O.Coleoptera, F.Carabidae	All year	Predators	
"	O.Coleoptera, F.Staphylinidae	Spring-summer-autumn	Predators	Probably attracted to alcohol
"	O.Coleoptera, F.Scarabaeidae	Autumn-winter-spring	Dead plant material & root feeders	
"	O.Coleoptera, F.Curculionidae	Winter-spring	Herbivores,mostly seed feeders	Scolytinae excluded
"	O.Coleoptera, S.Scolytinae	Autumn and spring	Wood borers	Probably attracted to alcohol
"	O.Coleoptera, (other families)	All year but low in winter	Various	Some attracted to alcohol
"	O.Diptera	All year	Various	Some attracted to alcohol
"	O.Lepidoptera, (larvae)	Spring	Live & decaying plant material	
"	O.Hymenoptera	Spring-summer-autumn		1.Some attracted to alcohol. 2.Formicidae excluded.
"	F.Formicidae, (no.of individuals).	All year with summer peak	Predators, nectar & seed feeders	
"	F.Formicidae, (species richness)	All year with summer peak	Predators, nectar & seed feeders	

* O, Order; SO, Suborder: SF, Superfamily; F, Family; S, Subfamily

Table 6. Comparison of invertebrate data between mine pit plots for the first eight and the last fourteen months of the study period.

The highest rank number corresponds to the plot where most invertebrates have been found. The numerical range and frequency of occurrence of each group in the forest plot is also shown. An asterisk means that the plots are significantly different from the stated plot U, P or S at at least the 0.05 level, N.S. means the differences are not significant, and unlabelled ranks have not been tested due to statistical limitations.

CLASS	TAXON	ABUNDANCE IN FOREST CONTROL PLOT TRAPS.		MONTHS FOR WHICH COLLECTIONS COMPARED July 1976-Feb.1977 (N=8)			March 1977-April 1978 (N=8)		
		RANGE CAUGHT PER PLOT PER MONTH	FREQUENCY OUT OF 16 SAMPLE DATES	UNPLANTED PLOT (U)	PLANTED PLOT (P)	SEEDED PLOT (S)	UNPLANTED PLOT (U)	PLANTED PLOT (P)	SEEDED PLOT (S)
Arachnida	O.Scorpionida	0-2	1	-	-	-	-	1	-
"	O.Pseudoscorpionida	0-2	1	-	-	-	-	-	-
"	O.Opiliones	0-21	7	-	-	-	-	-	-
"	O.Araneae	0-12	14	$1^{N.S.}$	$2^{N.S.}$	$3^{N.S.}$	$2^{N.S.}$	$1^{N.S.}$	$3^{N.S.}$
"	O.Acarina	0-135	13	$3^{N.S.}$	$2^{N.S.}$	$1^{N.S.}$	$3^{N.S.}$	$1^{N.S.}$	$2^{N.S.}$
Crustacea	O.Isopoda	0-3	11	-	-	-	-	-	-
Diploda		0-4	2	-	-	1	-	-	-
Chilopoda		0-2	5	-	2	1	-	1.5	1.5
Collembola		13-465	16	1^{*S}	2^{*S}	$3^{*U,P}$	$1^{N.S.}$	$2^{N.S.}$	$3^{N.S.}$
Insecta	O.Blattodea	0-3	6	1	2	3	-	1	-
	O.Isoptera	0-2	2	-	-	-	1.5	1.5	3
"	O.Dermaptera	0-338	12	$2^{N.S.}$	$1^{N.S.}$	-	$2^{N.S.}$	$1^{N.S.}$	-
"	O.Orthoptera, SF.Gryllacridoidea	0-49	7	-	-	1	$1.5^{N.S.}$	$1.5^{N.S.}$	$3^{N.S.}$
"	O.Orthoptera, F.Gryllidae	0-20	12	3^{*S}	$2^{N.S.}$	1^{*U}	1^{*S}	$2^{N.S.}$	3^{*U}
	O.Orthoptera, F.Acrididae	0-3	2	-	-	-	-	1	2
"	O.Hemiptera, SO.Homoptera	0-2	3	$3^{N.S.}$	$1^{N.S.}$	$2^{N.S.}$	1.5	3	1.5
"	O.Hemiptera, SO.Heteroptera	0-13	8	$1^{N.S.}$	$2^{N.S.}$	$3^{N.S.}$	2	1	3
"	O.Coleoptera, F.Carabidae	0-22	15	2	1	-	1^{*S}	-	2^{*U}
"	O.Coleoptera, F.Staphylinidae	0-221	15	1^{*S}	2^{*S}	$3^{*U,P}$	1^{*S}	$2^{N.S.}$	3^{*U}
"	O.Coleoptera, F.Scarabaeidae	0-3	9	-	-	1	-	-	-
"	O.Coleoptera, F.Curculionidae	0-2	7	1^{*S}	2^{*S}	$3^{*U,P}$	$2^{N.S.}$	$1^{N.S.}$	$3^{N.S.}$
"	O.Coleoptera, S.Scolytinae	0-8	7	$1^{N.S.}$	$2^{N.S.}$	$3^{N.S.}$	2	1	3
"	O.Coleoptera, (other families)	0-52	14	1^{*S}	2^{*S}	$3^{*U,P}$	$3^{N.S.}$	$1^{N.S.}$	$2^{N.S.}$
"	O.Diptera	0-28	13	$1.5^{N.S.}$	$1.5^{N.S.}$	$3^{N.S.}$	$1.5^{N.S.}$	$1.5^{N.S.}$	$3^{N.S.}$
"	O.Lepiodoptera (larvae)	0-9	3	2	1	-	1	-	2
"	O.Hymenoptera	0-6	9	$1^{N.S.}$	$2^{N.S.}$	$3^{N.S.}$	$2^{N.S.}$	1^{*S}	3^{*P}
"	F.Formicidae (no.of individuals)	36-274	16	1^{*S}	2^{*S}	$3^{*U,P}$	1^{*S}	2^{*S}	$3^{*U,P}$
"	F.Formicidae (species richness)	7-20	16	2^{*S}	1^{*S}	$3^{*U,P}$	1^{*S}	2^{*S}	$3^{*U,P}$
BEST RANK OF ALL TAXONOMIC GROUPS				1	2	3	2	1	3
BEST RANK OF TAXONOMIC GROUPS IN ROWS WHERE SOME SIGNIFICANT DIFFERENCE				1	2	3	1	2	3
TOTAL TAXA PRESENT		27		17	18	18	18	20	19

There is an increase in total ants, ant biomass index and species richness from the unplanted, through the planted to the seeded plot. Species richness does not attain the forest control values in any mine plots. The Shannon diversity index values are not discussed here since its two components, species richness and equitability, are here considered separately. The forest equitability values for the two sample periods corresponds with values found in other little disturbed areas (Majer 1977). The high equitability values indicate that the various species present have similar densities. The later planted plot, and both seeded plot records, show low equitability values indicating that certain species, namely *Iridomyrmex* spp., have attained relatively high densities.

The forest-mine plot similarity index values are all low when compared with values obtained by comparing more mature ecosystems (Majer 1978c). This is partly due to the low species richness in the mine plots although it is noteworthy that, in each sampling period, the seeded plot possesses the fauna most similar to that of the forest.

Table 7. Comparison of ant fauna parameters derived from bulked sample data. Values represent the first eight month and the last fourteen month periods of sampling in the four study plots.

Period	July 1976 - February 1977				March 1977 - April 1978			
Parameter / Plot*	a	b	c	d	a	b	c	d
Total ants	954	8	18	586	1056	16	382	1586
Biomass estimate	1797	11	27	995	1610	28	528	2109
Species richness	32	4	3	10	27	2	6	11
Shannon index of diversity	1.048	0.526	0.391	0.381	0.931	0.287	0.255	0.416
Equitability index	0.696	0.875	0.820	0.381	0.656	0.954	0.327	0.399
Similarity to forest fauna index	-	0.040	0.030	0.050	-	0.010	0.026	0.027

* Plots as follows: a - forest plot; b - unplanted plot; c - planted plot; d - seeded plot.

Discussion

This preliminary sampling programme has shown that a wide variety of invertebrates occurs in vegetated, and even unvegetated, mine pits. The unplanted plot supports the lowest variety of taxa and the groups present are generally less numerous than in the revegetated plots. The revegetated plots support a similar variety of taxa although numbers are generally higher in the seeded plot. The numerical differential of each taxon is generally much less between planted and unplanted plots than it is between seeded and the other two revegetated plots.

These observations are further supported by the data values for total ants, ant biomass and ant species richness (Table 7) which all increase in the plot order - unplanted, planted, seeded - and which are all considerably greater in the seeded plot.

These findings suggest that planting of mine pits has not made a very great initial contribution towards enrichment of the mine fauna. The relative abundance and diversity of the seeded plot fauna may be partially attributed to the fact that it is close to the forest edge, and that topsoil was not stockpiled before return and was returned at an earlier date than in the other two mine plots. It is considered, however, that the vegetation characteristics of the plots are primarily responsible for the observed differences.

The discussion will now focus on the influence of vegetation in the two revegetated plots. As already mentioned, these plots support a similar range of taxa although most occur in greater numbers in traps set in the seeded plot. The ant data also suggest that species richness is higher in the seeded plot (Table 7). The choice of ants for study at species level is appropriate since, as many are predators or occupants of specialised niches, species richness may reflect the diversity of other invertebrate food sources, of nesting sites and of foraging areas. There are no comparable studies on invertebrates in replanted and reseeded reclaimed lands although a number of workers have compared land converted to agricultural and forestry use. Dunger (1964) and Brunning *et al* (1965) both investigated invertebrate recolonization of coal spoil heaps used for agriculture and forestry. Dunger (1964) found that the diversity of most groups was greatest in the afforested areas although Brunning *et al* (1965) observed a higher invertebrate biomass in the agricultural land.

In order to relate the fauna to rehabilitation method, the differences in vegetation should first be considered. The seeded plot has the highest plant species richness, plant cover density, percentage area of ground cover (Table 4) and also has the most structurally complex vegetation. The greater density and cover of vegetation produces a more humid and cool soil surface and soil environment. Significant litter build up has been noted in the seeded plot although none has been observed in the planted area.

Murdoch *et al* (1972) have noted a positive correlation between plant and invertebrate species richness in old fields in Michigan although they were unable to resolve whether plant structure or species diversity was the important factor. Fox (1978) has attempted to relate the ant community in coastal heath, replanted after sand mining, to structural and floristic characteristics. The data suggest that certain plant structural characteristics have a major influence on the nature of the ant community.

Hutson and Luff (1978) have discussed the importance of microclimate in determining the species of Collembola in reclaimed industrial sites. Most members of this taxon require a relative humidity of at least 90 per cent in order to survive for any extended period of time. Many of the taxa sampled in the bauxite mine plots are poorly adapted to dessication so the more harsh microclimate of the open planted areas may be a limiting influence on certain groups. This would in turn limit the abundance of predators.

The final influence of vegetation which will be discussed is litter accumulation. Neumann (1971), working on rehabilitated spoil banks of coal mines, concluded that areas planted with trees producing high amounts of readily decomposable litter support more decomposer organisms than do other plots. It may be that the greater litter production in the seeded plot has also contributed to the greater diversity and abundance of certain taxa than in the planted plot.

This discussion has not resolved what the relative contributions each of these factors make in determining the type of invertebrate community, nor was elucidation of this the aim of the study. It may be concluded, however, that to enhance the rapid build up of a diverse and abundant invertebrate fauna, seeding of mine pits is preferable to planting.

A final consideration is the time scale of succession in the rehabilitated mine pits. These observations have been made during the first 22-23 months after revegetation commenced. Scott (1974) performed invertebrate surveys at Jarrahdale bauxite mine pits replanted with *Eucalyptus* spp. or *Pinus pinaster* Ait. eight years earlier. He found between 11 and 19 species of ants in the study areas which were larger than those used in this work. No comparable data is yet available in seeded plots but it may be that as plantings mature, and understorey species colonize the pits, the invertebrate fauna of planted pits becomes more similar to that of the seeded areas.

This study has revealed differences in the range and abundance of various taxa and in species diversity of at least one group, the ants, in mine pits revegetated by different approaches. It is now possible to discuss the implications of the findings for some of the points discussed in the first part of this paper.

That efficient decomposition, and hence nutrient cycling mechanisms, be established in rehabilitated areas is a necessity. Springett's (1976 a, b) comparison of soil micro-arthropods in pine plantations and jarrah forest showed that both ecosystems had similar densities of animals, although species diversity was less in the pines. Parallel investigations on litter decomposition suggested that the impoverished pine fauna decomposed litter at a slower rate than in the native vegetation. Prescribed burning of pines reduced microarthropod diversity and abundance and resulted in a further reduction in decomposition rate. No data are available on litter decomposition in the mine pits although Springett's work suggests that it would be slower in the planted plot than in the less impoverished seeded area. Figures for total nitrogen in the soil of each plot (Majer, unpublished data) support this contention since although there has been a steady reduction in nitrogen in the planted plot following revegetation, nitrogen values have been maintained in the seeded area. It would be interesting to measure decomposition rate in plots revegetated by the two main approaches.

Efficient soil turnover and aeration mechanisms are also desirable attributes of rehabilitated areas. Termites and ants are of major importance in this regard. Termites have not as yet established large colonies in any of the mine pit plots although ants have reached higher densities in the seeded plot. Most species are soil nesters. The greater abundance and diversity of ants in the seeded plot indicates that pedological activity would be greater here than in the planted plot.

Earlier it was mentioned that the presence of invertebrates is necessary for the return of certain insectivorous vertebrates. The relative abundance and diversity of invertebrates in the revegetated plots indicates that the seeding of mines is more likely to encourage such vertebrates than is the planting approach.

Finally, it should be mentioned that, at least in the case of the ant fauna, the seeded plot shows the greatest similarity to the forest control plot in terms of the species of ants present, ant species diversity and density of ants. This suggests that this rehabilitation approach is producing a regrowth which, of the two types investigated, is most similar to that of the forest in terms of its invertebrate fauna.

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Control of Dust from Slime Dumps at Kalgoorlie

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Abstract

The theoretical background and experimental results are given for a method of controlling dust generation by scattered rock fragments on slime dump surfaces at Kalgoorlie. Results from fullscale treatment of entire dump surfaces are also reported.

Introduction

A dusty atmosphere is characteristic of arid and semi-arid lands as part consequence of wind erosion. Depletion or absence of a protective ground cover results in a substantial increase in wind erosion (Marshall 1973) including atmospheric dust. Surface disturbing agencies such as traffic further increase the atmospheric dust. When this dust occurs in close proximity to human habitation the nuisance it causes becomes a problem. Such a problem has been perceived in the Kalgoorlie-Boulder area for over eighty years. An analysis of that problem was made by Richmond *et al* (1973) in which three major sources of dust generation were identified. These were the countryside around Kalgoorlie-Boulder; unsealed roads and tracks within and beyond the built-up area, and the slime dumps of the gold mines to the south-east.

This paper is concerned with control of dust from the slime dumps.

Theory

Reduction of dust requires isolation of the dust generating surface from disturbing agencies. For the slime dumps this means reducing the wind speed at the surface. Whether this is achieved by physical or vegetative methods, the relevant theory is the same. The method actually selected was a physical one. This was because there was a pressing problem which required early solution. A vegetative solution seemed less likely to meet this re-requirement because of the arid climate, the scarcity of suitable irrigation water, the water-shedding nature of the slime dump surfaces, the lack of sites for seed lodgement on the smooth surfaces of the dumps, and the high wind speeds with associated sand blasting and dessication on surfaces which occur up to 30 m above the surrounding countryside. Instead, a physical solution appeared more attractive in providing early control of dust generation and in effecting habitat changes which may subsequently favour natural colonisation of the dump surfaces.

Wind does not act directly on a surface to bring the fine clay particles (dust) into suspension in the area (Bagnold 1941). An intermediate agency is required which, in the case of wind generated dust, is the larger fine sand particles which are too heavy to be carried in suspension but which bounce (saltate) across the surface. The force with which these saltating particles return to the surface is sufficient to 'splash' the finer dust particles into the air. These saltating particles are also responsible for sand-blasting the surface and plants attempting to establish themselves. They also form a substantial part of surface moving dunes which can be another hazard of wind erosion.

Theoretically, dust control will be achieved if the wind velocity at a surface is lowered below the threshold for saltation. To do this, a continuous covering of non-erodible material would be effective but not strictly necessary. The wind force on an erodible surface is reduced to a negligible amount by a discontinuous covering of non-erodible material depending on the drag coefficient of unobstructed elements of the material and on their geometry according to:

$$Cf_o = b/\sqrt{L_c} + a \quad .... \quad (1)$$

where Cf_o is the unobstructed element drag coefficient

L_c is the lateral cover = L_a/A

L_a is the frontal area of the element

A is the average surface area per element

b is a constant of value approximately 0.0918

and a is a constant of value approximately -0.0459 (Marshall 1971).

Field measurements of several artificial and natural roughness elements indicate a value of 0.4 as being realistic for Cf_o (Marshall 1974 and unpublished data). Given this value it can readily be calculated that arrays of roughness elements spaced on average about 3.5 times their height apart should reduce the average wind force at the intervening surface to a negligible amount (Marshall 1972). These theoretical considerations formed the basis of experiments using rock fragments as a control of dust generation from the slime dumps. Because of potential savings in cost of further reducing the amount of material in the covering a treatment incorporating the optimistic value of CF_o = 0.8 was also devised.

The fewer the rock fragments used, the cheaper the solution. Consequently, another observation on the behaviour of saltating particles was drawn on in experimental design. It has been observed that when wind encounters an erodible surface saltating particles are not obvious immediately, but rather some metres downwind of the leading edge (Chepil and Woodruff 1963). This was incorporated into experimental treatments in which strips of scattered rock fragments were alternated with untreated strips.

Fig. 1. Mullock scattered on experimental plot on Kleman's dump at 30.6 t/ha. This treatment was subsequently selected for fullscale application on dump surfaces as a control of dust generation.

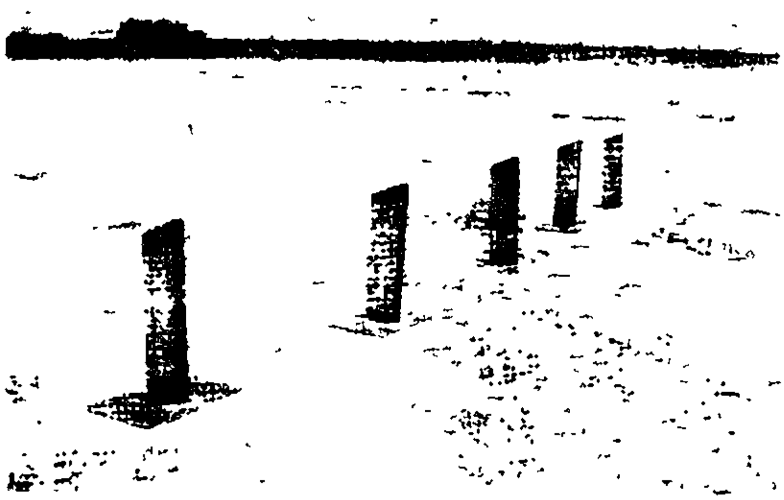

Fig. 2. Collectors for monitoring movement of surface slime dump material.

Materials and Methods

Examination of the material of Kleman's slime dump indicated it was pre-eminently erodible with its high proportion of find sand (Table 1).

Readily available rock fragments were mullock of average diameter 4 cm. This was spread in four treatment plots each 25 m x 50 m separated by 25 m wide untreated areas (Fig. 1 and Table 2). The treatment plots were aligned with the longer axes parallel to the direction of Kalgoorlie-Boulder.

Table 1. Particle size analysis of Kleman's dump material

Percentage				
Gravel	Coarse Sand	Fine Sand	Silt	Clay
0	9	82	4	5

Table 2. Mullock treatments

Drag coefficient (Cf_o in Equation 1)	0.4	0.8	0.4	0.8
Area covered	All	All	1/3 strips*	1/3 strips
Weight mullock (t/ha)	30.6	8.5	10.2	2.8
Fraction of continuous covering	1/19	1/67	1/56	1/200

* aligned across treatment plots.

Effects of the treatments were monitored by uni-directional soil collectors (Fig. 2). Material collected was removed for weighing after three to fourteen days or more depending on the winds and dump surface conditions over the collecting period. The material comprised both saltating and surface creep components with the suspended component negligible. No attempt was made to monitor atmospheric dust as affected by the treatments because the untreated source area (the remainder of the dump and surrounding dumps) was three to four orders of magnitude greater than the treated plots. Five collectors were placed about the midline at each of four positions in each plot: the leading edge, a quarter and halfway downwind and at the trailing edge.

