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Research-led adaptive management in rehabilitation

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Abstract

A research-driven approach has informed Alcoa's continuous improvement of mine site rehabilitation in Western Australia's Northern Jarrah Forest for more than 40 years.

Starting in the 1970s Alcoa pioneered the use of double-stripping and returning fresh topsoil to enable the return of plant species which store seeds in topsoil. Research into seed germination to enable additional plant return via direct seeding commenced in the 1980s. In the 1990s Alcoa built a tissue culture facility to propagate plants that are difficult to establish from seed, further improving the diversity of species returned to the rehabilitation.

Much of that research was responsible for Alcoa's transition in 1988 to using only native Northern Jarrah Forest species in rehabilitation rather than a prescription that previously included Eastern States' eucalypt species.

An annual rehabilitation monitoring program, alongside research trials, has resulted in numerous improvements including a reduction in fertiliser application rates, decreased tree stocking rates and adjustments to legume understorey seeding rates. Soil physical, chemical and biological properties have been the focus of several studies. To alleviate compaction and improve rainfall infiltration and root growth, studies in the 1980s led to the development of a winged tine for effective deep ripping, while later studies looked at soil nutrients and soil microbial recovery.

An important part of the research program is training the next generation of scientists, with Alcoa supporting university research students. Currently, four students are undertaking research into seed germination, erosion prevention, species diversity in rehabilitation and feral cat movement.

Significant factors contributing to the success of this research program include an in-house research team, long-term commitment to research trials and ongoing collaboration with Australian research institutions. Alcoa's research program not only sheds light on ways to continuously improve rehabilitation and biodiversity return in the Northern Jarrah Forest, but also offers valuable insights into restoration globally.

Keywords: *adaptive management, collaboration, fauna, flora, rehabilitation, research, trials*

1 Introduction

Alcoa has been operating in South West Western Australia since 1963. Two bauxite mines at Huntly and Willowdale provide ore to the alumina refineries (Figure 1). A third mine operated near Jarrahdale from 1963 to 1998 and was fully decommissioned and closed in 2001. The alumina is shipped to smelters for aluminium production.

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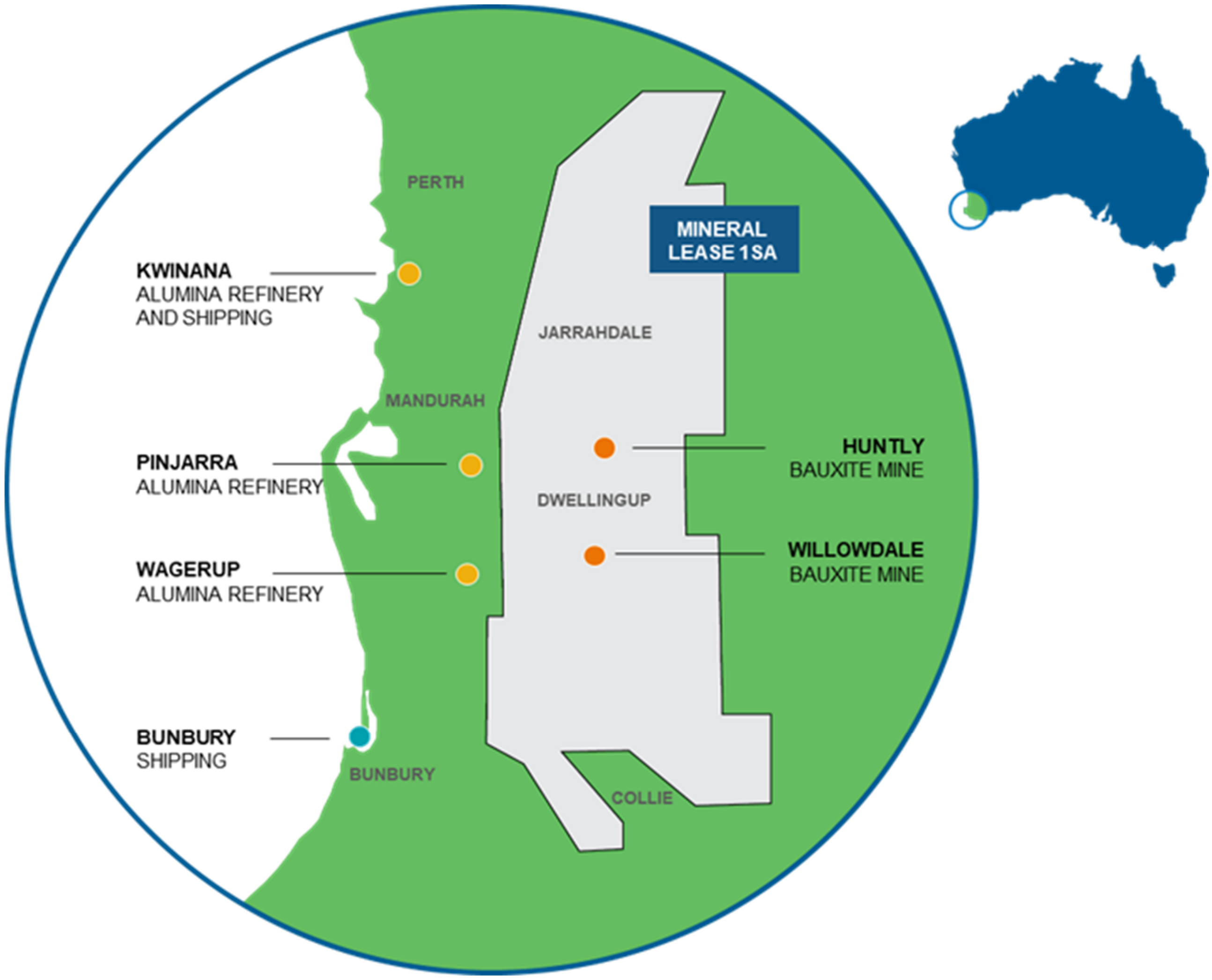

