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Restoration Following Bauxite Mining In Western Australia

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Introduction

The Darling range of south-western Australia is the world's leading producer of aluminum, accounting for approximately 38% of the world production in 1994 (Matlox 1999). In 1995/96 production of alumina reached 8.2 million tones and was valued at approximately $1,918 million (Chamber of Mineral and Energy 1999). Alumina is refined from bauxite with the principal mining sites located at Jarrahdale, Del Park, Huntly, Willowdale, and Mount Saddleback.

At the time of European settlement in western Australia the Jarrah Forest occupied approximately 3,300,00 ha of the region (Wolf 1998). Today there are only 304,500 ha of unlogged or unaltered forest left, of which 135,000 ha is in national parks, nature reserves, and conservation park. Conservation parks are protected from logging and mining (Wolf 1998). Currently, Aluminum Company of America (ALCOA) mines and rehabilitates approximately 450 ha of this forest each year at open-cut mines which are located between 55 km and 130 km south of Perth, the capital city (Ward et al. 1996). The population of Perth is approximately 800,000 and because of this close proximity to the capital, bauxite mining is being done on lands that are subjected to multiple usage. These uses include urban water catchment, timber production, recreation, and flora and fauna conservation.

Reclamation of bauxite-mined lands in western Australia began in 1966 three years after ALCOA of Australia commenced mining operation (Tacey and Glossop 1980). In the early years of ALCOA's reclamation program, the goal was to establish a stable, self-regenerating forest ecosystem. To achieve this goal the plan was to enhance or maintain water, timber, recreation, and other forest values. In recent years the emphasis has changed to restoration of the Jarrah forest after mining and re-establishing the high botanical diversity of the Jarrah forest (Ward et al. 1996).

Regional Description

ALCOA of Australia mines bauxite from the Darling Range in south-western Australia in an area known as the Jarrah Forest. The Darling Range is a mountainous region characterized by a dissected, uplifted peneplain with elevations of 300-400 meters above mean sea level (Tacey 1979). Bauxitic laterites occur as a shallow mantle over deeply weathered kaolinitic clay which is derived from the genesis of granites. The topsoil in the mined region is sandy gravel with an average thickness of 40 cm over the ore (Tacey 1979).

This area of south-western Australia is strongly influenced by seasonal Mediterranean climate with most rainfall occurring in the winter months of May to September (Wolf 1998). Mean annual rainfall ranges from 1255 mm in the interior to 635 mm near the coasts. Average monthly temperature ranges from 16^{o}C in the winter to 27^{o}C in summer (Wolf 1998).

Dry Sclerophyll forest occurs throughout the region with the dominant vegetation being *Eucalyptus calophylla* and *Eucalyptus marginata* Sm. (jarrah); hence the name Jarrah Forest. Species of *Casuarina* and *Banksia* along with native legumes, and various shrub, sub-shrub, and herbaceous species occur as understory trees (Grant et al. 1996, Tacey 1979). Over

200,000 ha of the forest is affected by the jarrah dieback disease caused by the pathogenic root fungus *Phytophthora cinnamomi* and, as a result, one of the main objectives of reclamation is the replanting of trees for timber production (Tacey 1979). *Eucalyptus* spp. and understorey trees in above mentioned forested region also provide a source of native species for the bauxite restoration program (Ward et al. 1996). The control of the dieback disease is therefore important if this propagule source to remain vaible.

Mining Operation

A major portion of the mining activity in south-western Australia is done at three main sites (Tacey, 1979).

1. Jarrahdale mines began operation in1962 and serve the Kwinana alumina refinery on the coast. This operation involves clearing, mining and rehabilitation of approximately 100 ha per year while producing 1.4 million tons of alumina.
2. Del Park mines supply the Pinjarra refinery. Del Park began production in 1972.
3. Huntly mines, which began operation in 1976, also supply the Pinjarra refinery and together with the Del Park mines produce 2.4 million tons of alumina. Clearing and rehabilitation by these two mines account for approximately 170 ha per year (Tacey 1979). Production in these three areas has since increased.

During the wet winter months drilling activities are suspended to prevent the spread of the jarrah dieback disease year (Tacey 1979). The disease is caused by a fungus which attacks the root systems of the jarrah and various understory species and can be easily transported in soil adhering to vehicle tires, especially in the rainy season. Once this rainy season is over, ore definition is carried out by a rubber tired drill rig that is designed to cause minimal forest disturbance. Following the approval of the Western Australian Forestry Department, usable timber is extracted by contractors prior to mining. The residual vegetation is then heaped into windrows and burnt (Tacey 1979). The gravelly sand surface covering the bauxite is then stripped and removed in two layers. The top 10-15 cm, referred to as top soil, is first removed followed by the removal of an additional 40 cm known as the overburden. The overburden and topsoil which contains most of the soil organic matter, nutrients, microorganisms, and seeds are stockpiled for future use or directly respread on areas ready for rehabilitation (Ward et al. 1996, Tacey 1979). The bauxite is mined using front-end loaders, power shovels, or hydraulic excavators and loaded in large trucks that can carry 50 to 100 tones. Australian bauxite is considered low grade and it takes 3 to 4 kg of bauxite to produce 1 kg of alumina (Hickman et al. 1992). Blasting is sometimes done to break-up cemented-cap rocks. After removal of the overburden, mine pits are typically 4.5 m deep with compact clay floors.