Monitoring was carried out over five periods preceding placement of the experimental treatments of mullock. Control, untreated plots were monitored both prior to and following placement of the experimental treatments. The entire experiment, including the pre-treatment monitoring phase, was carried out from December 1975 to February 1977.

Fullscale treatment of Chaffer's dump, with an area of 40 ha, was accompanied by similar pre and post treatment monitoring from September 1976 to April 1978.

Results

Experimental Treatments

The results are expressed in terms of g dry weight of soil moving over a cm of front each 24 hr day. The average amount of soil moving over each collecting period ranged from 0.4 g/(cm.d) to 40 g/(cm.d). Results from collecting periods allowed relationships between treated plots and the control plot to be established (Table 3).

The change in the relationship of soil movement on experimental and control plots before and after treatment can then be used to calculate the effectiveness of the treatments under conditions of slight, moderate and considerable soil movement (Table 4).

The effectiveness of the mullock treatments corresponded to theoretical expectation; namely that the greatest control would be obtained by the most dense treatment and that effectiveness would decrease rapidly at the less dense treatments. The variability in estimates for periods of slight soil movement indicates that results obtained at such low rates of soil movement are unreliable for assessing treatment effectiveness. The slight decrease in relative effectiveness apparent with increasing soil movement is not expected on theoretical grounds and may be due to experimental error of the data used to establish the treatment plot/control plot relationships.

Fullscale Treatment

On the basis of the experimental results, similar mullock was applied at the most dense treatment rate on Chaffer's slime dump. The average amount of soil moving over each collecting period on Chaffer's west dump ranged from 0.1 g/(cm.d) to 44 g/(cm.d). Results from that application are given in Table 5.

The effectiveness of the mullock treatment was greater on the fullscale treatment than on the experimental plots. This probably indicates the reduced effectiveness on the smaller experimental areas due to edge effects.

Observations made on occasions of extreme dust conditions showed virtually no dust generation from the treated area on Chaffer's dump (A. Curnow, February 1977, personal communication).

The results obtained so far form the basis for continuing application of the treatment to dump surfaces; for exploring treatment effectiveness using material of small particle size and for establishing relationships between

Table 3. Relationships of soil movement on experimental and control plots

Treatment* (t/ha)	Before Treatment# a	b	r^2	After Treatment a	b	r^2
30.6	1.795	-0.384	0.90	0.687	-0.462	0.97
8.5	1.103	0.766	0.99	0.877	0.437	0.99
10.2	1.046	-0.204	0.98	0.771	0.674	0.95
2.8	0.938	-0.389	0.99	0.869	0.516	0.95

* See table 2

\# Regression of form y = ax + b

Table 4. Effect of Mullock treatments on soil movement (percentage reduction)

Treatment (t/ha)	Soil Movement {g/(cm.d)} Slight 0.25	Moderate 2.5	Considerable 25
30.6	124	69	62
8.5	37	25	21
10.2	-1395	-8	23
2.8	-573	-37	4

Table 5. Effect of fullscale application of mullock on soil movement

Before Treatment a	b	r^2	After Treatment a	b	r^2
1.286	0.155	0.99	0.198	-0.178	0.96
Soil Movement {g/(cm.d)}			0.4	4	40
Percentage reduction			115	88	85

surface movement of material, windspeed, surface conditions and atmospheric dust load. The effectiveness of habitat modification using a combination of rock fragment treatment and contour furrowing in promoting the establishment of vegetation is also being assessed.

Discussion and Conclusions

The theory on which the experimental treatments were based was originally developed for prediction of erosion hazard consequent upon grazing rangelands (Marshall, 1970). The experimental results from applying mullock to slime dumps at Kalgoorlie-Boulder indicate the applicability of the theory in developing a workable method of controlling dust generation. The results also add to a growing body of evidence supporting the applicability of the predictive theory in the field. The significance of this is that, as far as is known, predictions are unrestricted to the type of non-erodible material and can thus adapt to whatever material is locally available. For example, calculations have been made for dust control coverings of car tyres, smelter slag, ironstone aggregates and rye-grass (*Lolium rigidum* Gaud.) for different densities and heights depending on fertiliser application.

Acknowledgements

Thanks are due to members of the Goldfields Dust Abatement Committee for support of the experimental programme and to members of the W.A. Forests Department and Department of Agriculture for installing, and maintaining the experiments and collecting material from the monitoring gauges. David Briegel of the CSIRO Division of Land Resources Management processed the material from the collectors.

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Establishment and Management of Vegetation on Mine Waste and Land Adversely Affected by Iron Ore Mining Operations in the Pilbara

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Abstract

The establishment of vegetation on land adversely affected by iron ore mining in the Pilbara is regarded as the most practical method for stabilization. In the absence of a foreseeable land use for these areas, a native plant community is favoured as the ultimate vegetation type. In the Pilbara, high temperatures and aridity are the major obstructions to vegetation establishment. Native species have the capacity to survive under these adverse conditions, but assistance during establishment, followed by suitable maintenance for an initial period, is required.

Work being undertaken and proposed for assisting vegetation establishment in the Pilbara is described, with particular reference to that by Hamersley Iron Pty. Ltd. at their sites of Dampier, Tom Price and Paraburdoo. The work is being done on a large scale to enhance site aesthetics and dust suppression, while being designed to provide data on vegetation establishment procedures.

Introduction

Definition of Areas

Vegetation work associated with mining involves both mined and non-mined areas. Mined areas are those commonly regarded as requiring vegetation, but in the Pilbara bare areas associated with ancillary facilities are also regarded with priority. Ancillary facilities include the port, railway constructions, mine plant areas and related borrow pits. Areas requiring vegetation may occur naturally, or result from the activity in establishing and operating these facilities.

The mined areas to be considered for vegetation are briefly: the ultimate pit floor, waste dumps and, where secondary processing occurs, tailings dumps. These resultant areas of mining are considered long term vegetation prospects due to the nature of the mining operation. Since the ore body is a high grade deep deposit and is mined by open cut methods, there is relatively little waste removed. Overall about one half of the material removed is dumped, with about one half to one quarter of this being waste and the rest low grade ore. It is therefore found that waste dumps are 'live' for long periods and cannot be worked on. Similarly the pit floor is inaccessible until production has ceased. Thus, large scale vegetation work on areas directly affected by iron ore mining is not possible in the immediate future on many sites. One site where this is possible is at Newman where mining operations in some sections of the mine have been completed.

One aspect of the mining operation which does lend itself to immediate rehabilitation work is detrital mining. This is where flat areas are excavated and screened for the detrital rock, either for the iron ore content or for use in construction work. These areas, although being of a different nature to the main ore body, represent short term operations for revegetation.

Why Vegetation?

This question of vegetation or revegetation has often been posed with the pros and cons being bantered about *ad nauseum*. Briefly, in the Pilbara no subsequent land use is envisaged for the area after mining. However it is Hamersley Iron's opinion that the mined or disturbed areas should be stabilized to a condition similar to the present natural surroundings. Vegetation provides a means of stabilization, which is not subject to erosional forces as chemical or physical stabilization methods are, and is aesthetically compatible with the natural surroundings.

Vegetation work in the Pilbara does not lead to land improvement, and hence a subsequent monetary gain is not foreseen for this work. It is therefore not desired to outlay excessive expenditure on this. With this restriction in mind, the experimental programme has been implemented to provide short term benefits while testing long term solutions to vegetation problems. That is, area stabilization, dust suppression, and general site aesthetics can be achieved while the knowledge for cost efficient vegetation work is ascertained.

Climate

The work outlined in this paper is centred on the experience of the authors at the Hamersley Iron Pty. Ltd. towns of Dampier, Tom Price and, more specifically, Paraburdoo. To bring these into perspective, their basic climatological parameters are given in Table 1, with locations shown in Fig. 1.

It can be seen that the major environmental stresses imposed on the vegetation are those of high temperatures and aridity. Paraburdoo exhibits the most extreme conditions with summer temperatures ranging from 27° to 41°C, winter temperatures from 12° to 24°C, and an average annual rainfall of 291 mm.

Table 1. Climatological parameters at the Hamersley townsites

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Parameter (Averages)	Dampier (Coastal) *												
Maximum temperature (°C)	37	36	35	35	29	26	27	29	30	33	36	33	-
Minimum temperature (°C)	26	27	26	22	18	14	14	15	17	20	23	26	-
Rainfall (mm)	38.0	44.2	76.1	6.6	27.4	37.0	13.9	10.3	0.7	1.4	1.6	19.0	276
Evaporation (mm)	361	318	314	296	235	193	195	230	292	353	369	377	3533
	Tom Price (291 km inland, 755 m a.s.l.) **												
Maximum temperature (°C)	37	36	34	30	26	23	22	24	28	31	35	37	-
Minimum temperature (°C)	24	23	22	18	14	11	10	11	14	17	20	24	-
Rainfall (mm)	58	61	70	27	29	47	17	17	5	7	20	74	432
Evaporation (mm)	339	256	244	213	160	134	150	189	244	315	351	323	2918
	Paraburdoo (320 km inland, 366 m a.s.l.) **												
Maximum temperature (°C)	41	41	38	34	28	25	24	26	31	34	38	41	-
Minimum temperature (°C)	27	26	25	21	15	12	12	12	15	19	23	27	-
Rainfall (mm)	47	33	45	15	19	39	19	9	5	6	12	42	291
Evaporation (mm)	400	357	300	262	206	152	157	214	282	300	387	353	3270

Source of data * Dampier Salt Ltd, ** Hamersley Iron Pty. Ltd.

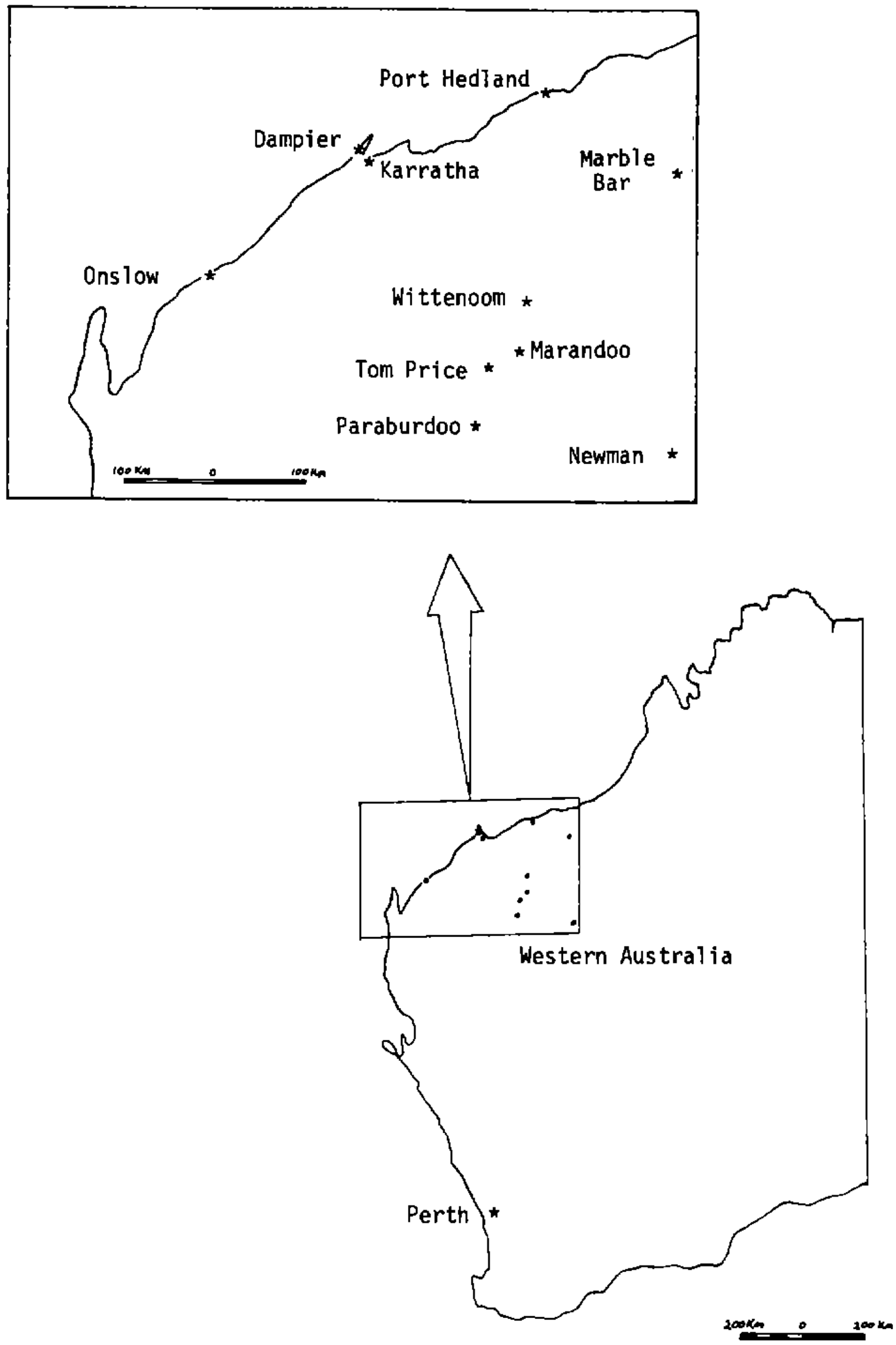

Fig. 1. Location of Hamersley Iron Pty. Ltd. townsites in the Pilbara region of W.A.

Initial Work

Liaison

One of the most important preliminary objectives in a vegetation programme is to develop a liaison with the people on site. This is most important in the present day due to the defensive attitude mining companies have adopted towards environmental activity as a result of the antagonistic actions of certain environmental groups. For successful revegetation work, the approval and support of the mining personnel, from managerial status to labourer, must be gained. This is normally forthcoming once the object of the programme is outlined and not confused with environmental impact work. It must also be considered that sceptics to the need and success of vegetation work will always remain.

It has been our experience that once vegetation work has commenced around working areas, and the benefits from this seen, the personnel become more amenable to it. Initial action is therefore focused on these areas. Apart from the benefit of gaining quick acceptance, this approach also allows the vegetation workers to gain some practical knowledge of the methods and local conditions in areas which are easily accessible and have water available.

When liaising with mining personnel for equipment and tradesmen utilisation, it must be remembered that the object of the mine is ore production. Hence the use of these machines and tradesmen must be coordinated with the mining operation. Where there is an alternative demand, delays will occur and these must be considered as part of the vegetation programme and allowed for.

One further consideration with regard to liaison is the establishment of vegetation on areas which may be mined, remined or in some way developed in the future. The establishment of vegetation on these areas is not favoured by mining personnel, as there may be objections to its subsequent removal. These objections need not occur because the vegetation should have fulfilled a short term function and its subsequent removal, though unfortunate, should not be resisted if it is necessary. The functions which the vegetation had fulfilled would be those of short term stabilization, aesthetics, and the provision of information for the long term programme. To prevent wasted exertion as would occur if the development followed too soon after vegetation establishment, liaison with the Long Term Planning Section of the mine is necessary.

Base Surveys

Before vegetation work is commenced, it is important to gain an understanding of the local vegetation and area characteristics. This is achieved by undertaking base-line vegetation and edaphic (soil) surveys and by collating basic geological and climatological data available for the area.

The major vegetation work being undertaken by Hamersley Iron is at Paraburdoo. Extensive field work has been done, concentrating on botanical and soil surveys, with work also covering zoological aspects and plant diseases.

The botanical and soil surveys were approached by laying out transect lines across topographical variations in the area surrounding the mine. Sample sites were then arranged along these transects and the floristic composition of each site analysed. Soil samples were taken and later analysed for: elemental content, pH, conductivity, cation exchange capacity, mechanical composition and organic content. The data gained from the floristic and soil analyses was then analysed in a computer study (using Principle Component Analysis) to determine sites of similar floristic content, and correlations found between these. Topographical parameters, such as slope, aspect and water accumulation - runoff characteristics, were also included in the analysis.

From this overall analysis, the vegetation types, distribution and possible reasons for existence can be ascertained. This information then provides valuable assistance in vegetation work.

Firstly, by doing the same physical or chemical tests on the vegetation site it is possible to determine the species composition which could occur naturally on that site. These native species have an established capacity to survive under the existing environmental conditions found on the vegetation site, and will blend in with the local flora to give an aesthetically integrated appearance.

Secondly, by doing a complete chemical analysis of the vegetation site, and comparing the results to the regional soil analysis data, possible chemical alterations in the form of pH changes or fertiliser additions can be hypothesized.

These two points, however, need to be tested by nursery pot or, more preferably, field plot trials. At Paraburdoo, a pot trial is being undertaken using mine waste and river sediments, and a field trial is being prepared on the *in situ* mine waste. These trials are aimed at determining plant survival and growth in the waste material, and also fertiliser requirements.

The botanical survey at Paraburdoo was carried out during the summer. By doing this, only the perennial species are considered as these are most desired for vegetation work. Certain seed collecting techniques, such as topsoil spreading or vacuum collection, to be discussed below, will introduce the annual population to the area. This is favoured for the establishment of a more complete and ecologically stable vegetation community.

In establishing a community of local species, it is not necessary to utilise only those species indicated by the floristic survey. Observations of natural regeneration on disturbed areas about the mine site have indicated those species acting as natural colonizers, or primary succession species, in these areas. At Paraburdoo, Tom Price, Newman and Marandoo, disturbed areas such as road and rail verges, borrow pits and gravel heaps have been invaded by various *Acacia*, *Cassia*, *Maireana* and *Ptilotus* species as well as the common *Petalostylis labicheoides* R.Br. and *Salsola kali* Linn. (locally known as Tumble Weed).

These species are also relatively dust tolerant and hence provide a suitable initial vegetation for stabilization and protection for other species. Colonizer species are short lived and will eventually die out, but leave a seed source. These colonizers are usually replaced by the more stable species of the undisturbed vegetation types.

Once the species have been selected for vegetation work, field studies can then further elucidate their growth and reproductive requirements. At Paraburdoo, studies such as these are in progress on some of the local species. Growth recordings are taken each month, and flowering and fruiting observations made. This information is then correlated with climatological data. From these relationships, seasonal and rainfall influences are revealed and this information can be helpful in vegetation programmes by indicating optimum watering periods for growth and seed set.

Another field study which may provide useful information for vegetation work is an analysis of the spacing of native plants on undisturbed areas. Such techniques as 'Nearest Neighbour Distance' provide a naturally occurring plant density estimate which, if used in the vegetation programme, is likely to be related to ultimate plant survival and spacing once artificial watering is removed. Natural plant density estimates can also influence the desired ripping spacing, planting density and planting pattern.

Preparation

It is important at the onset of a vegetation programme to determine the operations which are going to be the most time consuming. Three such operations are evident from our experience: area ripping, connection of a water supply and the ordering and transport of materials. These vary greatly from site to site. For example, at Dampier the availability of a bulldozer for ripping is very limiting, whereas at Paraburdoo, where heavy machinery is more common, this is not a major problem.

To alleviate the two on-site problems, those of ripping and plumbing, liaison is important, with suitable forewarning being given for co-operative planning. With the ordering of supplies, it is necessary to be organised at an early date. Areas to be revegetated must be identified, measured and the method outlined. Equipment quantities can then be gauged and orders sent, to be processed while other aspects of organisation and the initial work are undertaken.

Experimental Work

Experimental work in vegetation studies primarily involves the testing of selected plant species against suspected site problems for plant establishment, growth and long term survival. Site problems are those indicated by the initial survey work and may be related to regional environmental conditions, or site specific factors, particularly those related to the growth medium. The testing of these potential problems is best done on-site, and more specifically as field trials. Pot experiments and off-site glasshouse experiments yield information, but the information is often limited in its applicability.

Species selection should be based on the desired ultimate land use, but is often influenced by the propagating material availability at the time. As mentioned above, no definite future land use is envisaged for the Pilbara mining areas and hence a return to a native plant and animal community is desired. Thus our botanical survey has been used as one of our initial species selecting methods.

It is not always possible, however, or even advantageous, to begin the revegetation work using only those species identified by a regional botanical survey. Much of the initial experimental phase may be only of use in defining the site problems more accurately rather than solving them. The use of commercially available seed, or quick growing species, could help to more readily and rapidly move through this phase.

The perennial species of the undisturbed Pilbara regions are characteristically slow growing and may not produce the quantities of seed required at the time of the experimental work. The use of the faster growing and more prolifically seeding pioneer plants, or non-local species, could therefore be very beneficial for initial phase revegetation work.