Figure 1 Alcoa's operations in South West Western Australia

The mines are situated within the Northern Jarrah Forest, which consists of escarpment and undulating upland as well as valleys with streams and rivers. The 600–1,300 mm of annual rainfall mostly falls in winter. Dominant overstorey species in the forest are jarrah (Eucalyptus marginata) and marri (*Corymbia calophylla*), and there is a diverse understory. Twenty-nine mammal, 150 bird and 45 reptile species reside in the area (Nichols & Muir 1989), some of which are conservation significant. Plant species in the forest have various adaptations to fire, including resprouting and reseeding (Bell 2001), with seed germination of several species promoted by smoke (Norman et al. 2006; Roche et al. 1997). Feral animals, dieback (*Phytophthora cinnamomi*) and climate change all pose threats to the forest flora and fauna.

Bauxite mining is relatively shallow, as the ore is approximately 4 m in depth. Ore is mined in pods and areas are progressively rehabilitated on cessation of ore extraction (Figure 2). The rehabilitation process commences with pit floor ripping and landscaping followed by overburden return. Stockpiled topsoil is applied, followed by fresh topsoil which contains a topsoil seedbank (Koch 2007). Soil is then ripped on contour and seeded with seeds collected locally. Plants are hand planted in the winter months and areas are fertilised. Logs are placed in constructed habitats to provide fauna habitat that accelerates faunal return to rehabilitation.