Reclamation Process

Since the commencement of bauxite mining in 1963, methods for reclamation of bauxite mines have evolved over the years in response to information obtained from monitoring the result of previous techniques, and in response to environmental pressures by land users outside the mining area.

Past Reclamation Practice

In the 1960's forestry production was the main objective of the Australian Forestry Department and as a result no under-story treatment was required (Tacey 1979). Topsoil that had been stockpiled was respread and directly planted with potential timber producing trees such as *Eucalyptus* and *Pinus* species in a plantation style with 4m x 4m pattern (Tacey 1979). The *Eucalyptus* was selected because it was fast growing. These early plantations suffered from windthrow due to insufficient root penetration of the compact clay soil as the trees increase in size.

In 1971 ALCOA and the Forestry Department initiated a co-operative tree nutrient trial using inorganic fertilizer to improve nutrient level above those achieved in the 1960's. To overcome the compaction problem, a new technique of subsoil ripping was introduced. Ripping is an operation frequently carried out when preparing forest sites prior to planting and is a measure designed to loosen compact layers. In the case of bauxite mining activities, during the process of regrading and filling the mined sites, soil compaction by tractors became a problem. The ripping process however often left shallow depressions along these rip lines which would result in rapid runoff and soil erosion. To avoid the above-mentioned problems and to promote water penetration and storage, rip lines were made to follow contour lines and done to a depth of 1.2m which proved successful against the problem of windthrow (Tacey 1979, Hickman et al. 1992).

Protection of water catchment areas was also another major priority of the Australian government. The initial use of settlement ponds and level concrete overflows proved ineffective in preventing turbid runoff (Tacey 1979). In response ALCOA decided to confine in-pit runoff within the individual pits where infiltration was the dominant process. This was done by battering the faces of the pits to a slope of less then one in two which was an attempt to reduced the slope angle. This technique reduced the rate on runn-off, soil erosion, and increased infiltration within the pits. The in-pit runoff efforts relied on infiltration to dissipate surface flow.

Present Reclamation Practice

Two decisions were made in regard to managing mined lands in the mid 1970's (Tacey 1979). First, rehabilitation plans were prepared before submitting clearing applications to the State authority. These first set of plans included mining sequence, access, erosion control, earthworks, and contouring used to prevent turbid runoff during and after mining. Second, the Western Australian Forestry Department, recognizing that mining was a transient land use, stated that reclamation of bauxite mined sites should target re-establishing stable biological systems. Thus the following long term land-use goals were outlined; i) water supply, ii) wood production, iii) recreation and tourism, iv) flora and fauna conservation, and v) science and education. The continued provision of community corridors was also required (Tacey 1979). Legal requirements for mining, however, differed between areas. At Jarrahdale, ALCOA was only required to spread previously stockpiled topsoil then hand the mine back to the State Forest Department for replanting. At Del Park and Huntly, ALCOA was required to do restoration and reforestation at their own expense. There was also the requirement that efforts to prevent soil erosion and deep water pooling be undertaken at these two sites. The reason for this difference in legal requirement was not stated but the inference could be made that because Jarrahdale was the first site mined in Australia, the legal requirements was less stringent. Over the years, legislation became progressively tougher as rehabilitation techniques improved, land-use objectives became better defined, and outside pressure from the public increased (Tacey 1979, Hickman et al. 1992).

Reclamation of mined lands in the Darling Range of Australia now include the battering down of all vertical faces of mined pits to a slope less than one in two which proved to be safer and more aesthetically pleasing (Hickman et al. 1992, Ward et al. 1996). During the summer months, contour ripping to a depth of approximately 2 m was done to promote maximum lateral cracking of the clay. This task is done with an Allis Chalmers HD41® or Caterpillar D10® bulldozer specifically purchased for this job. To check overland flow and increase infiltration in pit banks and mounds of soil were constructed at heights of 1-2 meters along contour lines with 10 meters intervals. In the event of an extreme rainfall event, pipe overflows with 0.3 meter diameter and at a height of 0.6 meter were put in place .