At Newman, an agronomic approach was taken for the initial work, where commercially available tropical and temperate grass and legume species were used for trials on the mine areas. This work has since been expanded into the use of natives, in particular the salt-bushes, with the grass-legume vegetation being used as a protective crop, and subsequently as a mulch for the shrub species. Descriptions of these trials are given in Riches *et al* (1978).

Hamersley Iron Work

Two facets are seen to the vegetation research of Hamersley Iron. The long-term objective is ultimate site rehabilitation which is usually not possible on these sites for some time. Our short term objectives include aspects of immediate improvement of site aesthetics, dust suppression and erosion control. At the Hamersley Iron sites, where possible, vegetation experimental work is undertaken to comply with short term objectives, but also to provide data aimed at the long term result.

At Paraburdoo, experimental work is being undertaken on a large scale on non-mined, barren areas, about the mine plant. These areas were either previously bare or were affected to some degree during the establishment of the mine. Wind movement across these areas causes dust evolution, and the absence of vegetation prevents the trapping of windborne dust. Hence the establishment of vegetation here is aimed at the short term aspects of preventing dust emission and forming dust breaks, as well as general site aesthetics.

The species used for the initial work at Paraburdoo include some local species, some regional species and a range of Forests Department species. These latter species, predominantly *Eucalyptus*, are considered suitable for use in arid areas from work done in such centres as Kalgoorlie, but are generally non-Pilbara species. The supply of these plants, however, has facilitated the large scale nature of initial work which will be effective in site aesthetics and dust control. These species are fast growing and will therefore give rapid benefit, and also the range of species will produce a more diversified appearance rather than the mono-specific use of the local rivergum *Eucalyptus camaldulensis* Dehn.) as has happened in the past.

The experimental design of the work at Paraburdoo is aimed at determining the most efficient and effective watering methods, water quantities and planting procedures, as well as testing different species for drought and dust tolerance. Planted areas have different ambient dust levels, and are supplied with a range of water quantities. Plant heights are recorded for growth measurements. It is anticipated that the non-local, and hence less adapted, species will exhibit an increased mortality rate under adverse conditions of dust and water stress, and will thus provide an enhanced visible indication of these conditions.

Our results so far of drought effects on newly planted seedlings have indicated that, even when pre-hardened in the nursery, it is necessary to provide excessive water prior to, and after, planting the seedlings to gain successful establishment. A twelve hour pre-soak and at least one week of post-planting watering at three times per week, and twice a week watering for a month, is necessary. This pre and post-planting watering regime has been found to be important in both the summer and winter.

The dust suppression work being done by Hamersley Iron (for example at Dampier around the Pellet Plant) has mainly utilised tall trees for height and lower trees and shrubs for a hedge effect. These plantings have been largely local species but since the local tall trees, such as rivergums, are valley species, and only low species are found on the hills, it has been necessary to use some non-local plants. The characteristics needed by trees for this work are: height, tolerance of dust, and drought resistance. Such species as the Coolibah, (*Eucalyptus microtheca* F.Muell.), the Kurrajong (*Brachychiton* sp.) and Wild Fig (*Ficus* sp.) have shown great dust tolerance.

A mixture of buffel (*Cenchrus ciliaris* L.) and couch grass (*Cynodon dactylon* (L.) Pers.) is recommended for stabilization and dust suppression. Couch has the advantage of being able to germinate during the winter whereas the buffel is solely summer germinating. Buffel has the advantage of greater drought resistance over the couch grass.

The use of grass species at the Paraburdoo mine site is restricted because of their palatability to the free ranging cattle, which are a problem at this site. A cattle fence is to be erected for control.

Slope stabilization poses another specific problem for Hamersley Iron. Fortunately, the steep slopes of the waste dumps are not incongruous with the surrounding topography and therefore expensive earth movements can be avoided. These slopes are approximately 38 degrees and therefore pose a stability problem for plant establishment. Some work using the Mile-a-Minute creeper (*Ipomoea pes-caprae* (L.) R.Br.) and buffel grass on embankments at Dampier has proven successful in forming a complete and stable cover. On a waste slope at Paraburdoo, *Ipomoea* has also been successful in stabilization. Creepers planted about the top of the bank have grown down the 7 m slope providing complete coverage. Rooting at leaf nodes stabilizes the slope as runners continue to develop down the slope.

Future Work

The research planned for the immediate future involves extension of water relations work to a greater number of local species, and for this work to be carried out on the mined areas, or mined material. Extension of the work on slopes will be incorporated with various creepers such as the Seven Year Bean and Jack Bean (*Canavalia maritima* (Aubl.) Thovars) being used with the *Ipomoea* in stabilization trials.

When work commences on the waste slopes (as water becomes available), fertiliser trials will also be included as the soil analyses have corroborated the assumption that this material is very deficient in nutrients. Related studies on the nitrogen fixing properties of the native legumes will also be undertaken. The species to be considered include leguminous creepers and *Acacia* and *Cassia* species.

One species at present being used at Dampier for vegetation work which is showing promise as being a very suitable species for use at other sites, is *Sesbania bispinosa* (Jacq.) Fawcett *et* Rendle. This is a quick growing annual, attaining a height of about 2 m. It produces copious seed which are easy to harvest, and is a legume having substantial root nodulation. Nitrogen fixation analyses on this species are hoped to determine its capacity for nitrogen input and further tests on its potential as a primary colonizer are planned.

Seed collecting and dispersion methods are also under investigation. The use of a vacuuming apparatus, as used at other sites, is foremost in consideration. It is hoped to be able to use the vacuum machine on similar natural areas as those to be revegetated so that the appropriate complement of seed and micro-organisms can be transferred to the site. Then by reversing the vacuum it is hoped to be able to distribute this over the site. The same result as with the spreading of topsoil is expected to be achieved, but in a more economical and convenient way, without greatly disturbing the natural areas from which the seed is obtained.

Conclusions

The aim of vegetation or revegetation work is to produce a self perpetuating plant community for stabilizing barren areas. As continued management is not desired by the companies concerned, the management programme during, and after, plant establishment needs to be orientated towards producing hardened plants, capable of unaided survival. Correct species selection trials, from the base surveys to the experimental stage, are therefore paramount to successful vegetation work.

Adroit usage of water, as determined by the experimental work, will aid in producing deep rooting patterns and hardened plants. The water supply can be gradually reduced until no artificial watering is required. For better growth and increased survival, however, occasional watering, for instance during dry summers, can be implemented. Where the vegetation is being used for a purpose other than ground stabilization, continued watering is desired for optimal growth, as in the production of dust breaks.

The vegetation programme can be seen to progress through several stages:

* Development of a liaison and sympathetic relationship with the mining personnel.
* Outlining the potential problems facing the programme by conducting base-line regional vegetation and environmental studies.
* Determining site problems, which may be biological, physical or chemical.
* Providing solutions to these problems, both in the short term and the long term by experimentation.
* Provide a self-maintaining vegetation when the mining programme is finished.

Reference

Riches, J.R.H., Jones, H. and Boughton, T. (1978) Rehabilitation experiments at Mt. Whaleback (These proceedings).

Rehabilitation Experiments at Mt Whaleback.

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Abstract

The objective of rehabilitation experiments at Whaleback was to develop an efficient, practical and economical method of accelerating native vegetation establishment on abandoned waste dumps. Climatically the environment is harsh with extreme summer heat and low, unpredictable rainfall. The waste dumps are sterile, unweathered blasted rock of variable chemical and physical properties. Their normal construction mode often results in severe compaction and salt concentration.

Two basic experimental approaches involved the development of pasture mulch and the importation of native topsoil. Varying degrees of ground preparation and irrigation and a wide variety of native and exotic plant species were experimented with.

The most encouraging results were obtained using native topsoil and the native vegetation cover developed has withstood two years of severe drought without irrigation. The experiments have resulted in a practical technique for rehabilitation using local topsoil stripped in front of the advancing waste dumps. Further work is required to develop native vegetation cover when the finite topsoil resource is exhausted.

Introduction

The paper briefly describes rehabilitation experiments conducted at the Mt. Whaleback Mine of Mt. Newman Mining Co. Pty. Ltd. between May 1975 and June 1978. Relevant internal reports are listed in the reference section at the end of the paper.

The ultimate objective of these rehabilitation experiments is to develop an efficient, practical and economical method of accelerating native vegetation establishment on abandoned waste dumps so that these dumps would be stabilised against wind and water erosion, would trap passing fugitive dust and then become aesthetically more acceptable to the people living and working in the region.

The Mt. Newman Mining Co. Pty. Ltd.'s Mt. Whaleback Mine commenced production in April 1969 and by May 1973 had developed relatively large (70 M t) dumps of waste material, particularly on the south side of the mine. These dumps were the source of fugitive dust. Random, *ad hoc* experimentation took place in an attempt to contain it. Among the techniques attempted was the spraying of native spinifex (*Triodia* spp.) seeds on dumps and the placement of truck loads of native topsoil on the steep slopes of the dumps. These early experiments were of limited success and in the latter stages of 1974 experimental bitumised mulching techniques were used over an extensive area of waste dump but with no success.

A number of alternative ways were considered for implementing more extensive experiments, the two most obvious being:

* to have it all carried out by contract labour and equipment;
* to have it all carried out by in-house personnel and equipment.

The Company did not employ its own graduate agronomist for a number of reasons and it was felt that the technique of utilising proven expertise on a contract basis was more suitable to the very experimental nature of the work, particularly with the high rate of failure of previous experiments.

In early 1975 the Company engaged a consultant company (Dames and Moore) to advise them on establishment of vegetation on the waste dumps. Contact was also established with the West Australian Department of Agriculture for the same purpose.

An organisational procedure was set up within the Company whereby the Environmental Superintendent coordinated the work and liaised with the consultants while the Production Department supplied labour and equipment as required for various programmes. In this way the Production Department's operators were trained by the consultants in the various techniques necessary to prepare the ground, monitor plant growth, water application rates, etc., while the consultants retained overall technical control of the programmes.

It is felt that this method has not only resulted in a more diverse range of experiments and a more rapid training of company operators but has also established the principle that rehabilitation work is the last stage of the normal production operation, proceeding automatically without the employment of any outside earth moving contractors.

As the success of these experiments was expected to be controlled by the effect of the physical environment on the species grown, and the degree to which the environment could be modified, planning of experiments was preceded by surveys of local fauna and flora. Since experimentation began, this data collection program has been expanded to provide data of greater relevance to the revegetation program.

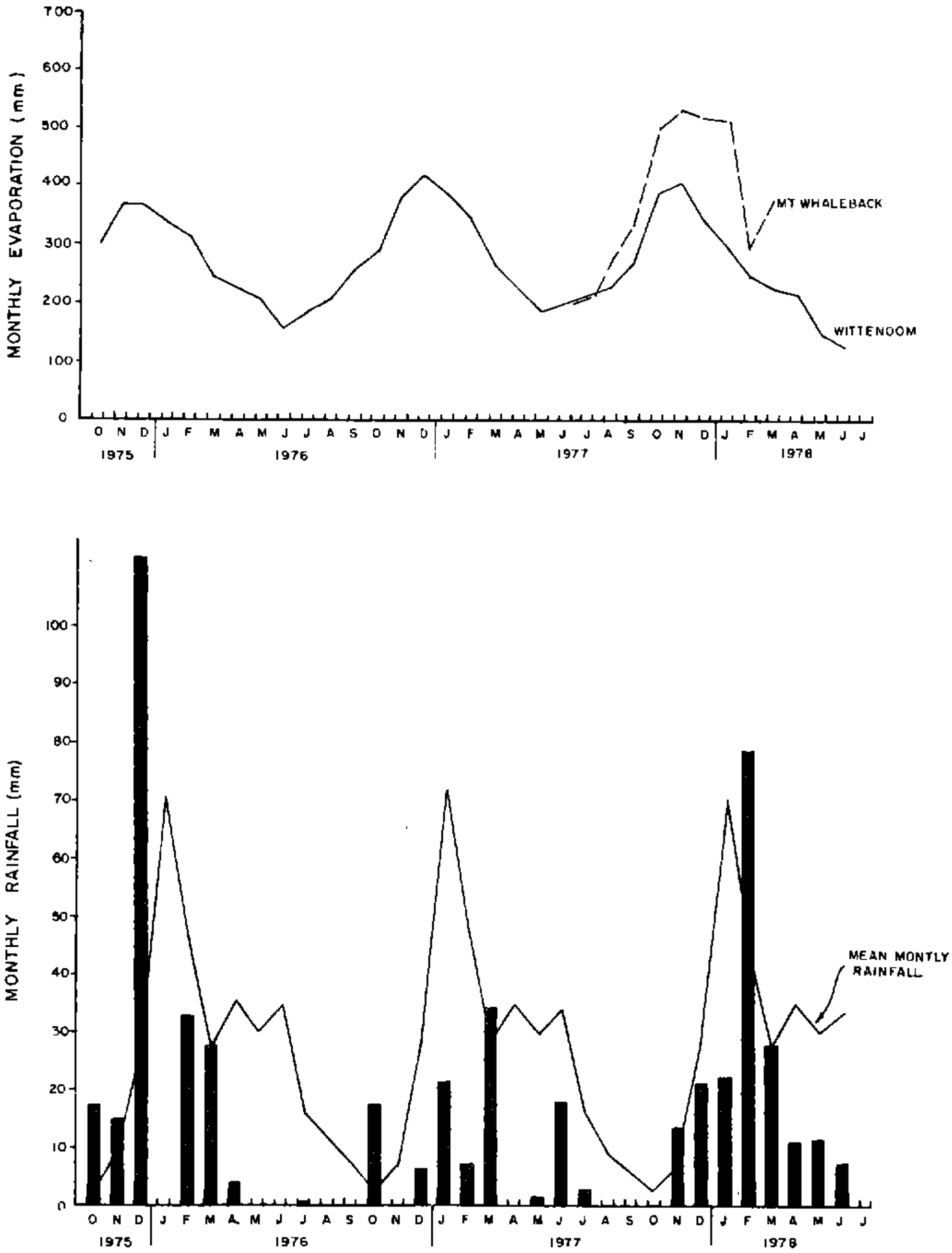

Fig. 1. Climatic data recorded at the experimental areas, Mt. Whaleback.

Description of Mt. Whaleback environment

Climate

Mt.Whaleback is situated 300 km south of Port Hedland at an elevation of approximately 700 m. Fig. 1 summarises the climatic data recorded at experimental areas over the past 3 years. Cool dry winters follow hot summers in which rain associated with tropical cyclones or thunderstorms occurs. Rainfall is unreliable, no significant falls were recorded during 1976-77 when extensive experimental programs were underway. Winds blow most commonly from between the north east and south east, with wind speed below 10 ms^{-1} 90 per cent of the time. Calm periods are extremely rare. Average monthly minimum temperatures range from 24°C in summer to 8°C in winter. Average monthly maximum values range from 39°C to 23°C respectively. Soil temperatures at 30 cm and 120 cm below the surface parallel air temperatures ranging from the low 20's in winter to mid 30's in summer. Variation in temperature of the bare soil surface is likely to be greater than that of air temperature.

Waste Dump Environment

The soil on the dumps is sterile unweathered blasted rock rather than a 'biologically active' surface soil. It varies with the geological origin of the waste. Further variation in soil properties is caused by compaction and concentration of salts on frequently wet road surfaces. These areas have a 30-60 cm compacted crust with physical and chemical properties very unfavourable for root growth.

Physical and chemical properties of the soils used in the experimental work are often different to soils naturally occurring in the area (Table 1). All are gravelly types with the fine material having poor structure. Soil tests suggest that the waste is less fertile than most agricultural soils. Pot trials using cereal rye show that, of the nutrients tested (N, P and Zn, Mo and Cu in No. 1 superphosphate), only nitrogen is deficient. These limited results do not provide definite information about the waste's ability to support plant growth.

The bare smooth surfaces of the dumps are likely to have a more severe microclimate than nearby hillsides as well as being affected by airborne dust loads which have ranged between 0.95 and 6.97 mg m^{-3}. However, other human activities of irrigation and surface roughening may favour plant growth by increasing the water supply as well as locally reducing the severity of the surface microclimate.

Experimental Program

Pasture mulch

One method of seeking to achieve a self sustaining native plant cover is the use of a mulch to improve conditions for colonizing on planted native vegetation. Pasture plants were used to create a mulch on Mt. Whaleback. It was hoped that they would encourage the growth of the natural species by one or a combination of the following -

* reductions in seed and soil loss
* provision of a more suitable microclimate for seed germination and seedling growth
* increases in soil organic matter content
* reduction in airborne dust loads.

The following pasture plants were used: buffel grass (*Cenchrus ciliaris* L.), birdwood (*Cenchrus setigerus* Vahl.), Rhodes grass (*Chloris gayana* Kunth.), molasses grass (*Melinis minutiflora* Beauv.) annual ryegrass (*Lolium rigidum* Gaud.), cereal rye (*Secale cereale* L.), and the legumes Townsville stylo (*Stylosanthes humilis* Kunth.), Verana stylo (*Stylosanthes hamata* (L.) Taub.), Cyprus barrel medic (*Medicago truncatula* Gaertner. *cv* Cyprus), Harbinger strand medic (*Medicago littoralis* Rohde ex Loisel *cv* Harbinger), Tornafield disc medic (*Medicago tornata* (L.) Miller *cv* Tornafield), Geraldton sub-clover (*Trifolium subterraneum* L. *cv* Geraldton), Hykon and Kondinin rose covers (*Trifolium hirtum* All. *cvs*), and Yamina and Beenong cupped clover (*Trifolium cherleri* L. *cvs*).

The stylos were the only species able to grow without irrigation but their density was below that required to form an effective mulch. Rhodes grass formed the most vigorous mulch under irrigation, reaching heights of over 1 m within 6 months of planting. A thick, dense mulch was formed with dry matter yields equivalent to 12 t/ha, active growth continued for the 8 months that regular irrigation was given. Buffel grass and birdwood grew in the Rhodes grass sward and all three grasses set seed.

When irrigation was stopped all mulch plants died off. With heavy summer rains a year later, very little new germination occurred, green growth among the old mulch being limited to regrowth of buffel and birdwood grasses from established root systems.

In areas where the agricultural legumes (clovers and medics) had successfully grown and set seed when irrigated, heavy summer rains one year later caused the germination of only one species (Cyprus barrel medic). Although these seedings were nodulated, indicating that the *Rhizobium* bacteria were able to survive in the soil, they were very stunted.

Table 1. Physical and chemical properties of the soils at the experimental areas, Mt. Whaleback.

(a) Physical Properties

Soil Type	Particle Size Analysis (%)					Water Retention of Gravel (%)		
	Gravel	Coarse Sand	Fine Sand	Silt	Clay	Water Content @-1/3 atm.	Water Content @-15 atm.	"plant available water"
Compacted saline waste (old road)	33	30	16	19	2	*	*	*
Ripped road surface	40	33	17	9	1	14.2	6.0	8.2
Waste	55	23	12	9	1	17.0	6.6	10.4
Scrub soil	52	34	7	7	0	13.4	7.2	6.2
Jaspilite waste	44	36	12	4	3	5.3	2.3	3.0
Shale waste	26	29	18	21	6	18.2	3.0	15.2
Natural scree slope	18	17	46	8	11	9.8	5.7	4.1

(b) Chemical Properties

Soil Type	pH	exchangeable cations (meq/100g)				
		C.E.C.	K	Na	Ca	Mg.
Jaspilite waste	8.1	2.2	0.13	0.17	0.90	0.71
Shale waste	6.9	1.4	0.06	0.09	0.30	0.43
Natural scree slope	5.8	4.6	0.23	0.09	1.60	0.58

(c) Nutrient Status

Soil Type	Nutrient (p.p.m.)					
	Cl	HCO_3P	K	Initial	Nitrate (NO_3) Released by incubation	Total
Compacted saline waste (old road)	1120	5	199	42	0	42
Waste	183	9	90	18	0	18
Scrub soil	95	3.5	252	8	3	11

* not done for this soil.

All the mulches grown were able to prevent soil erosion and trap airborne dust. A thin layer of dust was trapped on the leaf surface and a 1 cm thickness had accumulated on the soil surface. Although no microclimate data has been collected, it is thought that even the reduced mulch remaining 18 months after planting would have formed a less severe microclimate at the soil surface.

Topsoil

An alternative technique was to spread freshly collected topsoil and irrigate it so as to germinate and establish the contained native seeds.

This technique was initially developed as a method of quickly screening a wide range of native plants for their suitability/

adaptability for growth on the waste area stockpiles as it effectively overcomes the problems associated with lack of knowledge of which native species are suitable for a particular site, the collection of native seed, and the subsequent germination of that seed in a nursery.