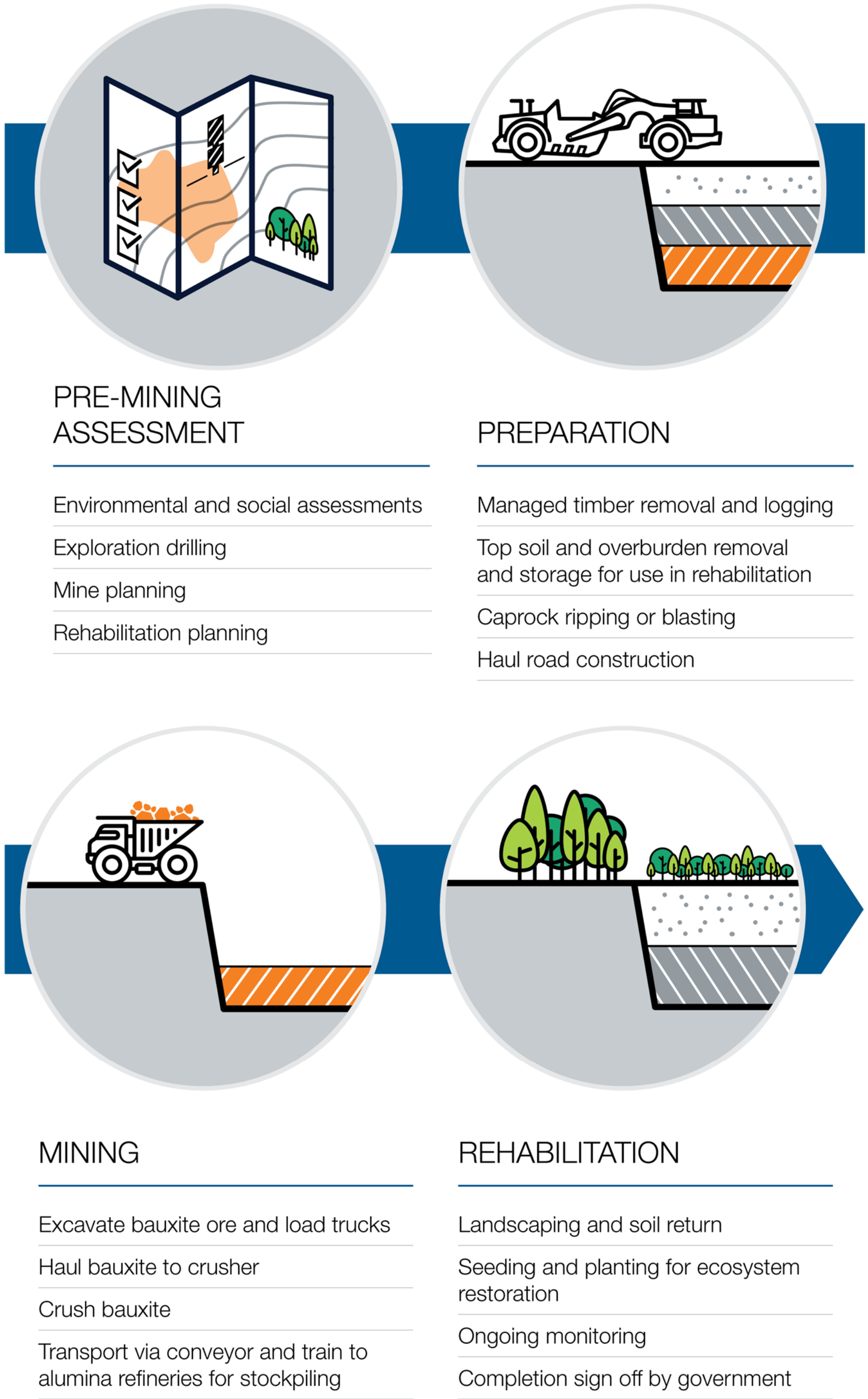

Figure 2 The mining process includes pre-mining assessment, preparation, ore extraction and rehabilitation

The current objective for rehabilitation is toestablish, and return to the State, a self-sustaining Jarrah Forest ecosystem, planned to enhance or maintain water, timber, recreation, conservation and other nominated forest values (DoIR 2015). Rehabilitated areas must become amenable to similar management practices employed in the surrounding jarrah forest.

Specific goals and targets are outlined in a set of completion criteria which is periodically updated. These updates have, at least in part, been informed by results from research projects which have led to adaptive management.

2 Research-led adaptive management

2.1 Research history

Research focusing on ground preparation, topsoil handling, direct seeding, plant propagation, fertiliser, vegetation communities in rehabilitation and fauna has been integrated into adaptive management practices (Koch & Hobbs 2007) (Figure 3).

