Restoring jarrah forest in southwestern Australia after bauxite mining

Andy Seiser

Introduction

Alcoa of Australia Limited is the world’s largest bauxite miner and alumina refiner. This company has mined bauxite in the jarrah forest in western Australia since 1963, and the first restorations were carried out in 1966 (Koch and Ward 1994). The goal of rehabilitation is to establish a “self-sustaining, jarrah forest ecosystem that maintains the water, timber, conservation, recreation, and other values of the pre-mining forest” (Ward et al. 1997). The jarrah forest of southwestern Australia is classified as open forest in the north and tall forest in the south (Dell and Havel 1989). The overstory is dominated by jarrah (30-40 m), the understory is composed of small trees (4-7 m), and the groundcover consists of woody shrubs and grass-trees (Dell and Havel 1989). Research done by Alcoa has shown that mine sites rehabilitated in the past are becoming more like the surrounding, unmined forest. Because of the evolution of mining techniques and extensive long-term monitoring, future rehabilitations will continue to produce quality ecosystems.

Site Description

Historically, three mine sites were operated by Alcoa of Australia Limited at Jarrahdale, Huntley, and at Willowdale on the Darling Plateau between 55 km and 130 km south of Perth, the capital of western Australia (Ward et al. 1996). The Jarrahdale mine was closed in 1998, after producing about 168 tons of bauxite in its lifetime. Approximately 12,400 ha of forest have been cleared since mining has begun, with an annual clearing rate of 550 ha (Alcoa 2001). Thus far, more than 10,500 ha have been revegetated with rehabilitation costs averaging $20,000 to $22,000 a year. A total of $13 million is spent annually on research, planning, environmental operations, and rehabilitation (Alcoa 2001).

The climate of the mining area is Mediterranean with cool, wet winters and dry, hot summers. Rainfall at the mine sites range from 1200 to 1400 mm a year (Koch and Ward 1994). Average daily maximum temperatures of 30 ºC occur in the hottest months of January and February. The coldest month is August, where high temperatures only reach 15 ºC (Koch and Ward 1994).

Koch and Ward (1994) describe the sclerophyll vegetation of the area as dominated by jarrah (Eucalyptus marginata), with varying proportions of marri (Eucalyptus calophylla). The most common middlestory species include Banksia grandis, Allocasuarina fraseriana, Persoonia longifolia, and Xylomelum occidentale. Understory species of the area are from the families of Liliaceae, Leguminosea, Orchidaceae, Apiaceae, Epacridaceae, Asteraceae, Restionaceae, and Cyperaceae (Koch and Ward 1994). More than 200 species of plants have been found at the Jarrahdale and Huntley mines in pre-mining surveys (Ward et al. 1996).

Soils of the Darling Range are ancient, and formed largely by the weathering of granite. At the surface, soils are generally coarse textured, but become finer textured as depth increases (Nichols et al. 1985). Close to the Darling Scarp, the soils have up to a meter of sand or gravelly sand that is often overcemented laterite. This cemented laterite and the 4 meters below are where the bauxite ores occur (Nichols et al. 1985). About 10 to 20 m down the soil profile is kaolinitic clay, which usually forms the bottom of the bauxite pits after mining (Koch and Ward 1993).
Mining and Rehabilitation Methods

The mining and rehabilitation of mine sites follow a series of specific steps that begin with planning and end with tree and understory planting. Mining rehabilitations were done as early as the 1960s by Alcoa of Australia Limited, and much has changed in these techniques over time. The description that follows is the methods that Alcoa typically used in the 1980s to rehabilitate mine sites.

Initial Planning of Mineral Exploration

Before mining can begin, bauxite ore deposits must be identified. This is done by a combination of aerial photograph study and ground reconnaissance to find the extent of the laterite development (Nichols et al. 1985). A broad-scale drilling operation is done to find where bauxite ore concentrations are likely to be 25% or greater alumina (Nichols et al. 1985). Larger-scale drilling plans can then be developed after these areas are identified.

Environmental impacts are also addressed at the planning stage. Areas with “high value” flora and fauna, like rare species, are noted and studied to determine if there will be any negative impacts from the mining procedures (Nichols et al. 1985). Hydrology of the mining area is also taken into consideration, such as the proximity of mining operations to dams and other water bodies (Nichols et al. 1985). Mining and rehabilitation plans must be submitted to the government for approval. After plans are accepted, actual mining procedures can begin.