Two trials have been carried out at Mt. Whaleback using topsoil. Trial I was designed to investigate the effect of irrigation and ground preparation on the germination and establishment of native species while Trial II was designed to investigate the effect of topsoil source and the quantity of irrigation on the establishment of native species. Two sources of topsoil were used:

* alluvial soil adjacent to a creek line which carried a vegetation of *Triodia pungens* R.Br. with an overstorey of *Eucalyptus trivalvis* Blakely and *Eucalyptus gamophylla* F. Muell.;
* hillside scree slope soil which carried a dominant cover of *Triodia angusta* N.T. Burbidge with a few inconspicuous *Maireana georgei* Diels. and isolated trees of *Eucalyptus leucophloia* F.Muell.

Topsoil from each source was spread into discrete strips 30 m x 5 m and each strip was given three irrigation treatments as shown in Fig. 2. The treatments were:

* six weeks watering.
* six months watering, with watering at monthly intervals after the initial six weeks.
* six months watering, with watering at weekly intervals following the six weeks establishment.

Thereafter, in each case, artificial watering ceased.

Results

The two trials showed results in close agreement and are dealt with together.

Plant Density

In irrigated plots initial densities were high, 5.8 plants/m^2, compared with 1.7 plants/m^2 in the non-irrigated plot (despite the fact that the non-irrigated plot received 110 mm of rain from cyclone Joan in December 1975 six weeks after topsoil spreading).

Densities of 2.4 plants/m^2 on hill soil and 3.1 plants/m^2 on valley soil were recorded on the heaviest irrigation treatments in Trial II. With time there has been a reduction of density in all plots on both Trials I and II, the largest reduction of density occurring immediately after irrigation ceases. This is shown diagrammatically for Trial I (Fig. 3).

Except for the following: *Maireana georgei*, *Cassia pruinosa* F.Muell. and *Cassia leurssenii* Domin., all species in Trial II suffered a reduction in number of plants/species/plot.

Species Present

Tables 2 and 3 show species found in the plots of Trial I and Trial II respectively.

Table 2. Species present at March 14, 1978, in Trial I, Mt. Whaleback. (Numbers of plants per plot given). Alluvial topsoil.

Species	Irrigated	Non Irrigated
Acacia bivenosa DC.	47	81
Acacia ancistrocarpa Maiden and Blakeley	-	3
Acacia tetragonophylla F.Muell.	1	7
Acacia sp.	3	5
Cassia oligophylla F.Muell.	1	5
Cassia pruinosa F.Muell.	3	1
Cassia leurssenii Domin.	2	6
Petalostylis labicheoides R.Br.	19	37
Glycine sericea (F.Muell.) Benth.	1	-
Ptilotus exaltatus Nees.	1	31
Ptilotus obovatus Gaud.	1	2
Gossypium robinsonii F.Muell.	2	1
Eucalyptus gamophylla F.Muell.	1	-
Corchorus sp.	1	3
Salsola kali Linn.	-	1
Maireana georgei Diels.	1	4
Enchylaena sp.	-	1
Trianthema sp.	-	12

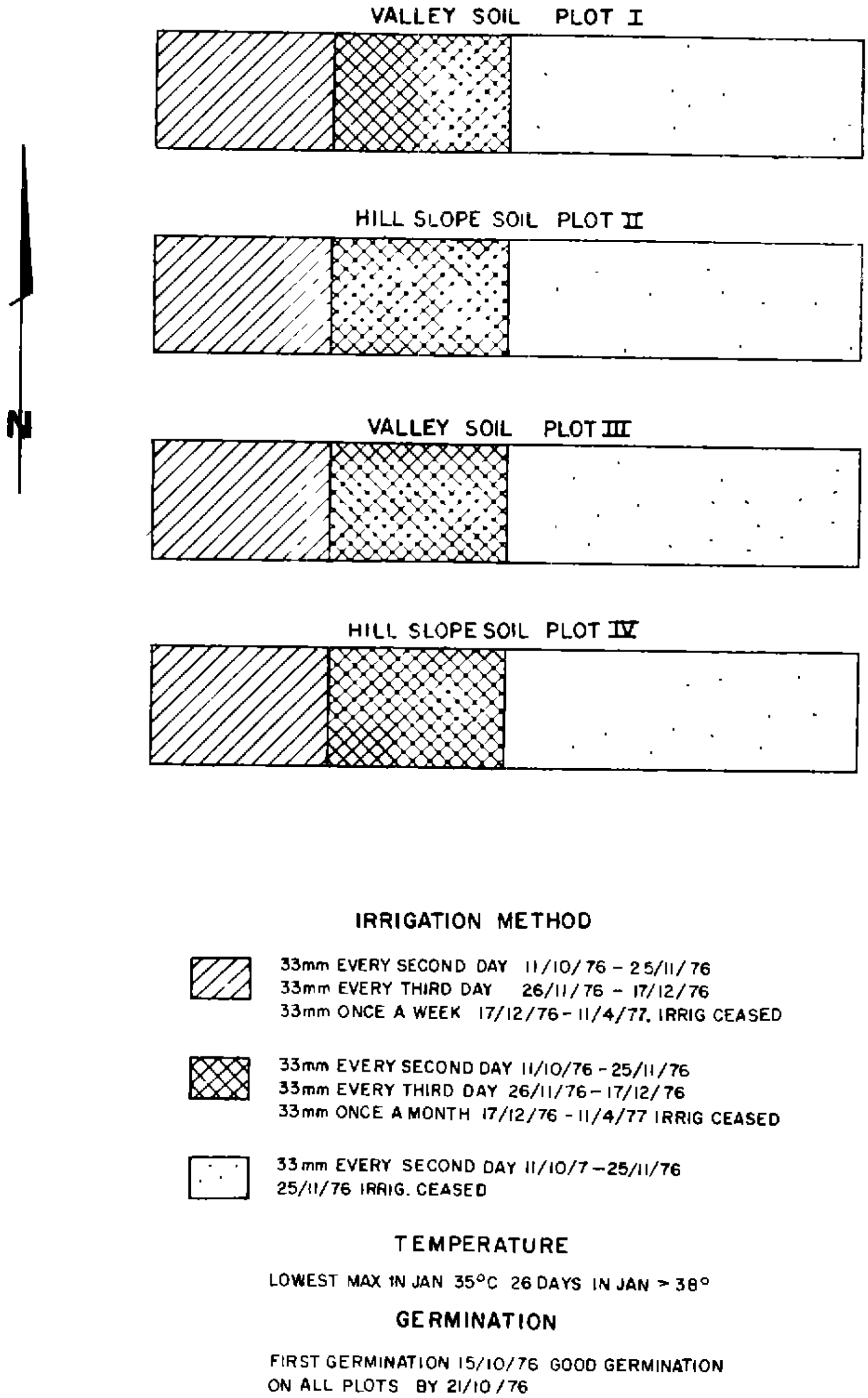

Fig. 2. Layout of Trial II, Mt. Whaleback. To investigate the effect of topsoil source and quantity of irrigation on establishment of native species.

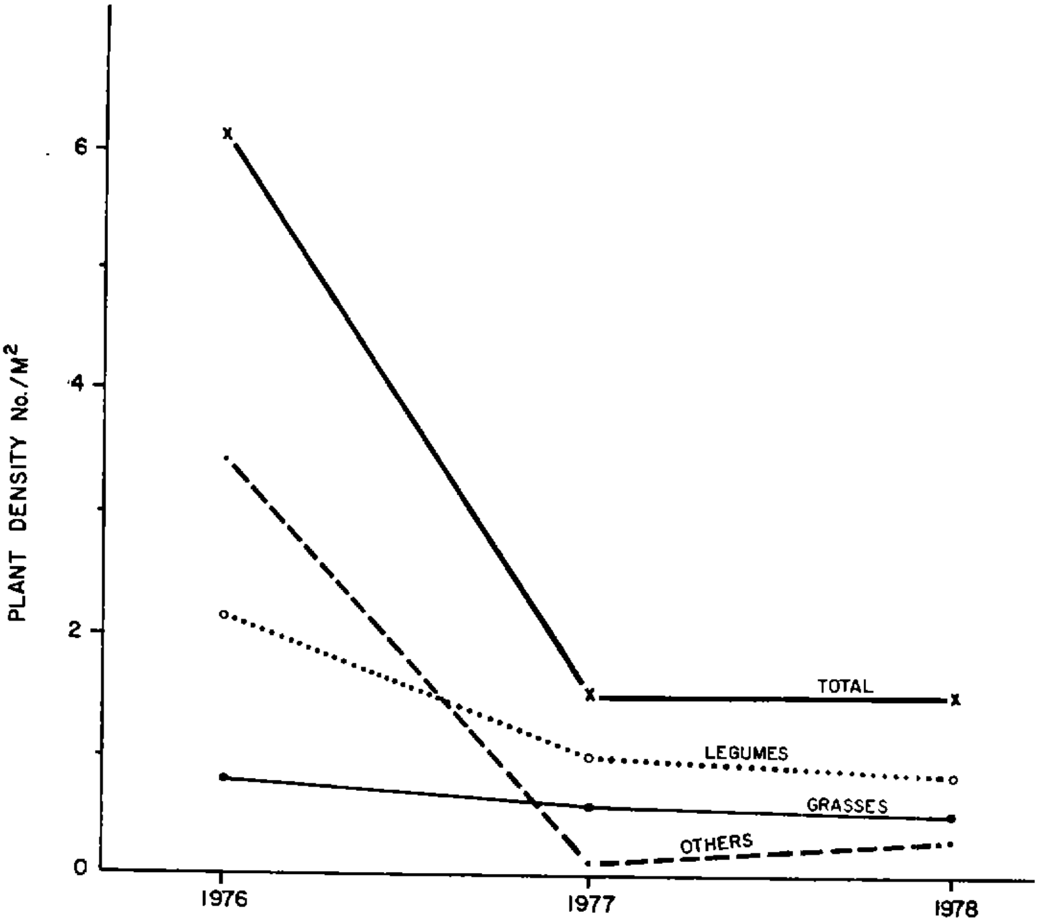

Fig. 3. Change in density of species groups for Trial I, Mt. Whaleback.

In Trial II it has been shown that topsoil source area (hill or valley) has a very important effect, a total of 17 species being mutually exclusive.

Plant growth

The height of all *Triodia* spp. is significantly greater on those plots which received more than 6 weeks irrigation. However there was no statistically significant response in height to additional watering by the *Maireana* spp., *Acacia bivenosa*, or *Petalostylis labicheoides*. Following 50 mm of rain in February 1978 (16 months after planting) a germination of *Maireana*, *Sida* and *Ptilotus* seedlings was noted in the untreated areas surrounding the topsoiled plots.

Ground Preparation

Long term survival of the seedlings was improved by ripping the waste before topsoil spreading. Average heights of *Acacia bivenosa* on ripped areas were significantly higher than ones on unripped sites. Other species (especially *Triodia pungens*) showed higher mortality on unripped areas.

Table 3. Species list for Trial II, Mt. Whaleback.

Irrigated.

Species	Alluvial creek soil	Hill soil
Triodia angusta	-	+
Triodia lanigera Domin.	-	+
Triodia pungens	+	-
Cenchrus setigerus	-	+
Chenopodium rhadinostachyum F.Muell.	+*	+*
Chenopodium sp.	+*	+*
Cassia leurssenii	+	+
Cassia notabilis F.Muell.	+	+
Cassia oligophylla	+	-
Cassia pruinosa	+	-
Maireana georgei	+	+
Maireana melanocoma F.Muell.	+	+
Acacia ancistrocarpa	+	-
Acacia bivenosa	+	+
Acacia dictyophleba F.Muell.	+	+
Acacia sp.	+	-
Ptilotus aervoides F.Muell.	+*	-
Ptilotus calostachyus F.Muell.	-	+*
Ptilotus exaltatus	+*	-
Ptilotus macrocephalus R.Br.	+*	-
Ptilotus obovatus	+*	-
Petalostylis labicheoides	+	+
Solanum horridum Dunal.	+	+
Salsola kali	+*	+*
Tephrosia sp.	+	-
Euphorbia sp.	+	-
Glycine sericea	+*	-
Trichodesma zeylanicum (Linn.) R.Br.	+*	-
Total species	24	15

* These species disappeared following the cessation of irrigation.

Dead remains were observed, in addition to the species listed for Trial II (Table 3), of four additional species for both the alluvial creek and hill soils. These were two unidentified annual grasses and *Chloris* sp. in both, plus *Setaria* sp. on the alluvial creek soil and *Enneapogon* sp. on the hill soil.

Discussion

The pasture mulch was successful at stabilising the ground in the trial area and capturing airborne dust but repeated attempts at establishing native species in the mulch were unsuccessful. Observations suggest that at Mt. Whaleback the growth of a mulch is not a useful stage in the achievement of a self perpetuating natural vegetation type. Studies around Newman and in other areas of the Pilbara appear to confirm that the best germination of native species is found in exposed areas (such as ashbeds or stone mulch areas), while few plants are seen growing under dead shrubs or in spinifex heaps beside newly made roads.

Thinly spreading fresh topsoil on prepared waste ore is a viable method of establishing native vegetation in required areas. Species typical of hillside areas *viz. Triodia angusta*, *Maireana georgei* and *M. melanocoma*, appear most suited to the waste dumps, best establishment occurring where the waste has been prepared by ripping to a depth of at least 1 m at a spacing not more than 3 m between rip lines.

Initial irrigation should be carried out at low intensities using small drop sizes to prevent crusting and so maximise seedling emergence. Irrigation should be limited to the establishment phase, irrigation beyond this period will result in the survival of species unsuited to the natural climatic regime.

Topsoil stripped ahead of advancing waste dumps is a finite resource. At present this is adequate for the relatively small areas to be rehabilitated in the near future. However, in the overall life of the operation it will not be sufficient to rehabilitate all waste dumps, therefore alternative methods of establishing native vegetation require further investigation. The direct seeding of selected native species into the waste is one such avenue.

This method would allow:

* Improved control of the native species introduced.

* A major reduction in earthmoving requirements (no topsoil introduction required).

* Operations to be carried out on steep slopes currently inaccessible to earthmoving equipment.

Several problem areas must also be resolved for this to be feasible:

* Basic research into *Triodia* spp.

  It is possible, for example, that the viability of *Triodia* seed is related to environmental conditions occurring during seeding. In particular that the germination percentage of seeds formed soon after flowering during moist conditions may be greater than seed formed later in times of water stress.

* The development of mechanical seed harvesting techniques for *Triodia* spp. and other native plants. A major obstacle to the use of *Triodia* species in direct seeding is the difficulty of obtaining adequate quantities of seed.

* Factors affecting the germination of native species under direct seeding conditions.

Conclusions

1. The program has now reached the stage where the Company is adopting these techniques on the broad scale for the revegetation of abandoned waste dumps.

2. With increased knowledge as a result of current and future research, more cost effective techniques are likely to be developed. Further basic research along the lines outlined in the above discussion will be needed before these new techniques can become part of the production process.

Acknowledgement

We are particularly grateful to Mr. K. Walker for carrying out day-to-day operational requirements. The operational diary recorded by Mr. Walker from February 1976 has been particularly valuable. Dr. Roger Black now of Allied Eneabba was intimately involved in the experimental program from May 1975 to May 1977.

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Establishment and Diversity of Jarrah Forest Flora on Bauxite Mined Areas

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Abstract

Establishment of groundcover on bauxite mined areas is important for erosion control. Encouragement of species indigenous to the jarrah forest would be expected to have added conservation value. Comparisons of the effects of various topsoil handling strategies on numbers of emergent volunteer plants were required to assist in achieving these objectives.

Topsoil handling treatment influenced the return of volunteer vegetation on rehabilitated mined sites. Double stripping involved the separate stripping and direct return of the top five centimetres of topsoil over lower layers. This led to increased groundcover compared to direct return of the whole mixed topsoil profile or return of stockpiled topsoil.

Decreasing germinable seed load with topsoil depth was demonstrated. Dilution of the higher seed concentrations at the surface probably explained the lower groundcover establishment rate on directly respread whole topsoil. Rotting and premature germination were considered most likely to account for decreased plant establishment from stockpiled material.

Assessments of frequency of species occurrence and percentage cover were made to assess diversity and likely erosion control capacity of rehabilitated three year old mined sites, compared to forested areas. Forested sites had greater cover and more species present than rehabilitated mined sites up to three years old. The diversity of forested versus mined sites was evaluated in terms of the Shannon-Weiner index. Diversity was similar on forested and double stripped rehabilitated sites. No significant differences in equitability were recorded. Double stripping resulted in a diversity of indigenous jarrah forest species which may have been difficult to achieve on rehabilitated land by other means.

A combination of techniques utilising agricultural species, broadcast native shrub seed and volunteer vegetation from double stripped topsoil may be a promising approach to achieving both short and long term erosion control as well as medium and long term conservation goals.

Introduction

Rehabilitation of bauxite mined land has been carried out within the Northern Jarrah Forest of South-Western Australia since 1966, following commencement of mining operations in 1963 (Alcoa of Aust. 1978).

Rehabilitation is preceded by earthworks to control drainage and decrease pit wall slopes and the return of topsoil to an average 40 cm depth. Contour ripping is carried out to improve subsoil conditions and check surface erosion. This results in the formation of parallel ridges and furrows about 1 m apart with a relief of 15-30 cm.

Several revegetation strategies have been applied, concentrating on the return of a plantation tree overstorey and, more recently, a shrub understorey. Rehabilitation is aimed at establishing stable vegetation systems which satisfy the long term land use objectives of the State Government.

The Western Australian Forests Department has recently listed the following long term land uses as desirable within the Northern Jarrah Forest:

* Water supply
* Wood production
* Recreation and tourism
* Flora and fauna conservation
* Science and education

(W.A. Forests Dept. 1977b)

Rehabilitation methods developed to date have favoured erosion control. Establishment of indigenous groundcovering species would help fulfill conservation and other objectives as well as contributing to long term erosion control.

The work of Hunter and Currie (1956) suggested that topsoil stockpiling led to degeneration of soil physical properties. As well as confirming these findings, Miller and Cameron (1976) have shown that there is disruption of mircobial populations and loss of organic matter. Clarke (1975) has suggested that the value of topsoil diminishes with stockpile age. Such conditions may be deleterious to plant propagules carried over in topsoil. To this end studies were made on the effects of various topsoil handling strategies on a number of emergent volunteer plants.

The concept of low diversity in pioneer stages has long been recognised in the ecological literature. Assessments of species frequency were initiated to gain some insight into the effectiveness of topsoil return as a means of contributing to habitat diversity. Estimates of groundcover were undertaken to assess the potential for erosion control by volunteer vegetation.

Methods

Topsoil Handling

Three topsoil handling techniques were compared. All topsoil sources had been cleared of vegetation several months in advance of stripping. Stockpiled topsoil was stripped to an average depth of 40 cm by scrapers and dumped in an unconfined heap approximately 7 m high, where it remained for approximately two years. On completion of mining this material was respread at the same average depth during 1975. Directly returned topsoil was stripped to a similar depth and directly trucked to a mined out area for immediate spreading in 1974. Double stripping involved the separate removal and immediate respreading of the top 5 cm of topsoil. This material was applied in 1975 over five plots amounting to half the area previously spread with stockpiled material of the same origin as that above. This resulted in a chequer board layout of five plots each of stockpiled and double stripped soil. No plants survived the stripping and respreading operation.

For the directly returned topsoil, numbers of emergent plants were counted on four replicate plots, each of ten one metre squares. Five replicates each of forty squares were counted on the other treatments. Groundcover was assessed simultaneously by ocular estimate. Time of counting was recorded as number of months after the first rains following respreading. No species determinations were made as the majority of plants occurred as seedlings only.

Seed Concentration with Soil Depth

Topsoil samples were taken from two areas cleared of vegetation prior to topsoil removal. Five replicate sites, each 25 cm square, were sampled on each area. Soil was removed by hand from the following depth intervals: 0-1 cm, 1-2 cm, 2-5 cm, and 5-10 cm. All samples from equivalent depths were bulked, sieved and subsampled. Subsamples were spread into seed trays at 1 cm thickness over 3 cm of sterile white sand above 2 cm of crushed rock. Five trays were set out per treatment. Trays were kept in a hothouse and watered as required. Numbers of emergent seedlings were scored after 15 weeks.