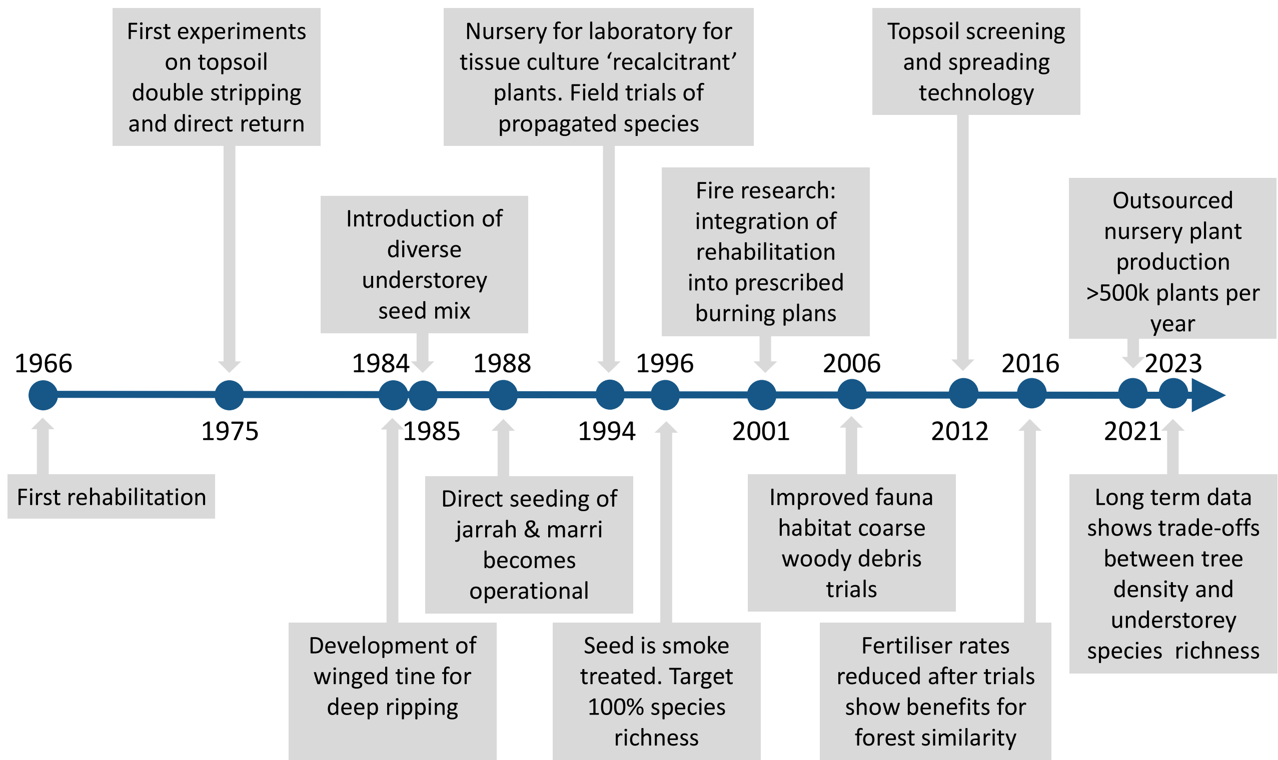

Figure 3 A history of research-led adaptive management at Alcoa's bauxite mines (see also Grant & Koch 2007)

Deep ripping of the compacted mine pit floor was trialled in 1969, then adopted as standard practice in 1971 (Croton & Ainsworth 2007). Ripping was undertaken using a single chisel tine. Then in the 1980s a winged tine was developed to improve ripping practices. This tine went through several iterations–firstly with a 1.2 m wingspan followed by a 1.8-m wingspan–then improvements were made to the shape of the wing and shank. Based on the adaptation of ripping technology to the mining conditions in the Northern Jarrah Forest, ripping now is a two-step process: firstly pre-ripping of the pit floor and then contour ripping following topsoil return (Croton & Ainsworth 2007).

Early research on topsoil handling by Tacey & Glossop (1980) trialled the use of double-stripping, whereby the top 5 cm of soil was removed first, followed by removal of the sub soil. This contrasts with single stripping, in which the top 40 cm of soil is removed. The study compared the direct return of the double-stripped topsoil with single-stripped topsoil and topsoil that had been stockpiled for two years. The double-stripping technique resulted in higher seedling emergence compared to both the directly returned and stockpiled single-stripped soil. The study also determined the distribution of seeds in the topsoil and found that the majority of seeds are in the top 2 cm of soil, with few seeds present at a 5–10 cm depth. Hence, single stripping is likely to have lower seedling emergence due to mixing of the seed bank and burial of seeds at a depth from which they are not able to emerge. Resulting from this trial in the mid-1970s, the double-stripping technique (whereby fresh topsoil is placed on top of stockpiled soil and overburden) became operational in 1978 and is still in use today.

Extensive research has been conducted to accumulate data on seed ecology, aiming to better understand topsoil seed banks, improve the efficacy of direct seeding and facilitate seed-based nursery propagation. Studies have included investigating the effects of heat and charcoal on seed germination (Bell et al. 1987), optimal incubation temperature for germination (Bell & Bellairs 1992), interactions between fire, temperature and light (Bell 1994), optimal seed burial depth (Grant et al. 1996) and smoke stimulated germination (Norman et al. 2006; Roche et al. 1997). Research has also focused on dormant species such as Persoonia longifolia (Chia et al. 2016; Mullins et al. 2002; Norman & Koch 2008). This research has informed seed pre-treatments currently employed.