Mining Process

Open-cut mining occurs simultaneously on several pits within each mine area, and the mining process, from forest clearing to rehabilitation, usually takes about 2 to 3 years to complete (Nichols et al. 1985). Mining is relatively shallow, with an average ore depth of 4 m that occur in “pods” of 1 ha to 10 ha (Koch and Ward 1994). Commercial timber is removed from the site above the bauxite ore, and some of the waste timber is saved for rehabilitation to provide habitat for certain species. Any other waste timber is burned (Nichols et al. 1985).

From the forested area, large roots are raked from the soil and stockpiled. The top 50 mm of surface topsoil is then stripped from the ground using heavy machinery (Nichols et al. 1985). The top layer is rich in organic matter, microbes, and seed, which is needed later to obtain good site rehabilitation. The bottom 200 to 800 mm of soil, called the overburden, is also scrapped off and stockpiled (Nichols et al. 1985). This process, called “double stripping,” has resulted in greater plant species numbers and diversity values more similar to unmined jarrah forests (Nichols et al. 1985).

There are two distinct layers of bauxite ore. The top layer is a cemented caprock about 1 m thick. The bottom layer is between 1 and 4 m of friable material (Nichols et al. 1985). Mining consists of fragmenting the caprock by drilling and blasting, and removing the bauxite using front-end loaders (Nichols et al. 1985). The ore is then placed into large trucks and shipped off to the nearest refinery. After mining, the pit has a 2 to 5 m vertical face and a soil floor that is heavily compacted from machinery used (Nichols et al. 1985).

Landscape Alteration for Rehabilitation

Rehabilitation earthworks try to blend the mined area to the surrounding area. Large bulldozers shape the mining pits to a slope that is similar to the surrounding terrain (Nichols et al. 1985). In most cases, the
objective of re-shaping the landscape is to encourage water infiltration as quickly as possible to prepare the land for replanting (Nichols et al. 1985).

To reduce compaction from heavy machinery, the pit floor is ripped to a depth of 2 m with a winged ripping-tyne that shatters the sub-surface (Nichols et al. 1985). Ripping lines follow the ground contour, which allows some storage capacity of water. Contour banks are constructed across the pit to act as a secondary control for water surface flow (Nichols et al. 1985). After the landscaping is complete, overburden and topsoil are replaced.

**Tree Plantings**

Tree planting begins after the first substantial winter rains. This planting occurs at a density of 625 trees per ha\(^{-1}\) along rip lines (Nichols et al. 1985). After 3 and 9 weeks, 100 g of 12:52 monammonium phosphate is applied to each tree (Nichols et al. 1985). Currently all tree species planted at rehabilitation sites are native to western Australia, but some of the earlier rehabilitations used exotic species that are native to eastern Australia. The selection of trees is based on several characteristics. Tree form, growth rate, wood quality, and resistance to disease are all considered when selecting trees to plant (Nichols et al. 1985).

**Understory Seeding**

Hand seeding of native species is done at a rate of 1 kg ha\(^{-1}\) in order to achieve a dense, early growth of legume species, mainly *Acacia spp.* (Nichols et al. 1985). These legumes fix nitrogen to the soil and establish ground cover quickly to help control erosion.

**Evolution of Techniques**

Much has changed in techniques used by Alcoa of Australia Limited since the first rehabilitations were carried out in the late 1960s. The following is a description of the rehabilitation techniques that have changed over the years due to research by Alcoa.

**Soil Handling Techniques**

Some of the first studies in mine rehabilitation done by Alcoa of Australia Limited involved soil-handling techniques in the early 1970s. Earlier rehabilitation methods were designed for erosion control and timber production, and soil was generally stockpiled for up to 3 years. A study done by W. Tacey and B. Glossop (1980) of Alcoa of Australia Limited looked at 3 soil handling techniques: stockpiling, direct return of the whole topsoil profile, and double-stripping (top 5 cm). The number of plants that emerged on each site were recorded, beginning after the first rain following respreading (Tacey and Glossop 1980).