Species Diversity and Groundcover

The previously described rehabilitated sites having stockpiled and double stripped topsoil were assessed for species diversity and percentage groundcover after three years. A mature forest site free of the effects of jarrah dieback (*Phytophthora cinnamomi* Rands) had been previously sampled (Tacey, unpublished). Ten randomly selected metre squares were assessed within each of two replicates in the chequer board layout described above. Five replicate plots, each with ten squares, were evaluated in the forest. All ground flora under 2 m in height was scored for presence by species; total live plant cover and litter cover were estimated visually as percentages. Diversity indices were calculated using the Shannon-Weiner function (Shannon and Weaver 1963).

$$H' = -\sum_{i=1}^{S} \frac{n_i}{N} \log_{10} \frac{n_i}{N}$$

Where H' = sample diversity

S = total number of species in a sample

n_i = number of individuals of the i^{th} species in a sample

N = total number of individuals in a sample.

Despite considerable debate on the usefulness of H' (Pielou 1966; Hurlbert 1971; Whittaker, 1972) it was selected because it incorporates both species numbers and evenness. It is useful for comparison within a single taxocene (Hurlbert 1971) where the same range of species are represented.

Equitability values were calculated using:

$$E = \frac{H'}{H_{max}}$$

Where E = equitability index

H_{max} = maximum possible diversity for a given S; equivalent to $-\log_{10} S$,

because E has been found to be a good estimator of equitability which is least dependent on the number of species encountered (Sheldon 1969).

Results

Topsoil Handling

Plant numbers were found to vary depending on topsoil handling strategy (Fig. 1). Double stripping resulted in a highly significant increase in plant numbers after 18 months compared to both other treatments. On average double stripped plots showed three to nine fold increases in plant numbers over other treatments. The difference between directly respread and stockpiled topsoil does not reach statistical significance at the 5 percent level.

General observations indicated that double stripped plots supported a wider variety of species than other treatments. In all cases plants appeared more concentrated in ripping furrows rather than ridges. Directly respread plots tended to be dominated by *Kennedia coccinea* Vent in later years. A distinctive smell, indicative of bacterial decomposition has been noticed when respreading stockpiled topsoil.

Topsoil Seed Load

The majority of germinable seed occurs in the top two centimetres of topsoil (Table 1). The reduction in germinable seed content below two centimetres depth was highly significant compared to the upper layers. There was no significant difference in average number of germinations per cubic decimetre between the top centimetre and the one to two centimetre depth. The difference between the two to five centimetre layer and the five to ten centimetre layer was significant at the 5 percent level.

Examination of total germinations (Table 1) after 15 weeks showed that some 93 percent of germinating seed occuring in the top 10 cm was present within 2 cm of the surface. This amounted to 25.7 plants dm^{-3}.

Fig. 1. Plants emerging on double stripped, directly returned and stockpiled topsoil with time.

Each point represents the mean of four (directly returned) or five replicates.

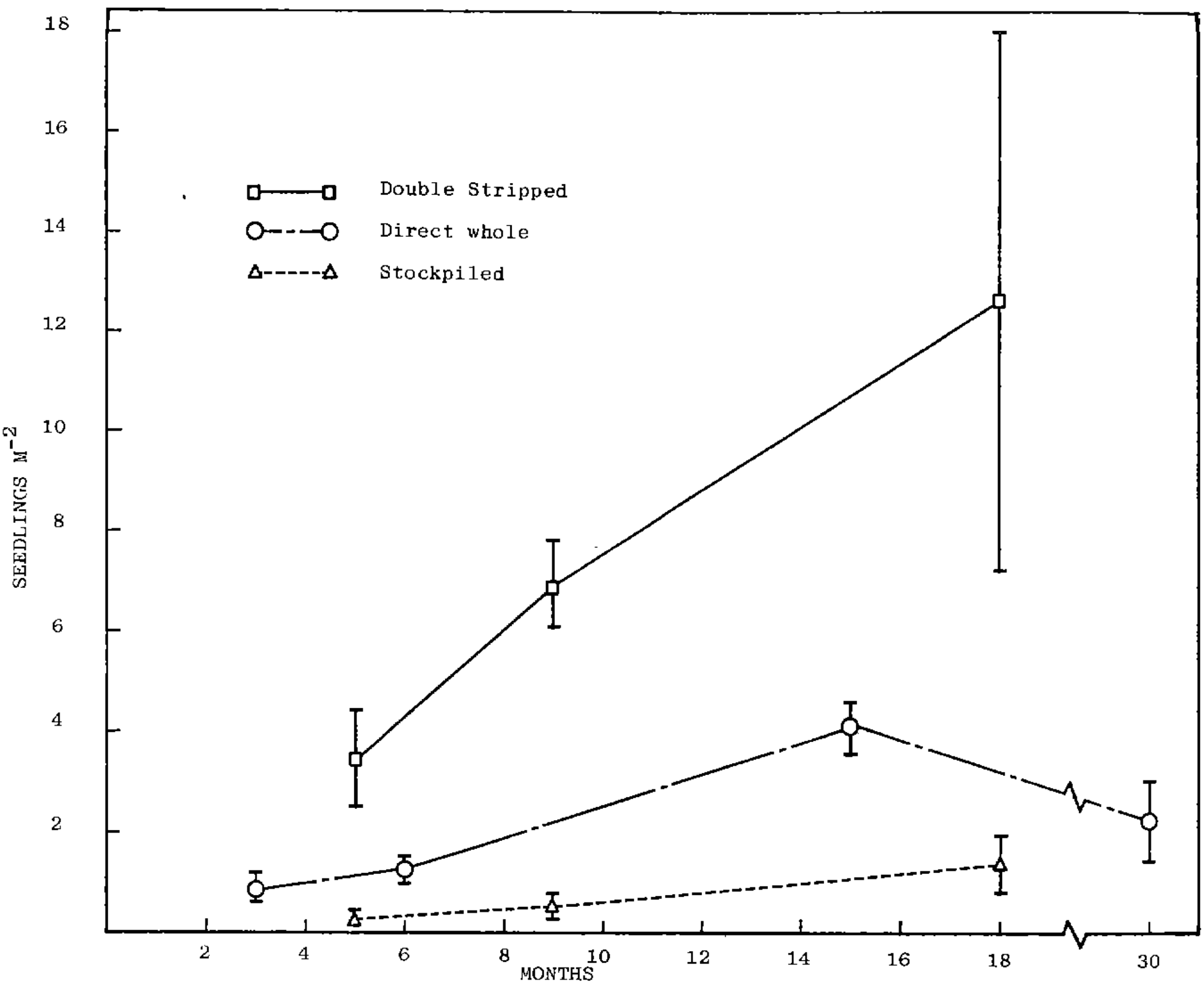

Table 1. Germinations from forest topsoil after 15 weeks in seed trays.

Results of 't' tests between all pairs of treatments are given. Values are means of five replicates, with standard errors in brackets.

Depth Interval (cm)	Plants dm^{-3}	't' test significance level (%) Depth Level (cm) 5-10	2-5	1-2
0 - 1	11.4 (6.5)	0.5	0.5	n.s
1 - 2	12.9 (6.4)	0.5	0.5	
2 - 5	1.42 (0.97)	5		
5 -10	0.55 (0.19)			

Species Diversity and Groundcover

Live groundcover tended to be highly variable on all sites (Table 2). Average values displayed a doubling of cover from stockpiled to double stripped sites again doubling in the forest. Individuals on pits were generally smaller than on forest sites. A few large individuals were encountered on rehabilitated sites, particularly the stockpiled areas, thus forcing up the average value and accounting for the high variability. Litter cover was also variable within site types (Table 2). High forest levels decreased markedly on double stripped sites and further still on stockpiled material. Litter cover was approximately double live cover in the forest, reducing to half the live cover value on rehabilitated sites. Observations indicated that litter was generally ubiquitous in the forest except on small burnt patches. Mature overstorey was not assessed in cover counts but would have contributed to litter. Litter fall was most often associated with a few large individuals on stockpiled areas and was fairly evenly spread on double stripped sites. A degree of patterning in both plant establishment and litter collection is evident with apparently higher concentrations in the ripped depressions on rehabilitated sites.

Table 2. Groundcover, species numbers, diversity and equitability indices of forested and rehabilitated mined plots.

Results are given as mean values with standard errors in brackets.

Site	Live Cover (%)	Litter Cover (%)	Average Species/* Plot	H'†	E†
Forest	40.0 (22.7)	81.3 (16.0)	29.4 (1.8)	1.3493 (0.0239)	0.9211 (0.0025)
Double Stripped Topsoil	21.1 (19.4)	12.9 (13.2)	28.0 (1.4)	1.3197 (0.0596)	0.9120 (0.0274)
Stockpiled Topsoil	11.3 (22.5)	7.3 (18.2)	11.5 (3.5)	0.9634 (0.1348)	0.9167 (0.0100)

* Each plot comprised 10, one metre squares.

† H' and E values calculated for individual plots each of ten, one metre squares, same plots used for species/plot determination.

Species numbers on mature forested and three year old double stripped sites were similar (Table 2). Less than half as many species occurred on stockpiled topsoil. Similar equitability indices on all sites reflect fairly even distributions of species. Because of this, species numbers were most strongly reflected in the Shannon-Weiner diversity indices, where forested and double stripped sites had similar values. Stockpiled sites were on average less diverse (Table 2).

Discussion

Comparison of germinable seed load within 5 cm of the surface (25.7 plants dm^{-3} Table 1) and number of plants on the double stripped field site (0.25 plants dm^{-3} Fig.1) revealed that about 1 per cent of seed present germinated in the field after eighteen months. This compares with 0.1 per cent (0.03 plants dm^{-3}) which germinated from stockpiled material.

Loss of viable plant propagules in stockpiles might be expected to be due to composting effects associated with these structures. The findings of Hunter and Currie (1956) on the anerobic nature of stockpiles and of Miller and Cameron (1975) relating to loss of organic matter lend support to such an explanation. Since little seed occurs below 5 cm depth, it may be possible to strip and directly respread this upper veneer then stockpile the remaining material until required.

Double stripped topsoil also produced more volunteer seedlings after eighteen months than directly respread whole topsoil. Composting would not be expected to account for the reduced germination on directly respread soil however. Some 93 per cent of seed on cleared jarrah forest sites occurred within 2 cm of the surface. If the majority of jarrah forest seeds normally germinate near the surface, deeper burial may well be detrimental. Mixing of the whole topsoil profile during collection and respreading may indeed lead to burial of a greater proportion of seeds at depths from which successful germination might not occur. Limiting conditions of light, moisture and temperature may occur for a number of species at depth. Failure to emerge prior to exhaustion of nutrients stored in the seed may also account for decreased germination from depth, particularly in small seeded species.

The drop in plant numbers on directly respread topsoil after thirty months probably reflects establishment and seasonal effects. Some of the material germinating in the early months may not survive. Prior to further production of seed by established plants, the total number of seedlings could be expected to drop with time due to failure to establish. The presence of a large number of small individuals soon after rehabilitation has been noted on bauxite mined sites previously (Tacey, unpublished).

Increased live cover on double stripped soil, compared to stockpiled material, reflects a maturation of the difference in seedling numbers observed between these treatments. After three years the double stripped area supported about half the cover of mature forest sites. The level of 40 per cent cover recorded here for the jarrah forest agrees with values recorded by Peet (1965, 1971) over a wide area. It appears that groundcover is fairly rapidly approaching this level on mined sites, where sufficient seed was present in a position from which it could germinate and establish. Litter cover seemed to be a consequence not only of plant cover, but also of site age. While live cover on forested sites was double that on double stripped sites, litter cover was six times as great. The presence of a large biomass of mature overstorey in the forest was likely to have contributed significantly. In addition, jarrah forest litter has a half life for breakdown of 2.7 years (Hatch 1955; in Bevege 1978), hence buildup to maximum levels would not be expected on three year old sites. Level of cover in the forest may be expected to offer greater potential erosion protection than that developed naturally on young rehabilitated areas. Vegetative erosion control in the early years after rehabilitation might be favoured by introduction of additional techniques such as mulching or use of agricultural legumes or direct seeded native understorey.

Nurse crops have been suggested by various workers (Plass 1968; Coaldrake 1973; Martinick 1976). Subterranean clover (*Trifolium subterraneum cv.* Seaton Park) has been found to establish complete ground cover six weeks after germination on mined sites in the Darling Range (Bartle pers. comm.). Following the return of stockpiled topsoil, it may be practicable to apply the top 5 cm of stripped topsoil and sow clover with phosphate in alternate bands along the contours A high degree of initial erosion control might thus be achieved by the clover with the fresh topsoil bands acting as a long term source population as clover declines due to the fixation of phosphate (Kirton 1965).

Conclusions

The diversity index of double stripped areas was similar to forested areas due to the similarities in species numbers and evenness of distribution. Further work would be required to define the proportions of individual species in the two cases but it was evident from observations that most species were common to both areas. This result would be expected in view of the forest origin of the double stripped material. It was evident that stockpiling reduced the diversity of jarrah forest species occurring on rehabilitated sites. Double stripping is considered to represent a means of returning a range of jarrah forest species to rehabilitated sites which might not be possible at present by any other practical technique.

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Rehabilitation after Mineral Sands Mining at Western Titanium Limited, * Capel, W.A.

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Abstract

The mineral sands mining industry began in Capel in 1956 and today is a major employer and export earner in the South West of W.A. The industry has achieved a standard of rehabilitation after mining that blends into the surrounding agricultural environment. The end land use provides a desirable balanced arrangement. Individual companies have investigated revegetation problems, working closely with available expertise to achieve their objectives. Pit mining processes vary little between companies, so that rehabilitation problems are common. There is, however, variance in the methods of establishing vegetation and its management. Present procedures are reviewed with particular emphasis on surface stabilisation and vegetation strategies.

Introduction

Western Titanium's heavy mineral deposit at Capel (Fig. 1) was formed on a series of beaches during a period estimated at 40,000 to 80,000 years ago in the late Pleistocene. At that time the sea level varied between 3 and 8 m above its present level. The old shore line was sub-parallel to that of the present day and approximately 5-6 km inland. In appearance the Pleistocene shore line would have resembled that of the present with one or two lines of typical dunes behind the beach containing a lower concentration of heavy minerals. Some remnants of these dunes remain as low ridges.

The growing season lasts from early May to mid October. The average annual rainfall is 873 mm and summers are mild (Table 1). Winds are mainly from west to north-west during the winter months, occasional gale force winds are associated with cold fronts from July to September.

Soils range from grey sands with clay hardpan to dark-brown surface sands which become greenish-brown at depth with fine ferruginous gravel. Currently mining is taking place in a portion of the Ludlow pine plantation though all future mining will be on company owned land, of which one third is cleared arable country. The uncleared land is considered to be of poor agricultural potential. There is a range of vegetation including *Banksia* woodland, light jarrah (*Eucalyptus marginata* Sm.) with peppermint (*Agonis flexuosa* (Spreng.) Schau.) in low open woodlands with marri (*Eucalyptus calophylla* R.Br.) on ridges and dispersed *Melaleuca* / sedge swamps. The latter are shallow and generally dry in summer. Fauna frequent the area in the winter months from the nearby Ludlow tuart (*Eucalyptus gomphocephala* DC.) forest which adjoins the Western side of the lease.

* This company is now known as Associated Minerals Consolidated (A.M.C.) Ltd.

The Mining Process

Following the clearing and burning of vegetation, the deposit is mined using bulldozers and front end loaders which are used to transport the ore from the mining face to a skid mounted hopper from which it is pumped as a slurry to a wet concentration plant. At the primary wet concentrator (P.W.C.) laterite gravel of > 125 mm is removed by vibrating screens. Dispersed clays in the slurry are removed by cyclones and pumped to a thickener (Table 2). Valuable heavy minerals are separated from the silica sands by wet gravity processes.

The heavy material is pumped as a concentrate slurry to a treatment plant 4 km away for further processing. The silica sands are pumped as a tailing slurry to mined out pit areas for backfilling. Clay slimes from the thickener are mixed with the tailings or dried and ploughed to form the basis of a pasture seed bed.

Physical Disposal

Clay Slimes

The method of clay slimes disposal used earlier was to bury the material within the sand tailings or create slimes pits for it to dry and be later bulldozed and spread. Many problems were experienced in handling clay slimes in this way. Drying time was often years. In recent times clay slimes thickening plants have been introduced wherein a chemical flocculant is added to dewater the material, and it can be pumped over returned sand tailings and ploughed. The slimes handling plant utilises a large diameter conventional rake thickener operating under the conditions shown in Table 2. Results in pasture establishment using thickened clay slimes have been very successful. The ability of clay slimes to retain moisture and fix fertiliser has now been proven. It is apparent that fertiliser usage can be reduced by 50 per cent in first year pasture establishment when dealing with clay slimes over sand tailings, compared to straight sand tailings. Wind drift is also overcome to a large degree.

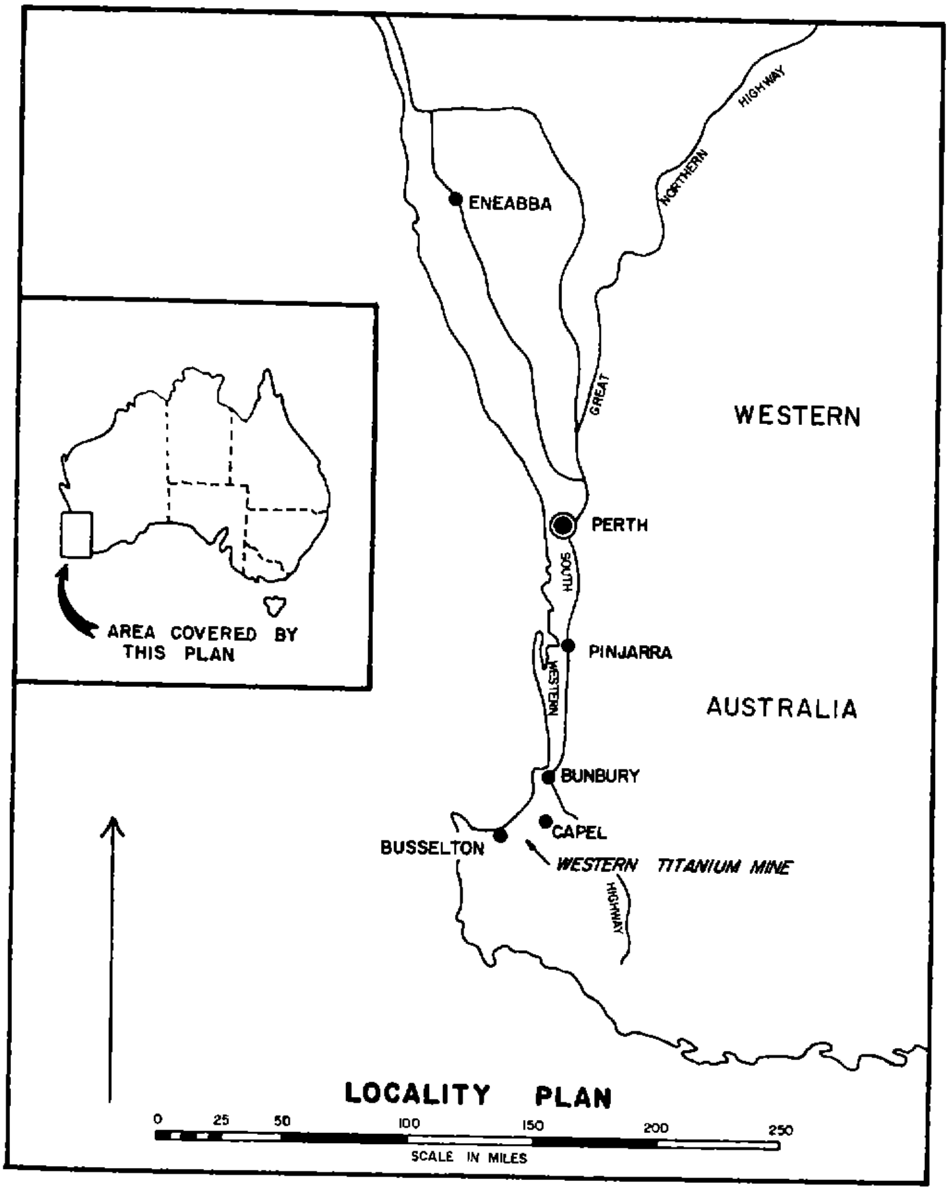

Fig. 1. Location of the Western Titanium minesite at Capel.

Table 1. Average mean monthly temperatures at Capel.

	^oC											
Month	J	F	M	A	M	J	J	A	S	O	N	D
Minimum	14.8	15.1	14.1	12.0	10.2	9.1	8.2	8.3	9.2	10.1	12.1	13.7
Maximum	27.5	27.6	25.8	22.9	19.8	17.6	16.8	17.1	18.2	19.9	23.0	25.6

Table 2. Clay Slimes Handling Plant Parameters

Operational characteristic	
Feed rate to thickener	11 m^3/minute
Feed pulp density w/w %	1.5 - 4.0
Underflow pulp density w/w %	23 - 28
Water recovery to pond %	87 - 96

A flocculant is used to accelerate the separation of clays from the water. The flocculant is an anionic polyacrylamide compound with a molecular weight in excess of 1.2×10^6.