The establishment of an onsite tissue culture laboratory and nursery in the mid-1990s allowed substantial research and development to be undertaken to increase the numbers of 'recalcitrant' or difficult to return plants for rehabilitation. Research has identified that optimal propagation techniques are species-specific. Some species, such as *Netrostylis spp*. and *Lepidosperma spp.*, are propagated via tissue culture: a micropropagation technique whereby tiny cuttings are grown under sterile conditions (Willyams 2005). Others such as Lechenaultia and Scaevola spp. can be grown using traditional cutting techniques. Some species, while they produce seed, do not display high recruitment through direct seeding, or produce insufficient seed for the seed mix and are grown as seedlings in the nursery, such as Stylidium spp. There are other challenges too, such as the ability to collect sufficient germplasm and good field survival. Through three decades of research, now over 20 species are grown in local nurseries and planted each winter.

The return of fauna to rehabilitation has been studied since the mid-1970s (Nichols & Grant 2007). Fauna presence in rehabilitation contributes to the aim of creating a self-sustaining Jarrah Forest ecosystem as they provide important ecosystem services in rehabilitation, such as pollination, seed dispersal and nutrient cycling. Alcoa has been involved in studies on the return of birds, reptiles, mammals and invertebrates to rehabilitation. All mammal species return to previously mined areas, however, they do so at different stages of rehabilitation growth due to different habitat requirements. Rehabilitation has been shown to provide habitat for threatened mammals such as the quokka (Craig et al. 2017) and western quoll (chuditch) (McGregor et al. 2014). Birds also return to rehabilitated areas, with about 90% of bird species recorded in rehabilitation. However, bird communities may differ between sites, and bird species that require hollow trees in which to nest may initially only use the rehabilitation for feeding. Threatened black cockatoo species utilise the rehabilitation for foraging after four years from establishment (Doherty et al. 2016). Reptiles show successional trends, with habitat generalists returning prior to habitat specialists (Craig et al. 2018). All trophic groups of invertebrates have been observed in rehabilitation, however, differences in species' composition between those found in unmined forest and rehabilitation remain (Majer et al. 2007).

Research focusing on fauna has also resulted in the implementation of management actions. To provide habitat in which fauna can bask, reproduce, hibernate, and take refuge from predators and unfavourable environmental conditions, Alcoa constructs habitats using logs, stumps and rocks. These are placed in the rehabilitation following soil return (Nichols & Grant 2007). These constructed habitats are critical to accelerate recolonisation and ensure the persistence of coarse woody debris (CWD)-dependent fauna (Craig et al. 2014). Following studies into the efficacy of fox baiting, a control program called 'Western Shield' was implemented across the entire Northern Jarrah Forest. This program is managed by the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) and funded by Alcoa, and now includes baits targeted at controlling feral cats as well as red foxes.

Field trials have scrutinised impacts of both tree and legume densities. Commencing in 1988, the research team established a study to better understand jarrah establishment from seed, survival and growth in relation to fertiliser and legume density. Later studies investigated tree physiology and ecological interactions, such as: understorey species richness, density and cover; jarrah tree survival, height and diameter at breast height over bark (DBH); and soil nutrients (Daws et al. 2023; Ward & Koch 1995). After 32 years, it was observed that increasing tree stocking rates increased stand basal area over bark but had a negative effect on understorey plant cover and species richness. Conversely, decreasing tree stocking rates resulted in higher tree survival and DBH growth. Seeding a higher density of legumes increased soil nitrogen but decreased tree survival, DBH and understorey species richness. This long-term study highlighted the trade-offs that exist between different restoration goals such as tree density and understorey richness (Daws et al. 2023). Reflecting adaptive management practices, tree density targets and maxima in the rehabilitation have decreased over time and currently aim for 1,000 stems per hectare with a maximum of 1,400 trees per ha.

Fertiliser has also been the subject of a long-running experiment. In 1994 a trial was established to determine the effect of different rates of nitrogen and phosphorus on tree growth, and understorey species richness, density and cover. Initially the trial showed that fertiliser increased species richness and density. However, after 20 years the richness, density and cover were highest in the plots without fertiliser applied, showing the limited long-term benefits of fertiliser (Daws et al. 2021; Walters et al. 2021). Like the trade-off between tree density and understorey richness, these fertiliser trials highlight the trade-off between rapid initial growth and long-term biodiversity outcomes (Daws et al. 2022). Insights from these trials have led to improvements in rehabilitation practices.