Results of this study indicate that seedling emergence varied depending on the soil handling technique used. Significantly more seedlings emerged from the double-stripping technique. While the results of the other two methods were similar to each other, they were much poorer overall than the double-stripping technique (Tacey and Glossop 1980). Due to nutrient leeching and the loss of beneficial microbes, the other two methods produced poor plant growth. Since 1976, the soil of mined areas is always double-stripped, and the topsoil is directly applied immediately whenever possible (Tacey and Glossop 1980).
Deep Ripping

Heavy machinery used in mining procedures significantly compact the soil floor. Studies done by Alcoa of Australia Limited have shown that compaction only occurs to a depth of 0.5 m or less, but this amount is enough to seriously inhibit root penetration (Nichols et al. 1985). From 1971, mining pits were ripped to a depth of 1 m using a single tyne attached to a bulldozer (Nichols et al. 1985). Because some sites still showed poor root penetration, ripping depth of all mining operations was increased to 2 m in 1978 (Nichols et al. 1985).

Planting Techniques

The earliest attempts, before 1976, at replanting of bauxite mine sites included hand-planting of nursery-reared, disease resistant *Eucalyptus spp.* (Majer and Nichols 1997). These exotic species, native to eastern Australia, were planted in rows with no understory component (Grant and Koch 1997). In the mid-1980s, rehabilitation techniques switched from hand-planting seedlings to direct seeding in order to establish mining sites more similar to surrounding native forests. Forests planted from seed result in a more natural distribution of trees instead of in rows. Some exotic eucalypts were still used in the seeding process (Majer and Nichols 1998). Since 1986, only native jarrah and marri species are used in direct seeding procedures.

The understory seed mix has also become more sophisticated, as it contains up to 62 species of understory plants. In contrast, only 7 understory species were used in seeding in 1976 (Armstrong and Nichols 2000). Currently, each of Alcoa’s mining sites has its own seed mix that is used in rehabilitation to get the best results (Ward and Koch 1996).

Smoke Treatments

Roche et al. (1997) state that there are 141 species that are important in rehabilitating bauxite mines in southwest Australia. Only 35 of these species have shown high levels of germination after conventional seed treatments of heat and water. If better germination rates could be achieved, plant diversity would be increased and substantial money would be saved.

Research was done by Roche et al. in 1994 and 1995 to determine how effective cool smoke seed treatments would be on increasing the germination rates of species planted in rehabilitated mine sites. Seed of 90 plant species were aerosol smoked before broadcast seeding, and 51 of the species showed a positive response to the smoke treatments (Roche et al. 1997). No plant species were hindered by the smoke treatments. In some cases, a few species only germinated after the smoke was applied. Three species in particular: *Hibbertia spp., Lamandra spp.*, and *Leucopogon nutans* responded well to smoke treatments, even though they are considered “hard to germinate” (Roche et al. 1997). These native species usually occur in very low numbers, if at all, in rehabilitated mine sites. Because of the promising results of this study, all broadcast seeding done by Alcoa of Australia Limited after 1995 are routinely smoke treated before application (Roche et al. 1997).

Effect of Timing

Due to variability in plant diversity on rehabilitated mine sites, Ward et al. (1996) of Alcoa of Australia Limited conducted a study designed to look at the effects of timing of ripping, seeding, and scarifying on the establishment of plant species. Results of this study show that ripping late in April or scarifying in June reduced the number of species in the seedbank (Ward et al. 1996). Since seedbank species were seen germinating in as early as June, any ripping in April or scarifying in June would kill germinating
plants. But species from broadcast seeding were found in the greatest numbers when they were spread in April or after scarifying in June (Ward et al. 1996). Since this scarifying could possibly kill topsoil species, the authors of the study suggest that pits should be ripped and sown by April. Seed could be sown as early as December, with better results than the conventional method of seeding after the break of the season in May or June (Ward et al. 1996).

**Monitoring**

Monitoring is needed in any restoration project to ensure that restoration goals are being met. This is also true in the rehabilitation of Jarrah forest of southwestern Australia. Long-term monitoring of flora and fauna has shown that the rehabilitation goals of Alcoa of Australia Limited are being met and viable ecosystems are being created after mining operations.

*Invertebrate Recolonization*

Invertebrate species play an integral role in forest ecosystems, such as improving soil structure, improving nutrient cycling, stimulating mycorrhizal activity, pollinating plants, and helping in seed dispersal (Majer and Nichols 1998). The return of invertebrate species can be an effective measure of rehabilitation success.