Surface Stabilization

Where it is economically and functionally possible a clay slimes covering is used as a prime stabilizer over sand tailings. The advantages to initial plant life have been mentioned above. However there are areas susceptible to both wind and water erosion where gravel screenings from the P.W.C. have been used as a stabilizer. The screenings contain root propagules which have been observed to produce many species of native flora. This is particularly noticeable where screenings have been used as a stabilizer on pond banks, gulleys and road verges. Species recorded are given in Table 3.

Agronomic Practices

Fertilisers are not varied in different soil types in the first year but quantities are applied at varying levels. For example, leaching in sand tailings is far greater than on clay slimes therefore less fertiliser is required on clay slimes. Following an initial soil sample test, agricultural lime is applied initially at a rate according to pH levels. The initial crop is sown with superphosphate, copper, zinc and molybdenum. Later on dressings of potash and nitrogen are applied. Care is taken to avoid leaching, particularly when applying nitrogen. Maintenance dressings in the second year using a superphosphate and potash mix have been adopted. Where nitrogen deficiencies become evident a nitrogen dressing is used. Details of application are shown in Table 4.

Table 3. Species recorded emerging from laterite screenings

Acacia extensa Lindl.
Acacia pulchella R.Br.
Anigozanthos manglesii D.Don.
Anigozanthos viridis Endl.
Beaufortia squarrosa Schau.
Casuarina humilis Otto & Dietr.
Conospermum stoechadis Endl.
Drosera menziesii R.Br.
Hibbertia hypericoides (DC.) Benth.
Hovea pungens Benth.
Hovea trisperma Benth.
Kennedia coccinea Vent.
Kennedia stirlingii Lindl.
Leptocarpus canus Nees.
Mesomelaena tetragona (R.Br.) F.Muell.
Oxylobium capitatum Benth.
Persoonia saccata R.Br.
Sowerbaea laxiflora Lindl.
Stirlingia latifolia (R.Br.) Steud.

Pasture Strategy

Varying soil types govern the selection of pasture species to be sown. It has been found that subterranean clovers *(Trifolium subterraneum* cvs.), serradella *(Ornithopus compressus)* and lupins (*Lupinus* spp. cvs.) are susceptible to wind blast when sown on bare sand tailings. Thus stabilizer crops are sown with cereal rye *(Secale cereale* L.) proving the most successful. Oats (*Avena sativa* L.) and lupins undersown with clover and serradella can be grown on a clay slimes/sand tailings mixture without fear of windblast loss. Other pastures sown include Wimmera rye (*Lolium rigidum* Gaud.), South African Veldt (*Ehrharta calycina* Sm.) and Tama rye (*Lolium perenne* L.). Typical seeding rates (kg/ha) in the first year of restoration are as follows:

	Tailings	Tailing/ Slimes
Cereal rye	60	-
Wimmera rye	5	4
S.A. Veldt	2	2
Tama rye	5	4
Oats ('Swan')	-	40
Lupin (white cvs)	-	25
Sub-clover	-	10
Serradella	-	6

Table 4. Schedule of Fertilisers used at Capel by Western Titanium Ltd.

(a) Tailings

First Year Fertiliser		Quantity (kg/ha)	Application time
Superphosphate, Copper, Zinc, Molybdenum No. 1		200	at seeding
Superphosphate - potash	3 - 2	200	{100 kg May {100 kg July
Superphosphate - potash	5 - 1	200	200 August
Agran	34 - 0	180	{ 90 kg at seeding { 90 kg June
Agricultural Lime		2000	before seeding
Second Year			
Superphosphate	5 - 1	200	Autumn
Agran	34 - 0	180	Immediately after germination
Third and subsequent years			
Superphosphate		200	Autumn

(b) Slimes/Tailings

First Year Fertiliser		Quantity (kg/ha)	Application time
Superphosphate, Copper, Zinc, Molybdenum No. 1		100	at seeding
Superphosphate - potash	3 - 2	100	May - June
Superphosphate - potash	5 - 1	100	July-August
Agran	34 - 0	100	at seeding
Second Year			
Superphosphate	5 - 1	200	Autumn
Agran	34 - 0	100	after germination
Third and subsequent years			
Superphosphate		200	Autumn

Stubble Mulching

Having established cereal rye on sand tailings the practice of dry sowing legumes and blade grasses in year two in a stubble mulch is well accepted. The legumes are lupin, serredella and sub-clover with the addition of rye grass and veldt. It is possible to establish a permanent pasture using this formula. Nitrogenous fertilisers are used when stubble mulching. Typical seeding used on second year restored land is as follows:

	kg/ha
Swan Oats	30
White Lupins	25
Sub Clover	10
W.A. Serredella	6

Performance to Date

Pastures as Stabilizers of Sand Tailings

Cereal rye is used to provide shelter for other less hardy species during germination and early growth. Growth is vigorous and provides a volume of straw which is a valuable organic addition. However the straw is slow to decay and takes up to four years to compost. Cereal rye will only regenerate if the seed heads are ploughed in as mulch in the second year and will give poor growth unless dressed with a nitrogenous fertiliser.

Wimmera rye is an ideal blade grass when sown with cereal rye and will sustain its growth through wind blast conditions. It will regerminate readily without summer ploughing but requires nitrogen fertilisers for vigorous growth.

Tama rye is a proven poor performer in a drained sand tailings situation whereas in moist or wet sand, growth rates are outstanding. In favourable conditions tama develops an enormous root system which successfully binds the sands.

Serradella, a legume, has similar characteristics to tama when sown with an initial crop. Ideally it can be used in the second year as an undercover strain.

Success in introducing sub clover to sand tailings in the first year has been limited. Significant stands have been achieved when mulch-sown in year two.

After several years of trials the white lupin has been found too fragile to survive in first year crops on tailings. The plant will not survive a growth check from wind blasting and, in fact, will collect sand particles being blown past around its base when it is in the two leaf stage, causing it to die. There are strong indications that the W.A. blue lupin will establish in the first year, if supported by a cereal rye cover crop. W.A. lupins have not been used to any great degree in pasture establishment due to the susceptibility of livestock to toxicity.

Little difficulty has been experienced with veldt grass establishment. It is an ideal soil stabiliser, palatable to stock and responds to summer rains. Veldt cannot be considered when sown adjacent to a nature reserve or forest area because of its takeover characteristics and future fire risk. (Veldt has established itself as a pest in King's Park in this regard).

Insignificant growth on tailings sands has been achieved with "Siah" oats. "Swan" and "West" oats have made satisfactory growth and their straw material produces organic material readily.

Having considered the performance of the various pasture crop species on *tailings sands*, there is need to consider pasture establishment as being a two year introduction. In year one the cereals and blade grasses are introduced followed by a mulch seeding with legumes in year two. When dealing with a slimes/sand material all the selected pasture varieties can be introduced in year one in a mixed seeding.

Livestock

Experience has shown that the early introduction of livestock on rehabilitated pasture areas has accelerated development. It has been found that sheep are superior to cattle due to their more even grazing habits. Their droppings are spread more evenly than cattle. Grazing management is important and pastures are never eaten bare or grazed during seed setting.

Noticeable seed spread from sheep following summer grazing, has been veldt grass, rye and natural blade grasses.

Artificial Wetlands

Water ponds are created as part of the mining process, and a series of linked ponds now exists on restored areas. The average depth of the ponds is 4 m and capacities are from 4.6 - 9.2 x $10^4 m^3$. The ponds are being frequented by waterfowl (listed in Table 5) coming in from neighbouring swamp land.

Table 5. Birdlife Observed on Restored Areas at Capel

Australian Raven	Mountain Duck
Black Duck	Maned Geese
Black Swan	Port Lincoln Parrot
Black Shouldered Kite	Quail
Black Winged Stilt	Reed Warbler
Blue Winged Shoveller	Straw Necked Ibis
Coot	Sand Piper
Common Bronze Wing Pigeon	Scarlet Robin
Emu	White Faced Heron
Grey Teal	Western Rosella
Grey Fantail	White Fronted Chat
Grey Butcher Bird	White Tailed Cockatoo
Hoary Headed Grebe	Willie Wag Tail
Kookaburra	Western Swamp Hen
Little Grebe	Welcome Swallow
Little Pied Cormorant	Western Magpie
	White Egret

During recent dry summers large flocks of ducks, swans and even pelicans have populated the ponds. They have interchanged from their natural habitat at nearby Wonnerup. Numerous native species of vegetation are being introduced by birdlife. As vegetation surrounding the ponds thickens and trees develop, it is feasible that many of the birds will nest and become permanent dwellers. Observations show that the kangaroo population on the rehabilitated land surrounding the ponds has increased, particularly in the summer months when feed and water is in short supply in neighbouring country. The Company introduced marron into an original pond in 1973 with a view to eventually stocking ponds as they were developed. There has been sufficient indication from monitoring carried out, that marron will breed in the waters.

Tree Planting

An annual tree planting programme of 5000 trees was considered essential in the revegetation programme as an important contribution to the aesthetic appearance of the rehabilitated land and as an encouragement to wildlife.

When the introduced pastures have begun to stabilize the sand surface (about 12 to 18 months after sowing) tree seedlings are planted out. Clump planting is preferred and site selection is regarded as important. Losses have occurred when trees have been planted on bare sand tailings, with moisture stress in summer months. No trees have been hand watered. Tree seedlings are grown for the Company by the W.A. Forests Department at their Hamel Nursery. Seedlings are produced in organic "jiffy" pots and are planted out without fertiliser. Growth performance in all species is governed by the availability of summer moisture with *Acacia decurrens* (J.Wendl.) Willd. and *Eucalyptus camaldulensis* Dehn. particularly responsive. Other species planted include *Acacia melanoxylon* R.Br., *Agonis flexuosa*, *Casuarina obesa* Miq., *Eucalyptus botryoides* Sm., *E.calophylla*, *Eucalyptus globulus* Labill., *Eucalyptus lehmannii* (Schau.) Benth., *Eucalyptus robusta* and *Melaleuca preissiana* Schau.

Conclusions

Mining and rehabilitation of rural and semi-rural land to a standard of productivity and aesthetic improvement has been Western Titanium's objective and achievement in its operation. The Company has mined and rehabilitated land, which in the main it owns. However currently, and for the next five years, its operation is in State pine forest. The area was put to pines in the 1930s and has matured indifferently. After mining the Company has and will return the land to a contour suitable for reafforestation which conforms with its agreement with the State. It has also continued to develop the land to rural use which undoubtedly is beneficial to future replanting of forest. It is envisaged by the Forests Department that a proportion of the State Forest mined in areas convenient to access roads will be developed by them, to a condition suitable for some types of recreational use. An area has been recently allocated for lease by the South-West District Rifle Clubs Association adjacent to the mined areas and is the first definite step in multiple land use.

The understanding of revegetation processes after mineral sands mining has been constantly improving. Continued improvement can be achieved with an interchange of knowledge between operating Companies and advisory bodies. It can be confidently predicted that the mineral sands mines in the South West will contribute towards an improved and desirable environment.

COMMUNICATIONS

Direct Seeding of Native Species - a Technique for Revegetation of Disturbed Jarrah *(Eucalyptus marginata* Sm.) Forest.

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Abstract

A direct seeding technique for revegetation of disturbed areas which results in the establishment of a dense and diverse shrub and understorey layer is described.

Introduction

The vegetation on extensive areas of jarrah (*Eucalyptus marginata* Sm.) forest is being severely degraded as a consequence of the spread and intensification of jarrah dieback and land use activities such as strip mining for bauxite and coal, power line location and gravel borrowing. Natural recolonization of disturbed areas does occur but the process is usually very slow and the species composition limited. Where funds have been available and where it is considered desirable, the traditional method of revegetation has been planting with container-grown and open rooted nursery stock. Trees are planted and usually only one species is used. In bauxite mined areas rapid replacement of topsoil has increased the speed of recolonization but there are logistical problems associated with ensuring that the topsoil remains fresh (Tacey, pers. comm.). Even if replacement of topsoil was practicable, enrichment of the species regenerating from topsoil would be desirable.

Over the past several years a revegetation technique involving direct seeding of mixtures of native seed of a variety of shrub and understorey species has been developed. In this paper we outline the technique and briefly discuss its use for revegetation of disturbed areas in the jarrah forest.

Preparation

Seed Collection and Cleaning

Seed is gathered by hand from naturally-occurring concentrations of desired species. In the future it is anticipated that areas currently being seeded will become sources of seed. There is a potential for mechanisation of seed collection but the current procedures are considered adequate and costs of collection are not excessive.

Collection is timed to fit in with warm, dry weather, labour availability and seed ripeness. The period of availability of seed varies between plant families. Many *Hakea* species have old woody pods from which viable seed can be obtained over much of the year. Species of the family Myrtaceae have ripe seed present in capsules throughout the year but the Leguminosae (Mimosaceae, Fabaceae) have a distinct summer seeding season. Marked heavy seed years are apparent in many species especially in the genus *Eucalyptus*. Collection of unripe seed has been found to be a common error and only mature capsules (no longer green) should be collected. Seed number per gram and season of ripening of the seasonally available species which have been used for revegetation is shown in Table 1. Other species used include many *Eucalyptus*; and also from the Myrtaceae: *Leptospermum laevigatum* (Gaertn.) F.v.M., *Melaleuca microphylla* Sm., *M. nesophila* F.Muell., *M. hamulosa* Turcz., *Calothamnus validus* S. Moore, *C. quadrifidus* R.Br., *Callistemon speciosus* (Sims) D C. and *Kunzia baxteri* (Klotz.) Schau. The following *Hakea* species have also been used: *Hakea cyclocarpa* Lindl., *Hakea lissocarpha* R.Br., *H. lasiantha* R.Br., *H. multilineata* Meissn., and *H. undulata* R.Br.

Preliminary seed cleaning is carried out at the site of collection where possible. This avoids transport of a bulk of pods and branches, and a later disposal problem. Seed bearing twigs and branches are cut with secateurs and laid on black plastic sheeting in the sun for up to several days. Capsules or pods open after dessication and the seed is shaken from the capsules onto the plastic.

Seed collection costs vary markedly with species. Collection costs for leguminous species range from \$20 to \$30 per kg of clean seed.

Seed Preparation

With the exception of species of the Leguminosae, no special pre-treatment is required. Heat treatment of most legume species is essential. The relationship between heat and legume regeneration has been examined in detail for a number of species (Christensen and Kimber 1974; Shea *et al* 1978). The relationship varies between species but for most species germination in excess of 90 per cent is achieved by scalding with boiling water for 3 to 8 minutes, although the temperature and duration of heating is not critical.

A small laundry copper has proved suitable for large-scale treatment. One man can treat approximately 100 kg per day. Seed is doused into boiling water in a mesh basket for 3 to 18 minutes and then spread in the sun to dry. Seed must be adequately dried if it is to be returned to storage. Treated seed has been stored for one year with little loss in viability.

Table 1. Seed weights and season of ripening for a number of jarrah forest native species

Species	Seeds/g (No.)	Months of Ripening
Mimosaceae		
Acacia baileyana F.v.M.	50	1-2
A. cyclops A.Cunn. ex G. Don	63	1-2
A. dentifera Benth.	81	1-2
A. drummondii Lindl.	121	1-2
A. extensa Lindl.	79	1-2
A. myrtifolio Willd.	60	1
A. pulchella R.Br.	172	1-2
A. saligna (Labill.) H. Wendl.	44	1-2
A. strigosa Link.	200	1-2
A. urophylla Benth.	150	12-1
Albizia lophantha (Willd.) Benth	17	1-2
Fabaceae		
Bossiaea aquifolium Benth.	74	1-2
B, ornata (Lindl.) Benth.	588	
Daviesia cordata S. Moore	46	2
Mirbelia dilatata R.Br.	455	2-3
Hovea chorizemifolia (Sweet) DC.	45	
H. trisperma Benth.		
Templetonia retusa (Vent.) R.Br.	75	1
Viminaria denudata Sm.	137	3
Sapindaceae		
Dodonaea attenuata A. Cunn.		2-4

Site Preparation

Direct seeding is rarely succcessful without some site preparation to remove competition and to prepare a favourable seedbed. On rebuilt soil profiles such as on mine sites, provided that seeding is carried out within one year, establishment is excellent. On dieback areas, high intensity burning to establish ashbeds or superficial cultivation in conjunction with fertiliser application is essential.

Application

Time of Sowing

The seed must be sown in early winter. At this time ant and bird predation are low and seeds germinating have a long period to establish a root system before the onset of dry conditions.

Method of Application

Initially, application was carried out by hand but as areas increased in size machines were introduced. Trials were carried out with a hydroseeder with the seed applied in water or in a water paper mulch slurry. The mulch did not improve seeding establishment or distribution. A hand-operated chest-mounted fertiliser applicator was more efficient than the hydroseeder and gave excellent results. An aerial application trial was carried out in a bauxite mined site in 1977. A mixture of seed at a rate of 1 kg/ha was applied simultaneously with superphosphate at the rate of 300 kg/ha. One kg of seed per ha was equivalent to 12 seeds/m^2. Establishment rates 4 and 8 months after application were 1.8 and 1.6 seedlings per square metre respectively. A stocking rate of one seedling per square metre is considered satisfactory for shrub establishment on bauxite mine sites. The cost of aerial application of superphosphate was approximately $100 per hectare.

Seeding and Establishment Rates

There has been no systematic study of the relationship between seeding rate and establishment for individual species. The data in Table 2 show the establishment rates of a variety of species which were sown onto a bauxite mine site. The rates of leguminous seed (legumes are the predominant species in the seed mixes) were initially as high as 25 kg/ha. These were reduced stepwise and currently 1 kg of mixed seed per hectare is applied. A typical seed mix is shown in Table 3 and the results of a seeding rate trial which was carried out in conjunction with the aerial seed application trial is shown in Table 4.

Less is known of desirable seedling rates of fine seeded species. 0.8 kg/ha of mixed eucalypts gave a population of 3524 eucalypt seedlings per ha in year 3. In another more extreme case 8.4 kg/ha of mixed eucalypts gave a population of 54,000 plants/ha in year 2. Both of these were in bauxite pits where the only competition was that arising from simultaneously sown shrub seed. The results from these preliminary trials suggest that for eucalypt establishment application rates of less than 0.5 kg/ha will be adequate.

Table 2. Establishment rates of shrub and tree species direct seeded onto a bauxite mine surface

Species	Seed weight applied (g m^{-2})	Seed number applied (per m^2)	Plants established after 12 months (per m^2)
Acacia strigosa	.50	100	7.44
Bossiaea aquifolium	.40	30	1.2
Acacia extensa	.37	30	.7
Acacia decurrens (J.Wendl.) Willd.	.56	36	.5
Albizia	.30	5	
Mirbelia dilatata	.17	80	4.1
Dodonaea sp.	.45	118	1.0
Calothamnus validus	.05	- *	4.5
Calothamnus quadrifidus	.02	-	
Callistemon sp.	.04	-	
Leptospermum laevigatum	.04	-	7.4
Viminaria denudata	.02	-	.5
Melaleuca nesophila	.005	-	.5
Melaleuca microphylla	.002	-	
Eucalyptus marginata Sm.	.25	-	1.1
Eucalyptus laeliae Podger & Chippendale	.05	-	
Eucalyptus maculata Hook.	.10	-	
Eucalyptus leucoxylon F.Muell.	.05	-	
Eucalyptus citriodora Hook.	.05	-	.8
Eucalyptus resinfera Sm.	.04	-	
Eucalyptus cladocalyx F.Muell.	.05	-	.3
Unidentified *Eucalyptus* sp.	-	-	2.3

* Remainder are fine seeded species.

Table 3. Typical seed mixture

Species	g/ha	seeds/m^2
Acacia extensa	340	2.72
A. urophylla	80	0.66
A. myrtifolia	80	0.48
A. drummondii	80	1.80
A. strigosa	80	1.60
A. saligna	80	0.35
A. microbotrya Benth.	80	1.30
Albizia lophantha	200	0.34
Calothamnus validus	10	*
C. quadrifidus	2	
Hibbertia polystachya Benth.	40	
Dodonaea attenuata A. Cunn.	40	

* Remainder are fine seeded species.