Stockpiled topsoil was used to restore mined sites to the average depth that existed before mining. Topsoil replacement was done during the dry season. Stockpiling involved stripping the site to an average depth of approximately 40 cm and placing this topsoil in an unconfined heap

10 meters high for two years before it was respread on a mined site. This practice of stockpiling changed after 1979 when all rehabilitation sites at Jarrahdale and a quarter at Huntly had the top

5 cm filled with topsoil freshly returned from another mine site that had just been cleared. This process is known as double-stripping (Tacey 1979). Double-stripping involves spreading topsoil that had been stockpiled for two years onto a mined area to a depth of 40 cm and then covering with a 5 cm deep layer of soil that has been freshly removed from another unmined site (Tacey and Glossop 1980). This technique resulted in greater cover, more species, and increased groundcover that supported about half the live plant cover of a mature forest soil. This proved to be a better technique for revegetation of the mined areas. Soil stockpiled over a long period of time often resulted in the soil loosing it's biotic activity, structure, and nutrient status, particularly nitrate. Thus the soil becomes basically inert and requires a large amount of fertilizer application to restore the nutrient status. Double-stripping could therefore be more cost effective and result in a faster rate of recolonization of plants on these sites.

Direct transfer of topsoil is achieved by a process called windrowing where the top 5 cm of topsoil is first scraped by a grader from the surface, piled in rows, and then loaded onto trucks. This first load is then dumped at pre-determined intervals where it is again graded out to 5 cm thickness. These soils are often the seed bank for emerging species, but the sites are also planted with seeds grown over the summer.

Seed Source and Revegetation

After regrading these mined sites, the final stage is the re-vegetation of the areas. A combination of seed collection and direct topsoil transfer techniques are used to establish the vegetation on mined areas (Tacey 1979). Understorey shrub seeds are collected by hand from the forested area and on-site native seed orchard during the summer. This is to ensure that the composition of the forest in the mined areas are similar to the original forest cover. (Hickman et al. 1992). The species are selected on the basis of : 1) Their natural occurrence in the jarrah forest. 2) Their adaptation to early successional stages i.e. species that are capable of rapid growth and having nitrogen fixing ability. 3) the ease of collection (Tacey 1979). Common species include *Banksia grandis* (bull banksia), *Allocasuarina fraseriana* (sheoak), *Trifolium subterraneum* (subterranean clover), and *Xylomelum occidentale* (woody pear) to name a few (Ward et al. 1996).

Planting begins in the month of June and usually about six weeks after the first summer rains. With the timing of the rains there is usually no need for irrigation and plants are planted along the contours at 4mx4m spacing. The success of the re-vegetation program has been varied. Tacey (1979) reported an average survival rate of 85% for a study site in western Australia following bauxite mining. If the survival rate was below 80%, the failed tree were replanted the following year. In other cases, plant diversity has sometime been below expectation on these rehabilitated sites and is often attributed to the differences in the timing of the various rehabilitation procedures (Ward et al. 1996). The explanation that timing is the cause of reduced plant diversity may not be entirely true because of the effect of landscape scale stresser (factors that alter the original composition or processes of a site at either the landscape or site scale) such as hydrology and change in drainage pattern. After mining pits are regraded to reduce erosion and in the process the original topography of the land is altered thus changing the drainage pattern as well. This alteration introduces a streser on the site which can also affect the re-colonization of plants.

Hickman et al. (1992) also reported that rehabilitated areas attracted back approximately 85% of the animal species and a rapid reintroduction of invertebrates. Live cover, litter cover, and the number of species present on topsoil sites that have been directly transferred have double those on stockpiled sites and the diversity values is also closer to those of the neighboring forest community after 3 years (Tacey1979). There was however a lack of birds which require hollow branches as nesting site (Hickman et al. 1996).

Conclusion and Recommendation

The reclamation of bauxite mined lands in Australia has evolved over the years since production started in 1963. These reclamation efforts involve the establishment of stable communities of plants in an effort to satisfy the Government of Australia long term land-use objectives. As a result early reclamation techniques included the planting of *Euclayptus spp.* for timber production and erosion control was later improved on as reclamation techniques changed.

Improvements in reclamation techniques and adjusting the timing of topsoil removal and replacement have lead to better ways of controlling erosion on these sites, improve aesthetic, and revegetation of these sites. The Australian count there efforts as examples of successful restoration techniques. It is evident from this account of reclamation of bauxite mined lands in Australia that techniques are dynamics and the important thing is to learn from the pass attempts.

Thus the process of restoration involve constant re-evaluation in an effort to improve on what was done before.

To further improve restoration success of bauxite mined lands it is recommended that in addition to looking at the internal (site scale) factors, ALCOA should also examine the external processes or landscape scale factors. Erosion problem resulting from the removal of trees is the main focus of physically restoring mined sites and thus the grading of these areas are often be site specific in an effort to ameliorate the problem. This process can often alter the drainage pattern of the area and consequently affect ecological restoration.

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