A study was done in 1975 to look at how ant species recolonize rehabilitated bauxite mines and was repeated again in 1998 to see how recolonization has changed by ant species (Majer and Nichols 1998). Four plots were studied in 1972 and 1998: an unmined forest control plot, an unvegetated plot, a planted plot, and a seeded plot. In 1994, a total of 52 species were found in the forest control plot, 25 in the unvegetated plot, 32 in the planted plot, and 39 in the seeded plot (Majer and Nichols 1998). These results show that the ant species of the rehabilitated plots were found in the greatest amounts in the seeded plots. While ant species numbers were not as high in the rehabilitated plots as in the forest control, this study shows that there was a steady increase in both the number of species per year and cumulative species richness as time progressed from the first study (Majer and Nichols 1998).

The absence of ant species at rehabilitated sites may be due to several factors. Species that nest in dead standing timber or dwell in forest litter were found at lower numbers at rehabilitation sites because these specific habitat requirements were yet to be fulfilled (Majer et al. 1984). Ant species from particular functional groups, such as climate specialists, cryptic species, and specialized predators were also underrepresented at rehabilitation sites (Majer and Nichols 1998). As rehabilitated areas become more like the surrounding forest areas, invertebrate species generally increase. The rehabilitation of the study area was done in the 1970s. Techniques and methods of rehabilitation have greatly improved since then, and current rehabilitations can expect to get better results of invertebrate recolonization in the future.

*Avifaunal Recolonization*

Recolonization of bird species can be an indicator of restoration success like invertebrate species. Bird recolonization studies have been completed by Alcoa of Australia Limited in 1981, 1987, and 1993. Plots were chosen from both unmined forested areas and rehabilitated areas. In 1993, 25 out of 34 species (74%) of birds were found in both the forested control sites and rehabilitated sites (Armstrong and Nichols 2000). This figure was only 65% in the 1981 study, which indicates that bird recolonization has increased as the rehabilitated areas have become more like the forest control sites (Armstrong and Nichols 2000). Most of the species that were absent in the rehabilitated plots were also found in low numbers in the surrounding forest areas. For a few species, the absence of habitat requirements can explain why the species occur in only the forested control sites (Armstrong and Nichols 2000). Again, techniques have
progress substantially since the forest of this study has been rehabilitated. Recolonization success can be expected to be better in the future, as sites become established quicker and with better quality.

**Frog and Reptile Recolonization**

Frog and reptile (herptile) recolonization has been studied in rehabilitated mine sites since 1978, and follow the same techniques as the avifauna studies. Twenty-three out of 31 (70%) of the herptile species found in forest control sites were also found in rehabilitated areas in 1981 (Nichols and Bamford 1985). Almost all herptile species not found in rehabilitated areas were also uncommon in surrounding forest communities (Nichols and Bamford 1985). Legless lizards, blind snakes, and some frogs were not found at the study sites, indicating that habitat requirements of these species are still not being fulfilled (Nichols and Bamford 1985). Because mine rehabilitation research is an ongoing process, mining areas are becoming more like the surrounding forest more quickly. This should allow for the recolonization of frog and reptile species to occur at a much greater rate in the future.

While these flora and fauna studies do not suggest that habitat requirements for all species are being fulfilled, it does show that the mining process is not forming a barrier to fauna movement (Ward et al. 1990). By monitoring rehabilitated sites, techniques can be changed to encourage the recolonization of species that are underrepresented after mining procedures. The more advanced a rehabilitated site is, the more similar the site will be to the unmined, surrounding jarrah forest.

**Conclusion**

Alcoa of Australia Limited has mined and restored the jarrah forest of southwest Australia since the late 1960s. The goal of rehabilitation is to re-create the forest ecosystem that existed before mining occurred. Long-term monitoring of flora and fauna has shown that mine sites retain a majority of the qualities of the surrounding forest, which can be an indicator of restoration success. Bauxite mining is an intensive process that destroys all aspects of the ecosystem. Efforts by Alcoa of Australia Limited show that quality ecosystems can be reproduced after a severe human disturbance.

Long-term monitoring also allows techniques to change as new technologies are found. While the majority of fauna species return to rehabilitated sites, habitat requirements for many species are yet to be fulfilled. Future research should focus on fulfilling the needs of these underrepresented species. Most of the monitoring by Alcoa of Australia Limited has occurred on sites rehabilitated in the 1970s and 1980s. Techniques have changed since then, and current rehabilitations have advanced substantially. Future monitoring should continue on these sites to ensure that the current methods are the best ones. Because of the efforts of Alcoa of Australia Limited, bauxite mining can continue to benefit southwestern Australia economically, while still addressing the ecological aspects of the area.

**Literature Cited**


126:213-225.