Table 4. Establishment following a seeding rate trial

Seeding rate (kg/ha)	Seeds/m^2	Seedlings/m^2 at 4 months	Seedlings/m^2 at 8 months
1	12	1.8	1.6
2	24	3.7	1.8
4	48	8.0	6.9

The initial trials that were carried out on bauxite mined sites included mixtures of native and common agricultural pasture species. The objective was to determine if it was possible to achieve rapid establishment with agriculture species (principally *Trifolium subterranean* L.) which would assist stabilization of the soil while still establishing the slower growing native species. These trials showed that when agricultural and native plant seeds were sown simultaneously the native seed establishment was negligible. Clover persistence, two years after establishment, even when initial phosphate application was as low as 30 kg per hectare, was still sufficient to suppress native plant establishment.

Fertilisation

There have been no detailed studies on the response of native species to fertiliser application. Preliminary observations indicate that there is a large response to phosphorus and a lesser but significant response to nitrogen. In the absence of basic data and since most seed mixtures are dominated by legumes, standard practice in bauxite pits is to apply 300 kg/ha of superphosphate with 1 kg/ha of seed. This rate was chosen as a compromise between cost and response desired. The nitrogen fixing species which dominate the seed mixture are anticipated to make significant additions of nitrogen to the ecosystems and contribute to a more efficient cycling of nutrients.

Another technique that has been used is to spot fertilise to favour selected plants. This method can be used in amenity plantings to reduce the competitive advantage of already established vegetation.

Conclusions

The technique has been applied successfully to revegetate dieback affected forest, areas which have been strip mined for bauxite, coal, power lines and gravel pits. In all these situations it has been possible within two years to establish a continuous canopy of a range of shrub and tree species with an average height of two metres. Stabilization of disturbed soil surfaces is achieved by the second year after establishment.

Direct seeding has a number of advantages -

* a diverse and therefore more stable understorey and shrub layer is established
* stabilization of surface soils is achieved
* the establishment of a variety of species is pleasing aesthetically and has conservation value
* the establishment of leguminous species will result in the contribution of nitrogen to the ecosystem and there is some evidence that a legume understorey will confer resistance to *P. cinnamomi* Rands. on susceptible eucalypt species (Shea & Kitt 1976, Shea & Malajczuk 1977)
* the establishment of a dense understorey will increase water consumption per unit area which would stabilize water salt balances in salt-prone areas of the jarrah forest
* the capacity to establish a large number of eucalypts together with the shrub species is an advantage where it is not known which tree species would successfully grow on the disturbed site. Some eucalypt species form lignotubers under the dense shrub layer and these have the potential to form a tree crop if the planted trees fail.

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Preliminary Investigations into the Effects of Fertiliser in Revegetation Trial Plots at Marandoo, W.A.

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Abstract

Fertiliser applied in trial plots at Marandoo in the Hamersley Range of Western Australia appears to have inhibited the germination of perennial species although the germination and growth of annuals of the genus *Chenopodium* was greatly increased. The implications of the use of fertiliser in revegetating disturbed areas in the Pilbara are discussed.

Introduction

Texasgulf Australia Ltd has been conducting revegetation studies at its proposed Marandoo minesite since 1974 in an effort to find the best way to re-establish a stable community of native plants on the site during and upon completion of mining activities. Where dust is a problem it is desirable to produce an immediate vegetation cover to stabilize backfilled waste material and its soil cover. Measures to ensure the prompt establishment of the perennial species which will make up a stable, self-perpetuating community also need to be taken. One of several parameters under investigation in five different sets of trial plots on the site is the effect of artificial fertiliser on the native plant species selected for use in the revegetation programme.

Method

Six trial plots constructed near the Texasgulf exploration camp at Marandoo were selected for the fertiliser experiment. Each plot consisted of approximately 30 cm of topsoil spread over a 1 m thickness of typical mine waste material excavated from a large test pit in the proposed mine area. The soil used in the plots was typical of that present in the mine area. It is a slightly alkaline, poorly developed loam, low in organic content and characterised by a large coarse fraction throughout the profile. Each plot measures 20 m long and 5 m wide. Three were seeded with different combinations of *Chenopodium* and *Cassia* species as well as a mix of annuals and perennials. Another three plots were correspondingly seeded and treated with a general fertiliser (N, P and K) at the reasonably heavy rate of about 375 kg/ha. Each plot was irrigated at ten day intervals with approximately 6,000 litres of water. The trials began in March, 1977. On 1st January, 1978, the plots were equally divided and water withheld from one half. The number of individuals of each species was recorded on four occasions. In many cases, determination to genus level only was possible.

Results

Data from all six plots are shown in Table 1. The data have been grouped because of the small number of some species present on individual plots. The only annuals tabulated because of their overwhelming numerical abundance are those of the genus *Chenopodium*. *Triodia* and *Plectrachne* were combined because it was found to be impossible to distinguish between the two as seedlings.

Table 1. Tabulation of four types of plants observed in six Marandoo trial plots

Date	*Chenopodium* spp		*Acacia* spp.		*Cassia notabilis*		*Triodia* + *Plectrachne*	
Regime:	Fert	No Fert	Fert	No Fert	Fert	No Fert	Fert	No Fert
27.8.77	2000	1350	11	109	-	122	-	-
7.10.77	300	300	20	70	6	127	1	18
1.1.78	90 and 150 Seedlings	170 No seedlings	45	83	19	92	7	26
1.7.78	100	NIL	65	81	30	99	20	45

Table 2 presents data from one pair of identically seeded plots (Nos. 6 and 10). The two are of particular interest as they were heavily sown with *Cassia notabilis* F.Muell., a species common in early post-fire and disturbed areas in the Pilbara.

The number and initial cover of *Chenopodium* species in each of the six trial plots is shown in Table 3. The seeds were broadcast sown only in plots 7 and 11. The seeds, which are extremely small, were spread to the other plots by wind action.

Table 2. Plants observed in Plots 6 and 10. Both plots seeded with *Cassia notabilis*, Plot 10 fertilised

		Chenopodium spp.		*Acacia* spp.		*Cassia notabilis*		*Triodia + Plectrachne*	
Date	Plot No.	6	10	6	10	6	10	6	10
27.8.77		500	800	15	-	100	-	-	-
7.10.77		100	100	10	4	100	1	-	-
1.1.78		50	40 and 60 Seedlings	15	13	63	10	3	-
1.7.78		-	35	61	32	16	4	26	7

Table 3. Tabulation of *Chenopodium* spp. observed in six trial plots. Plots 10, 11 and 12 were fertilised

Date	Plot No.	6	7	8	10	11	12
27.8.77		500	350	500	800	600	600
		20% Cover	10% Cover	15% Cover	70% Cover	25% Cover	25% Cover
7.10.77		100	100	100	100	100	100
1.1.78		50	60	60	40 and 60 Seedlings	30 Seedlings	50 and 60 Seedlings
1.7.78		-	-	-	35	25	35

Discussion

The results of the experiment show an inhibition of germination in *Cassia notabilis*, *Acacia* spp. and *Triodia + Plectrachne* along with an increase in germination of *Chenopodium* spp. in the fertilised plots. With time, however, the degree of inhibition has decreased. Soils in the Marandoo area are very low in phosphorus and an intolerance to increased phosphorus levels is suggested as the cause of the initial low germination of *Cassia notabilis* and the perennial species. Such inhibitions have been observed elsewhere in the Australian flora (Heddle and Specht 1975). Other causes must be considered, however, since the observed inhibition of germination correlates with the presence of larger numbers of *Chenopodium* plants as well as the application of fertilisers. These other possible causes include:-

1. Competition for water. The high rate of irrigation makes this effect unlikely.

2. Occlusion of sunlight. Sunlight is known to be a factor in the germination of some species, but no information is available on those observed

here. It is felt that while at one stage the *Chenopodium* plants may have been able to produce a blocking effect, these effects were small when the perennials were first observed to germinate.

3. Excretion of inhibitors. Some plants are known to inhibit germination around them by the secretion of organic substances. *Chenopodium* species are not known to do this. It is felt that a similar argument as used in (2) must apply. The *Chenopodium* were not established adults when the *Acacia* and other perennial species were starting to germinate. It appears unlikely that the *Chenopodium* would have been able to produce significant amounts of inhibitors at such an early stage of development.

The increase in germination of *Acacia* spp, *Cassia notabilis* and *Triodia + Plectrachne* over time in the fertilised plots is probably due to a decreasing level of phosphorus. This could have been caused by its being taken up by plants, washed out in the course of regular watering or bound up in an unavailable form.

Species of the genus *Chenopodium*, whose germination and growth was clearly stimulated by the fertiliser, seem to be very suitable for use in establishing a quick initial plant cover in unstable areas. These plants have other advantages in that their seeds are easy to collect, they have a short life span, a maximum size of less than 50 cm, and they do not appear to pose a competitive threat to seedlings of perennial species as other annuals such as the ubiquitous *Salsola kali* Linn.

At the levels of fertiliser used in this study, a trade-off exists between obtaining a quick initial cover and the establishment of perennial species. Such trade-offs are a problem in much minesite revegetation work (Specht 1975).

Conclusions

1. The use of phosphorus fertilisers can inhibit the germination of perennial species whose development is desirable for establishing stable communities in rehabilitated sites at Marandoo.

2. The germination and growth of *Chenopodium* species can be improved with fertilisers.

3. At the levels of fertilisation used here, a trade-off exists between gaining a quick cover and the early establishment of perennial species.

4. Further studies at lower levels of fertilisation and higher levels of *Chenopodium* seeding are required to show if the trade-off can be avoided.

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Abandoned Mines and Workings - Where does the Responsibility Lie?

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Introduction

There are a number of problems associated with abandoned mines. The inherent dangers to man and fauna must surely be the prime consideration when assessing responsibility. Public safety and rehabilitation tend to be closely related phases when closing down mine workings. However, this being a meeting to present and discuss papers on rehabilitation, I must concentrate this communication around that aspect.

Before I progress very much further, I believe it to be essential to define 'Mine', 'Mining' and 'rehabilitation'. There are very few people who realise the wide variety of operations which are classed as a mine, and I have never yet found two people who fully agree on the meaning of rehabilitation.

Mine - To Mine - Mining

The Mining Act, 1904-1973 through which mining tenements are held, defines 'Mine' as -

> "Any land held, occupied, or used for mining purposes"

and 'Mining' or 'to mine' as -

> "All modes of prospecting and mining for and obtaining gold or minerals".

It can be seen from this definition that the Mining Act is primarily interested in gold and minerals; it does however include prospecting for those commodities.

There are, of course, many mining operations for other commodities such as rock, sand and gravel. It is for this reason that the Mines Regulation Act, 1946-74, has a far more embracing definition of a mine, and is as follows:

> 'mine' means a place where any operation to obtain any rock, metal, mineral or mineral substance for commercial purposes or for subsequent use in industry has been, is being, or is to be carried on, or where the products of such a place are transported, treated or otherwise dealt with and includes pellet plants, sinter plants, smelter and blast furnaces, privately owned railways built to transport the mine ore or material and the ore storage at the rail terminal, and quarries, together with any project for the time being declared to be a mine pursuant to subsection (2) of this section, but does not include steel making plants, rolling mills, administration offices, residential areas or recreational centres and the ground used in connection therewith;
>
> and,
>
> 'mining' or 'to mine' means to drill, blast, disturb, remove, cart, carry, wash, sift, melt, refine, crush or otherwise deal with any rock, stone, quartz, clay, sand, soil or mineral by any mode for the purpose of prospecting, developing or working a mine or quarry;

Consequently, a mine is not only a hole in the ground, but incorporates such places as alumina and nickel refineries, mineral sands plants, pig iron and pellet plants, talc grinding mills and rock crushing plants.

It can therefore be seen that a great many mines are located in, or very close to, established residential or industrial areas. The problems of rehabilitation are therefore very complex. Not only must the nature of rehabilitation vary greatly from mine to mine, but the organisations and authorities concerned with, and affected by that rehabilitation, vary from place to place.

Rehabilitation

Most dictionaries define rehabilitation as restoring something to its previous condition or former capacity. It is often said that 'nothing is impossible', but frankly it is impossible to restore a mined area to its previous condition. Unfortunately, there are many people who consider that rehabilitation should mean complete restoration to a previous condition and doggedly stick to their principles. Such people cannot be reasoned with. It is my opinion that rehabilitation of a mining property should endeavour to achieve the following:-

* The land should be established as a useful and functional property.
* It should serve the community by being either economically productive or a place for recreation, or both.
* The method adopted should be compatible with the local environment.
* The final result should be aesthetically pleasing.

Consequently, people and organisations responsible for rehabilitation must be enormously flexible, and capable of thinking of rehabilitation in terms relative to the future potential of the land, and not in terms of restoration to a previous condition. The word rehabilitation is thus used in the above context throughout this paper.

There are many mining operations, such as large open cuts and most underground mines, where only a token gesture can be made towards rehabilitating the land. In most cases, refilling of the workings is neither practicable nor economically feasible. Fortunately, most such occurrences tend to be well away from centres of large populations, and those that are not (such as Kalgoorlie) are generally accepted as a way of life by the local populace.

However, there are a considerable number of old mining centres throughout the State where abandoned mines and surface workings exist. It is probably the existence of these old mines which prompted the organisers of this meeting to put forward the title of this paper.

In a great number of these cases, it would not be desirable for such old mines and workings to be rehabilitated. Not only would the costs be disproportionate to the benefits gained, but the majority are old gold mines, many of which are repeatedly examined, and in some cases re-worked as a result of new finds or changing economic circumstances. It would not be in the best interest of the State to carry out rehabilitation of any old gold mine which would prevent its being reworked. The current rising gold price has created considerable activity in gold prospecting and has already resulted in a number of old mines being reopened.

Action - Where Public Safety Concerned

When an abandoned mine becomes potentially hazardous to the public, the Mines Department takes action to ensure the safety of the public. The growing population and the high degree of mobility which the people of this State enjoy, is increasing the public's contact with abandoned mines and workings. This, of course, is creating some problems with respect to their safety. Periodically the existence of such a situation is brought to the attention of the Mines Department by a Local Government Authority (L.G.A.), a member of the public, or by an officer of the department. In all cases an investigation is made by a Mining Engineer who reports on what action is necessary to safeguard the public.

In some cases, the L.G.A. concerned assists the Mines Department either monetarily or by the supply of manpower and equipment. This form of co-operation has worked well on a number of occasions when hazardous conditions have arisen.

In recent years, abandoned workings have been made safe at Kalgoorlie, Yalgoo, Galena (on the Murchison River) and at Collie. In the metropolitan area, a number of land owners have been successfully encouraged to make safe various sand and limestone pits which had ceased operations.

At Collie, an ever increasing amount of work is being undertaken on abandoned mines, which goes well beyond the 'safety only' aspect, by the two coal mining companies on leases held by them, and by the Mines and Forest Departments and Shire Council on land outside company ground.

A number of abandoned mines do exist throughout the Collie field and from time to time serious hazards arise. These may occur as collapsing shafts, adits, or underground workings, sometimes causing large and dangerous holes, or often as areas of hot ashes. Many old dumps and filled in pits contain quantities of coal which are set alight by bush fires. This coal may smoulder for months on end, completely unsighted and unknown to anyone. A number of serious burnings have occurred as a result of people walking over such areas and falling into the ashes when the soil crust has given way under their weight.

As a consequence, the Mines Department has been progressively removing these hazards as they become apparent, and together with the Forests Department are actively seeking out areas of potential danger.

Where old dumps have caught alight the department has had them bulldozed to form regularly contoured surfaces which are then covered with soil to prevent further burning of the carbonaceous material. Following this, the Forests Department has planted trees upon the old dumps.

Mined out areas which have been returned to the Forests Department as State Forest are now receiving considerable attention from that department. Some areas are being cleaned up and replanted as forest. The Stockton open cut, which now contains a large expanse of water, is being developed for public recreation with picnic and boating facilities.

Consequently, it can be seen that although no statutory provisions exist for the responsibility of rehabilitating old abandoned mines, the State has assumed responsibility where they are on Crown land and has taken action particularly in cases where public safety is involved. Where private land is concerned, the owner of that land must bear responsibility, and nowdays rehabilitation conditions are insisted upon by the Mines Department in the granting of mining tenements to authorise mining of the Crown's minerals on such land.

Responsibility - Present and Future Mines

Over the years, the State has become very conscious of the problem of rehabilitation and has taken positive steps to ensure that rehabilitation of present day mining operations is carried out on a progressive and continuing basis. In other words, the aim is to place the responsibility for rehabilitation with the operating company and to make every effort to see that rehabilitation is completed before the property is abandoned.

The State is achieving this by using one or more of the following methods:-

1. By entering into an agreement with the individual company and having that agreement ratified by Parliament;
2. by using the powers under the Mining Act, 1904-73, to grant mining tenements subject to strict environmental and rehabilitation conditions, sometimes subject to a bond, but always subject to loss of the tenement for failure of the holder to carry out the obligations imposed by those conditions;

3. by using powers under the Local Government Act, 1960-77, to grant extractive industries licenses on private land subject to strict environmental and rehabilitation conditions; and to a lesser degree,

4. by using the relevant safety requirements of the Mines Regulation Act, 1946-74, and Regulations.

Agreements

Companies intending to commence large scale mining operations are entering into agreements with the State, which are then ratified by Acts of Parliament. These agreements call for an 'Environmental Review and Management Programme' to be prepared by the company. The programme must contain plans for rehabilitation and be approved by the State for the operation to continue.

Mining Act, 1904-73

Other mining operations are permitted by virtue of mining tenements, conditional upon the relevant rehabilitation requirements being met. Such tenements are granted under the Mining Act which gives authority for conditions to be imposed, as necessary.

Most non-rehabilitated abandoned mines are an inheritance of the past because few, if any, rehabilitation conditions were added to the tenement certificates when granted. This is still fairly much the situation for tenements granted for gold and base minerals well away from populated areas or areas not regarded as being environmentally sensitive. If a large operation eventuates on such tenements, then an agreement as in (1) above may be negotiated. However, where a small operation eventuates, some would still have few rehabilitation requirements because generally the excavations are required for future prospectors and there would be little impact on the environment due to the isolation of the prospect.

The situation is very much different for tenements being granted for minerals which are obviously to be worked by open cut methods (e.g., mineral sands, silica and tin) particularly where such tenements are near populated areas. In such cases, interested Government Departments and the L.G.A. are generally consulted before the conditions are formulated.

Local Government Act, 1960-77

Excavation operations on private land for materials such as stone, gravel, sand, etc. which are not regarded as minerals for the purposes of the Mining Act, may come within the control of Extractive Industry by-laws made under the Local Government Act.

Providing the L.G.A. makes by-laws accordingly, it has the power to issue licenses for regulating such excavation operations. A set of model by-laws for use by Local Government has been gazetted and the L.G.A either adopts them in full, or follows them very closely. Most sand pits and blue metal quarries in the metropolitan area are licensed under such by-laws.

Ample provision can be contained in the by-laws to permit a local authority to fully control the rehabilitation of an excavation site. An authority can even carry out the work itself should the excavator fail to do so. The costs involved being redeemable, through a court of law.

Many authorities who have not adopted the by-laws do not impose rehabilitation controls but this is generally recognised as an indication that such excavations have not posed any great problems, or that there is very little private land in that particular district against which by-laws could prove effective.

Mines Regulation Act, 1946-74

The Mines Regulation Act and Regulations play a lesser role in the rehabilitation phase of mining. In fact, under Section 50 it is an offence to damage or render useless any shaft or mine workings, except on freehold land, without the consent of the inspector.

As previously stated, this Act is more interested in the safety aspects of abandoned mines, any rehabilitation occurring more as a side effect as a result of safety measures than as an intentional objective.

Heavy Metal Mobilisation from Lead Mine Tailings, Northampton, W.A.

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Abstract

This paper outlines preliminary results of an investigation to determine whether heavy metal mobilisation is occurring in lead mine tailings heaps in the Northampton district of W.A., and if so, whether they are being contained within the minesites.

Introduction

Lead mining has been carried out in the Northampton region since 1851, when the Lady Geraldine mine adjacent to the Murchison River was first opened. Since that date a large number of mines have been developed in the Northampton district. Many of the mines have only extracted high grade ore which has been sent untreated out of the district for secondary processing. A few of the larger mines have crushed the ore on site to produce a concentrate. Mines where secondary processing has occurred are characterised by the presence of unvegetated tailings dumps.

Two mines where secondary processing occurred were selected for the study - the Prothero mine located 20 km south-east of Northampton on a tributary of the Chapman River and the Galena mine on the Murchison River 70 km north of Northampton.

The Prothero mine is surrounded by agricultural land, the adjacent land being used for wheat production. Sheep have access to the minesite and are able to drink from the creek downstream of the mine. The drainage line from the minesite and tailings dumps flows into the Chapman River which is used by farmers as a source of stock water. Most house supplies are not drawn directly from the river, rather from shallow wells adjacent to the river.