In Aloca's older rehabilitation areas, historic prescriptions have resulted in tree densities that are higher than the surrounding forest. High tree density was in part influenced by the initial uncertainty of seed germination and survival rates, as well as forestry being a designated post-mining land use (reviewed in Grigg 2012). However, these dense areas of trees use more water than areas of lower density, posing a challenge as the region has experienced a decline in rainfall over the past few decades and, with changing climate, rainfall is likely to decrease further. The Jarrah Forest serves as a water catchment area for many of Perth's drinking water reservoirs, and high tree density combined with declining rainfall could negatively impact streamflow into these dams. To address this, seeding rates were reduced and completion criteria adjusted to lower tree densities in new rehabilitation. Despite these changes, the high density in older rehabilitated areas persists. Thinning these areas has been explored as a means of enhancing streamflow into reservoirs, with experiments investigating the effects not only on water yield but also for tree growth, biodiversity and soil health. Ecological thinning is also being considered for unmined forests to manage dense regrowth following logging. Thinning of dense rehabilitation at Alcoa is now being trialled on a larger scale.

In summary, this research has driven adaptive management in mining rehabilitation. A decrease in fertiliser application rates and tree density, coupled with an augmentation in the number of recalcitrant species planted, an improvement in the efficacy of direct seeding and optimisation of topsoil handling have led to higher species diversity in rehabilitated areas. Long-term studies are crucial as they reveal outcomes that may not be evident in short-term studies. In addition, progressive rehabilitation is beneficial because it provides learning opportunities (Figure 4). Both long-term research and progressive rehabilitation have facilitated learning at Alcoa, which has informed adaptive management and shows the benefits of maintaining an in-house research team which, together with operational staff, has continuously applied findings to improve practices.

(a) (b) (c)

Figure 4 Rehabilitation following mining. Progressive rehabilitation, along with research trials, afford numerous benefits to adaptive management. (a) 1980; (b) 2001; (c) 2017

2.2 Current research

Currently, our research portfolio is investigating ways to further improve rehabilitation techniques, successional trajectories of rehabilitation and fauna return to rehabilitation. This research is being undertaken by our in-house research team alongside external collaborators from Western Australian universities and state government departments.

The approach to landscaping and site preparation is crucial for successful rehabilitation. Even minor deviations from optimal practices can significantly affect erosion. Current research at Alcoa is investigating the factors that may lead to erosion and how to control them, alongside the use of remote sensing technology to improve outcomes. Contour ripping is one of these factors as, if soil is ripped even slightly off contour, water can flow along and pool in the rip lines, potentially leading to gully erosion. In response, current research is exploring the use of remotely sensed data to accurately map contour riplines, which could change the way we monitor site preparation and assist in determining the causes of erosion. These studies are intended to contribute to an improved implementation of rehabilitation.

Several studies are focusing on plant return in rehabilitation. These include investigations into the topsoil seed bank, directly returned seeds and planting of species challenging to return via seeds. One trial is continuing the research into topsoil seedbanks to inform topsoil handling practices. Seed sourcing from warmer and drier environments is being investigated to confer plant resilience against climate change, building on previous research summarised in Koch & Samsa (2007). Efforts are also focused on improving the seed germination of dormant species such as Hibbertia spp. through the development of seed pre-treatments. Through working with engineers, technological advancements are being made in direct seeding machinery to ensure better seed placement, seed survival rates and subsequent germination success. Finally, a long-term study on recalcitrant plants is providing insights into the most effective pot sizes and planting treatments to improve the survival of planted seedlings and cuttings, with immediate applications in rehabilitation practices.