The Galena mine, on the other hand, is surrounded by uncleared native shrubland and is immediately adjacent to the Murchison River.

Sampling Procedure

At both minesites samples were taken of:

a) surface tailings;

b) downstream sediment;

c) water.

In an attempt to determine whether heavy metals from the tailings are being concentrated by organisms in the natural environment, one dozen oysters were collected from Kalbarri which is situated 70 km downstream of the Galena mine at the mouth of the Murchison River. The oysters were divided into three groups and each group analysed for heavy metals, the results being expressed in terms of wet weight.

Analysis of all samples was by flameless atomic absorption spectrophotometry.

Results

The results are given in tabular form with heavy metal concentration from soil samples expressed as parts per million and from water samples as micrograms per litre.

Table 1. Soil samples at Prothero lead mine

Site description	pH	Metal concentrations (p.p.m.)				
		Cu	Pb	Zn	Cd	As
Surface material of tailings	4.5	42 000	1 200	1 250	46	200
Surface material of tailings	3.5	2 750	8 730	4 250	20	150
Creek sediment immediately downstream of mine	4.1	1 600	1 100	8 700	6.1	-
Chapman R. sediment 2 km downstream of mine	5.5	42	219	337	1.0	2.0
Soil samples above flood level 2 km from mine	7.0	396	231	101	4.0	2.0
Soil sample mouth of Chapman R.	8.2	9.0	168	21	2.0	2.0

Table 2. Water samples at Prothero lead mine

Site description	pH	Metal concentrations ($\mu g l^{-1}$)				
		Cu	Pb	Zn	Cd	As
Seepage immediately downstream of mine	3.3	3 120	2 630	105 000	65	9
Stream sample 2 km downstream	7.2	27	70	140	< 1	6
Chapman River mouth	7.7	18	27	27	< 1	10

Table 3. Soil samples at Galena lead mine

Site description	pH	Metal concentrations (p.p.m.)				
		Cu	Pb	Zn	Cd	As
Galena tailings dump	6.3	1 220	13 000	6 010	16	25
Stream sediment 100 m downstream of mine	6.3	882	21 500	3 690	3	35
Sediment sample at junction of creek draining mine into Murchison R.	6.6	57	3 800	355	5	< 0.5
Sediment sample 50 m downstream of creek junction	7.4	451	3 490	2 630	3	3
Sediment sample 400 m upstream of creek junction	7.9	14	63	87	1	2

Table 4. Water samples at Galena lead mine

Site description	pH	Metal concentrations $\mu g l^{-1}$				
		Cu	Pb	Zn	Cd	As
Murchison R. 300 m from mine (stagnant pool)	7.0	6	40	15	< 1	10
Galena open-cut	6.6	150	2 000	14 000	20	10
Murchison R. mouth	7.2	3	1	3	1	10

Table 5. Oyster samples from mouth of the Murchison River.
Results expressed in terms of wet weight for three replications.

Replication number	Cu (p.p.m.)	Pb (p.p.b.)	Zn (p.p.m.)	Cd (p.p.m.)	Hg (p.p.b.)
I	20	190	117	0.6	0.05
II	28	280	187	1.0	0.03
III	27	250	174	0.8	0.04

Discussion

The water analysis figures should be viewed in terms of the World Health Organisation International Standards for Drinking Water (World Health Organisation 1971). These are given in Table 6.

Table 6. W.H.O. International Standards

Element	Concentration $\mu g l^{-1}$	Notes
Cu	1 500	2
Pb	100	1
Zn	15 000	2
Cd	10	1
As	50	1

Notes: 1 Suggested tentative limits for toxic substances in drinking water.

2 Maximum permissible limits for drinking water.

The results indicate that copper, lead, zinc and cadmium are being mobilised from the sulphide wastes on exposure to the atmosphere and that these metals are being concentrated in the acid environment of the tailings dumps. Furthermore, results show that effluent from the tailings dumps is highly toxic, e.g. Prothero effluent is as follows: (μg/litre)

pH	Cu	Pb	Zn	Cd	As
3.3	3 120	2 630	105 000	65	9

These values for lead, zinc and cadmium are many times greater than the maximum permissible limits outlined by the World Health Organisation (see Table 6). However, in less than 2 km the drainage water (probably as a result of increase in pH and dilution effects), is well within the limits suggested by W.H.O. While this toxic effluent is rapidly diluted downstream from the minesite, sheep do have access to this polluted seepage and those few plants growing immediately adjacent to it. It is quite possible, therefore, that heavy metals from these tailings could find their way into the biological, and perhaps even the human food chain.

It is well known that many shellfish take up and concentrate heavy metals which occur in their environment (Bloom and Ayling 1977). The oysters at Kalbarri illustrate this effect. Copper, for example, is higher in these oysters (20-28 p.p.m. - Table 5) than in the waters of the Murchison R. mouth (3 μg/litre - Table 4). Furthermore, these copper levels in oysters appear elevated when compared to those from cultivated oysters (3-11 p.p.m.) in the relatively uncontaminated Tweed R. in northern New South Wales (Mackay *et al* 1975). The Australian National Health and Medical Research Council recommended maximum concentration for copper in seafoods is 30 p.p.m. wet weight (cited by Mackay *et al* 1975).

Conclusions

This preliminary work suggests that:

1. The sulphide tailings are being oxidised on exposure to the atmosphere, and the resulting acid environment is causing a mobilisation of heavy metals.
2. As a result of inadequate design standards for the tailings disposal, retaining walls have failed and toxic effluent is leaving the minesite.
3. Heavy metals are escaping into the environment and are being fixed, and perhaps concentrated in the biological food chain.

Further work will continue to define the situation at these minesites, and to quantify the extent to which heavy metals are being released into the environment with the aim of determining whether past tailings design criteria are adequate in protecting the environment after the decommissioning of mines.

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Bauxite Residue Rehabilitation at Alcoa of Australia Ltd.

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Introduction

Kwinana and Pinjarra refineries have respective annual alumina production capacities of 1.4 and 2.2 x 10^6 t. In order to service current Alcoa alumina production levels, a total of 12.5 × 10^6 of Darling Range bauxite is mined annually.

Alumina is extracted from bauxite by the Bayer process. At both refineries a caustic soda solution circulates, initially dissolving hydrated alumina from the bauxite. This solution then undergoes clarification in which solid wastes are separated. The solid wastes form a red mud slurry, still containing some caustic soda. Production of alumina from Darling Range bauxite yields a little over two tonnes (dry weight) of waste material for each tonne of alumina produced.

This annual volume of residue (approximately 7.5 x 10^6 t) is deposited in sealed impoundments especially constructed for residue disposal. The water which settles with the residue contains dissolved caustic soda and sodium carbonate. The concentration of lake water averages 12 g/l total alkali. Lake water readily reacts with carbon dioxide on exposure to the atmosphere and converts the sodium hydroxide to sodium carbonate.

Bauxite residue consists of a mud fraction, approximately 70 per cent of which is 325 mesh size, and a sand fraction, of which approximately 95 per cent is 80 mesh size. There is only a small quantity of material in the intermediate particle-size range. After deposition, the residue can separate differentially according to particle size. This particle size effect can create areas of soft mud in the filled lakes which require special rehabilitation techniques.

The bauxite residue presents both physical and chemical rehabilitation problems. This paper presents a brief description of how these problems can be overcome.

Rehabilitation can be defined in the following terms:

* Rehabilitation is the return of an area to a stable state with long term productive uses.
* Rehabilitation is the last stage of an operation; but must be considered in the planning stage.
* Successful rehabilitation of an area concludes when the planned future land use is being carried out.

At Pinjarra refinery, bauxite residue areas are situated on land formerly used for grazing. Rehabilitation at this site will be aimed at returning the residue areas to grazing.

At Kwinana, future land use options are much more complex. The bauxite residue is deposited several km from the refinery in an area surrounded by urban, industrial, agricultural and recreation pursuits. Rehabilitation at Kwinana has been aimed at demonstrating a wide range of possible future land uses. At Kwinana three mudlakes have undergone the initial stages of rehabilitation. Two are now capable of supporting permanent pasture and seasonal grazing of sheep.

The establishment of a pasture is seen as the first working stage of rehabilitation. Once a pasture is established and livestock introduced, a rapid nutrient cycle is initiated. With this cycle initiated, soil fertility increases and can be raised to the level necessary for future land use. If open park land were envisaged, two years of pasture and grazing development would provide adequate base fertility. Market gardening would require more; light industry less, if any.

The problems that must be overcome in establishing permanent pasture on a bauxite residue disposal area are:

* Presence of pH levels up to 11.5.
* Absence of soil nutrititional and structural properties.
* Some soft mud areas incapable of supporting mobile equipment.
* Wind erosion.
* Potential dust damage to plant growth.

Identification of these properties has enabled selection of an amelioration technique which can convert process residue into a soil medium prior to revegetation.

It is essential to know the chemical and physical properties of any material being rehabilitated.

The mixing of hot caustic soda solution and crushed bauxite during refining ensures that the residues are saturated with sodium. The residue soil prior to rehabilitation is characterised by:

* A high total level of dissolvable salts which can reach 10,000 ppm in the top 5 cm.

* A very high free sodium ion concentration in the soil solution. This concentration is well above toxic levels in most plants.

* Soil pH ranging from 10.5 to 11.5 with associated nutrient availability problems.

* Clay setting hard on drying causing seed emergence and water infiltration problems.

These difficulties are further exaggerated by the seasonal water table fluctuations. In Western Australia's Mediterranean climate, the high winter rainfall can lead to above-surface water tables. This can cause partial redistribution of caustic material throughout the profile. During summer the water table falls, but capillary rise and subsequent evaporation can cause an increase in total dissolved solids at the surface.

Procedural Alternatives

The seasonal water table fluctuation is being overcome by the use of an eductor system which is essentially a series of jet pumps which withdraw liquor from the bottom of the residue. The water retrieved is pumped into an operating mudlake and eventually re-used, forming a large proportion of the water used in the refinery. The eductor system, therefore, controls the water table level and at the same time recovers water and caustic soda for re-use in the refinery process.

The eductor system maintains the lowered water table. Pumping and supplementary irrigation will be necessary until soda concentrations are sufficiently diluted by rainfall, at least in the surface layers to allow a normal agricultural drain system to be operated.

The alternatives for long term management of the area are:

* Subsurface drainage

* Surface drainage

* Continued long term pumping

* Cropping with salt tolerant species

* Surface sealing of the lake

* Use residue as a resource.

Gypsum has been looked at as an amelioration treatment for high sodium content and for reducing the high pH of the residue. In a pot trial, improved germination of cereal rye has been obtained with increased application rate of gypsum (see Table 1).

Table 1. Germination of *Secale cereale* L. (cereal rye) in bauxite residue at different levels of gypsum ($CaSO_4.2H_2O$).

Gypsum (t/ha)	Germination %	pH
0	2	10.5
25	0	10.5
50	1	10.2
100	6	9.6
200	53	8.4
400	66	8.1

Gypsum is a 'waste' product of superphosphate production.

Bauxite residue does not contain organic matter and, therefore, does not possess the buffering and nutrient storage properties of a normal soil. Residue chemical properties reduce biological activity by soil fungi and bacteria. Thus, organic matter must be introduced, usually in the form of fowl manure or sewerage sludge. These, too, are also 'waste' products. These is a low level of all essential plant nutrients in bauxite residue, with chemical fertilisers currently fulfilling requirements.

As a consequence of differential settling for the different residue fractions, all filled disposal areas have areas of coarse sand interspersed with areas of fine mud, reflecting the pattern of dumping points. The sands represent much less of a problem in revegetation than do the mud areas. The coarse sand, although structureless, does possess voids which allow rapid infiltration. This permits soda to be dissolved and flushed down the profile. To further improve infiltration, ripping to 60 cm depth at 60 cm centres was carried out on the rehabilitated lakes at Kwinana in 1977 and 1978 to break up the hard setting surface.

The soft mud areas are currently covered with coarse sand to permit equipment to travel over them. This requires a massive earthmoving operation and is, hence, a costly exercise. It is not always possible to cover all mud areas, even the old, relatively small, filled lakes at Kwinana. The size of the lake now operating at Kwinana is 165 ha, making it essential to periodically rotate the dumping point to assist the even distribution of residue and minimise the formation of mud lenses.

Wind erosion can occur on the mudlakes prior to the establishment of a vegetative cover. The windblown material is, for the most part, the bauxite residue itself and sodium carbonate. Other materials can adversely affect plant growth. Benefits, therefore, are obtained by wind erosion control. In the long term wind erosion is controlled by revegetation but before this is carried out dust blow from the lake surface is controlled in a number of ways:

* Straw mulch and bitumen emulsion
* Bitumen emulsion alone or other surface sealant
* Crimped straw mulch
* Rocks randomly spread on the soil surface
* Hydromulcher technique
* Deep ripping and surface roughening.

Having modified the bauxite residue by ripping, deliquoring stabilisation, application of organic fertilisers and cultivation, it is possible to sow a crop of cereal rye and rye grass (*Lolium perenne* L.) With proper grazing management, permanent pastures can be established.

One residue area of 20 ha at Kwinana self-regenerated from seed during the 1978 winter. This occurred four years after rehabilitation with the present method.

During early 1978, a wide range of vegetables was successfully grown on the surface of Kwinana A lake. The vegetables were grown according to standard local horticultural practice. The irrigation water was pumped from a bore adjacent to the rehabilitated lake.

A range of *Eucalyptus* and *Acacia* species, principally for ornamental purposes, will be planted on Kwinana residue areas in winter 1979. This will follow 4 years of trials of their tolerance to the soil conditions in these areas.

Conclusions

A wide range of possible future land uses is being demonstrated at Kwinana including rehabilitation, pasture production and vegetable production. With further residue settlement, light industrial development will most likely be a practical proposition. This will provide each of Alcoa's refinery locations with a range of management alternatives for future filled residue areas.

Goldfields Dust Abatement

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Introduction

Deteriorating seasonal conditions from 1969 to 1972 caused a prolonged drought and a resurgence of the dust problem to the residents of Kalgoorlie and Boulder, culminating in the very large dust storm of October 6th 1972. This caused a public outcry which finally resulted in the formation of the Goldfields Dust Abatement Committee (G.D.A.C.), comprising representatives of local government, mining and local industry, state government, service clubs, media and the general public. The G.D.A.C. functions under the auspices of the Department of Conservation and Environment, with a technical sub-committee consisting of Mrs J. Verschuer, landscape architect and consultant to Western Mining Corporation, R.H. Hacker, Department of Agriculture and P.C. Richmond, Forests Department.

Three main sources of dust were identified:

1. Within the towns, areas bare of vegetation.
2. Periphery of the towns, areas denuded in the past and subject to grazing or areas of woodland subject to unrestricted vehicle, pedestrian and animal movement.
3. Mine waste dumps.

Subsequent to the drought, there followed an unprecedented three year sequence (1973-75) of rainfall well above average. This was responsible for the development of a dense ground cover in and around the towns which virtually eliminated the dust hazard from undisturbed areas. The effect of this dense cover is still evident but is declining, after below average rainfall in 1976 and 1977.

Dust Abatement

A number of measures have been implemented to date for the different areas.

Within Towns

Publicity, to make the general public aware of the problem and how to alleviate it, was the initial approach. Various avenues have been used: public meetings, publication of a brochure, talks to schools and service clubs, display at the community fair, radio and television interviews and sustained news reports in local newspapers and on radio.

An annual tree planting programme of at least 300 trees is financed by the committee. To date 2,000 trees have been planted in vacant and denuded areas within and around the towns. Only arid area species are planted and are irrigated as necessary for the first year only. An average survival rate of 70 per cent has been achieved and this is considered satisfactory. The beneficial results of the earliest plantings in 1973 are now evident.

A wood chipping machine was purchased and utilized by local councils and institutions to obtain a suitable ground mulch cover from trees which had to be removed during construction works. With current water restrictions, numerous householders are laying mulch around their houses. This is strongly recommended and every help and encouragement is given by the committee.

As laneways were a constant source of dust, bitumenizing has been recommended to local councils but has not been undertaken because of its high cost. Chemical sealing with 'Petroset' was tested but was very costly and was not sufficiently durable.

Periphery of Kalgoorlie and Boulder

Previous habitation and domestic grazing has resulted in quite large tracts of denuded land in the immediate vicinity of the towns. For the remainder, the natural bush is broken up with miners' homestead leases, rubbish disposal areas, gymkhana and motor racing sites and old dairy holdings.

The technical committee recommended that vermin proof fenced regeneration zones, about 1.6 km in width, be created around Kalgoorlie and Boulder. In 1974-75 the first (No. 1 zone) was established to the north-west of Kalgoorlie covering 1550 ha. There were a number of unforeseen problems which included land tenure, council gravel pit, rubbish dumps and access. In the final form, the No. 1 regeneration zone was a compromise of a fenced area with limited access. Experience has now shown even limited access defeats the purpose of obtaining an undisturbed area of vegetation which will flourish during good seasons and last through adverse seasons, thus minimizing the dust problem. Where feasible, access will now be restricted by construction of internal fences.

The No. 2(A) regeneration zone of 160 ha was created to the north of the towns in 1978. There is restricted access into this area, but vandalism of the fence has occurred spasmodically. It was found that very little, if any, damage occurred where there was no access track alongside the fence. In future, the fence will be separated from the access track by several metres of undisturbed land.

Two further areas, regeneration zones 2(B) and (C) are programmed to the north-east of the towns. It was recommended that a third zone be created to the south of Boulder, however existing land tenure would result in the zone being too far from the residential areas to be of any great benefit.

Mine Waste Dumps

These are the major dust hazard, especially to Boulder, as their surface area is approximately 475 ha of largely bare ground. In 1974 W.A.I.T. AID was financed by G.D.A.C. to investigate factors influencing the natural colonization of the dumps and make recommendations on species most suitable for colonization.

Very briefly, this study (B. Lamont, unpublished data) found half the dumps showed signs of colonization. Those were mainly the older, lower, smaller, more isolated and less steep dumps. There were only minor differences in overall chemical, physical and biotic characteristics of the vegetated and non-vegetated dumps and there was no evidence of cyanide or heavy metal contamination. Lack of colonization on bare dumps was due mainly to lack of seed source and absence of suitable sites for seed to lodge. Run-off from bare dumps was seen as a factor in limiting the effectiveness of rainfall. Analysis for N and P suggested these elements would be required to ensure rapid plant establishment.

During 1974, Dr. J.K. Marshall became interested in the dust problem and the G.D.A.C. adopted a research proposal submitted by him on the placement of rock fragments on the dump surface. Initial monitoring of saltating particles commenced in late 1975, varying intensities of rock fragments were placed during 1976 and monitoring continued and results evaluated (Marshall *et al* 1978).

Contour Bank Experiments

During 1978 a number of contour banks were constructed on both a high and a low dump. Some smelter slag was incorporated into the banks and segments of banks were treated with 'Vigran' or superphosphate at rate of 2 kg per 20 m. Early results of the project were encouraging on the low dumps as good natural revegetation resulted (see Table 1). However, no germination whatever occurred on the high dump, presumably due to lack of a seed source.

Table 1. Plant counts August 1977, first contour bank experiment on a low dump

	Treatment		
	'Vigran'	Superphosphate	Control
Mean No. of plants per metre of furrow	1.75	3.79	0.44

Plant survival one year later was reduced to some extent but the superphosphate treatment was still the most effective and has been adopted as the standard treatment.

In December 1977/January 1978, a further dump of 36 ha was treated. After levelling, contour banks were formed at 0.5 m vertical intervals and rock fragments applied at 40 t/ha costing $563/ha. An area of 6 ha was treated with superphosphate at the rate of 250 kg/ha. In June 1978, *Atriplex nummularia* Lindl. was planted, as a potential seed source.

Direct seeding of native species was also attempted in 1975 with much the same results as the 1976 experiment. There was good early germination of *Acacia graffiana* F. Muell., *A. aneura* F. Muell. ex Benth and *Atriplex vesicaria* Miq. but poor germination of several eucalypts. Survival of all species was drastically reduced by the dry seasons of 1976 and 1977.

Conclusions

For the future, the G.D.A.C. will continue to be an active body. It will attempt to improve the awareness of the general public of what can be done to reduce the dust nuisance around the town. It will also attempt to have regeneration zones accepted as an amenity for the benefit of all residents and continue with an annual tree planting programme.

Finally, it will continue research on the slime dumps and aim for a self-sustaining vegetative cover which will retain the aesthetic value of the dumps ('pyramids'), and yet minimize the occurrence of dust.

Reference

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