Research continues on rehabilitation development well after the implementation phase. Successional trajectories are being monitored through a network of long-term monitoring plots, and the long-term impacts of management decisions and rehabilitation inputs elucidated. For instance, rehabilitation in the 1990s had higher tree densities than current practices and these areas are due to be thinned to reduce tree density. Ecological thinning is a practice being trialled to reduce dense stands to promote forest health and resilience for multiple potential benefits such as increased groundwater recharge and streamflow, improve resilience to droughts and heatwaves, and alter single-aged stands to a multi-aged structure (Conservation and Parks Commission 2023). Given previous trials investigating the effect of tree density on understorey richness (Daws et al. 2023), monitoring will look at the effect of thinning on understorey richness, and specifically which species or functional groups benefit from, or are impacted by, thinning. Also, understorey richness and functional groups will be explored in areas of the mine which experienced bushfires. Building on historical research on fire ecology, additional plots will be installed or remonitored in burned and unburned areas of rehabilitation of various ages as well as unmined forest. Data gathered will enable us to better understand the effects of fire (in the contemporary context of climate change impacts on rainfall and the frequency and intensity of wildfire) on rehabilitation trajectories, species turnover and soil seedbanks, and assist land managers in determining rehabilitation ages that may be resilient to fire.

Our fauna research is focusing on four key areas: birds, short-range endemics, mammals and feral animals. Avian projects are determining both the use of hollows in retained nest trees as well as the suitability of artificial hollows for black cockatoos, which will lead to improved decision-making around the protection of habitat and return to rehabilitation. Resulting from concerns about the welfare of captured cryptic short-range endemics, our team has designed and created a trapdoor spider trap. This trap eliminates the need to excavate a trapdoor spider from its burrow, allowing it to be safely captured for identification and returned. Research projects into endemic mammals and feral animals (cats, foxes and pigs) are employing the use of camera traps to identify where populations occur to inform mine planning and target feral animal control, plus determine the species returning to rehabilitated areas. These fauna projects were designed to directly address management queries and, once complete, results can be applied through an adaptive management process.

Research needs are determined by speaking directly to the research users: those undertaking environmental management and implementing rehabilitation. Recently we held three co-design workshops in which we asked environmental and operational rehabilitation staff to share their knowledge gaps and ideas for improvement. We then asked them all to prioritise these ideas to establish a short list. Following this process, we worked alongside the research users to further develop these ideas and design research projects. Using this approach, employees are invested in the outcomes of the research and change management will be easier to implement.

Science communication is an important part of our work. We organise an annual research symposium to enable our staff and collaborators to share their research findings with each other and with the science and land-management community working in the Northern Jarrah Forest. In 2024 the Symposium attracted over 100 attendees from more than 20 organisations. Hosting the Symposium enables knowledge transfer from research to management, and it also gives land managers the opportunity to ask questions and make suggestions to direct research.

One of our most successful collaborations currently is with the Cooperative Research Centre for Transformations in Mining Economies (CRC TiME). This collaboration has allowed Alcoa to access research skills and expertise from across the country and ensure we are involved with cutting-edge research that is both transferable and scalable. There is also the added benefit of learning from research projects being undertaken through CRC TiME at other mine sites through webinars, networking events and project reports. Alcoa has been involved with several CRC TiME projects, including:

- natural capital accounting in the mining sector
- the Australian Seed Scaling Initiative
- finding evidence of effective climate-adapted seed-sourcing strategies
- the *Foundations of Mine Closure and Sustainable Transitions* course.

Alcoa is currently supporting three PhD students and one Master’s degree student. Two of these students are undertaking internships at Alcoa, which is providing them with in-depth knowledge of industry issues and the skills required for employment within the mining industry while also providing Alcoa staff with expertise from the university sector.

Current research at Alcoa has built on a comprehensive legacy from the past several decades and is looking to the future for new opportunities.

2.3 The Forest Research Centre: a new opportunity

In 2024 Alcoa announced a new opportunity: the Forest Research Centre (Alcoa 2024). Through the Centre, the internal research team will more than double, and an operating budget of AUD 15M over five years will increase capacity for external collaboration. Research will address five core pillars, continuing the focus on plant return in rehabilitation, fauna recolonisation and water stewardship while introducing new areas of research to support forest conservation beyond mining and embrace Indigenous cultural values and practices through a 'two-way' science program (Figure 5).

Figure 5 The five pillars of the Forest Research Centre

3 Conclusion

Alcoa's history of research over the past 40+ years, with outputs including 260 refereed journal papers and book chapters, 80 technical studies and 60 higher-degree research theses, has resulted in ongoing adaptive management in mine site rehabilitation. This success is due to the dedication of the in-house research team, support from management and an enormous number of collaborators from the Australian research community. The model of an in-house environmental research team collaborating with external scientists to solve management issues and improve practices appears to be unique in Australia (Grant & Koch 2007).

Acknowledgement

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