Appendix 70 Jarrah Forest Rehabilitation – Peer Review

Alcoa Jarrah Forest Rehabilitation - Peer Review

PREPARED FOR GHD | November 2023

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Stantec

Revision schedule

Rev No	Date	Description	Signature of Typed Name (documentation on file)			
			Prepared by	Checked by	Reviewed by	Approved by
A	12/06/2023	Draft for client review - initial	BL, NB, DJ	NB	DJ	NB
B	06/09/2023	Revised following client review - final (except section 4) Section 4 – draft for client review	BL, DJ, NB	NB	DJ	NB
0	01/11/2023	Final report	BL, DJ, NB	NB	DJ	LR

Quality statement

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Executive summary

In response to Alcoa of Australia Limited's (Alcoa) proposal to transition to new mining regions for the ongoing supply of bauxite to the Pinjarra and Kwinana refineries, the WA Environmental Protection Authority (EPA) requested that Alcoa commission:

- an independent peer review of rehabilitation methods and success to date and proposed ongoing rehabilitation methods and, taking into account the key biodiversity indicators, assess whether ongoing rehabilitation for the proposal is likely to be consistent with the ongoing ecological integrity of the Northern Jarrah Forest; and
- an independent assessment of the efficacy and suitability of the rehabilitation methodology in the context of a drying/heating climate.

This peer review was conducted to address the following Terms of Reference that were developed in response to the EPA request:
1. Examine the current draft Environmental Review Document (ERD) (Alcoa 2022) to provide context of the Proposal with regard to the historical, current and proposed rehabilitation program.
2. Assess and discuss the historical, current and proposed rehabilitation methods and success to date, with reference to the approved completion criteria and the proposed Northern Jarrah Forest post-mining land use.
3. Summarise the rehabilitation success to date by vegetation unit.
4. Analyse, assess and discuss the efficacy and suitability of the rehabilitation methodology in the context of climate change (drying/heating climate).
5. Provide comment and if required recommendations for changes to current and proposed rehabilitation methods based on the outcomes of the above.
6. Taking into account the key biodiversity indicators, assess whether ongoing rehabilitation for the Proposal is likely to be consistent with the ongoing ecological integrity of the Northern Jarrah Forest.

For this review, we considered the Environmental Review Document (ERD) prepared by Alcoa for the Proposal, together with summarised vegetation monitoring data that was provided, dating back as far as 1991. In addition, we reviewed published literature relating to bauxite mine rehabilitation, and the Northern Jarrah Forest (NJF) more generally. As a complement to the information review, we took part in a one-day visit to the Huntly Mine in April 2023 together with several members of Alcoa's environmental team, and were given a thorough explanation of current bauxite rehabilitation practice, shown examples of various rehabilitation outcomes, and provided with the opportunity to explore any aspect with the Alcoa personnel.

For the purposes of this review, we have considered the Northern Jarrah Forest to encompass both native forest and areas of mine rehabilitation. The structure of this review was based on the terms of reference, but has been adjusted to optimise the sequence of discussion, with key headings as follows:

- Assessment of rehabilitation success to date - vegetation
- Alignment of rehabilitation methods and success with proposed Northern Jarrah Forest post-mining land use
- Consistency with ongoing ecological integrity of the Northern Jarrah Forest
- Conclusions on current and proposed rehabilitation methods

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1 Introduction

Alcoa of Australia Limited (Alcoa) is proposing to increase production at the Pinjarra Alumina Refinery by five per cent, and transition the Huntly Bauxite Mine to the proposed Myara North and Holyoake mine regions (the Proposal). In addition, the Proposal includes clearing of 2,652 ha of jarrah forest for the supply of bauxite to the Kwinana refinery. The WA Environmental Protection Authority (EPA) has determined that the Proposal requires assessment at the level of Public Environmental Review.

As part of the EPA's assessment of the Proposal, it requested that Alcoa commission:

- an independent peer review of rehabilitation methods and success to date and proposed ongoing rehabilitation methods and, taking into account the key biodiversity indicators, assess whether ongoing rehabilitation for the proposal is likely to be consistent with the ongoing ecological integrity of the Northern Jarrah Forest; and
- an independent assessment of the efficacy and suitability of the rehabilitation methodology in the context of a drying/heating climate.

This peer review of rehabilitation, and assessment in the context of climate change, is for the Huntly Mine and excludes rehabilitation at the Pinjarra refinery. The review aimed to address the following Terms of Reference:
1. Examine the current draft Environmental Review Document (ERD) (Alcoa 2022) to provide context of the Proposal with regard to the historical, current and proposed rehabilitation program.
2. Assess and discuss the historical, current and proposed rehabilitation methods and success to date, with reference to the approved completion criteria and the proposed Northern Jarrah Forest post-mining land use.
3. Summarise the rehabilitation success to date by vegetation unit.
4. Analyse, assess and discuss the efficacy and suitability of the rehabilitation methodology in the context of climate change (drying/heating climate).
5. Provide comment and if required recommendations for changes to current and proposed rehabilitation methods based on the outcomes of the above.
6. Taking into account the key biodiversity indicators, assess whether ongoing rehabilitation for the Proposal is likely to be consistent with the ongoing ecological integrity of the Northern Jarrah Forest.

For the purposes of this review, we have considered the Northern Jarrah Forest to encompass both native forest and areas of mine rehabilitation. The structure of the review is based on the terms of reference, but has been adjusted to optimise the sequence of discussion, with key headings as follows:

- Assessment of rehabilitation success to date - vegetation
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2 Assessment of rehabilitation success to date - vegetation

For this review, an assessment of the rehabilitation success is framed around the extent to which the rehabilitation has met completion criteria, as prescribed from past to present. Although varying over time, several key metrics to assess ecosystem development have been retained over time including measures of vegetation establishment, creation of fauna habitat, stability of landforms, recreation and visual amenity. The completion criteria have become more prescriptive over time, and since 1979 have included reference to Working Arrangements established between Alcoa and the Department of Biodiversity, Conservation and Attractions (DBCA, Parks and Wildlife) specifying the rehabilitation prescription, monitoring and reporting procedures.

While a key measure of the creation of a self-sustaining jarrah forest is the development of a healthy, resilient vegetation community, the planning and implementation phase are recognized as key components of rehabilitation success. As such, current criteria relate to five different stages, ranging from planning (prior to mining) to late rehabilitation (10-15 years). Completion criteria are reviewed every 5 years in accordance with Ministerial Statement 728, via the Mining and Management Program Liaison Group (MMPLG), an inter-agency group chaired by the Department of Jobs, Tourism, Science and Innovation, and involving public consultation. As such, monitoring, evaluation and learning from each prescription are critical to adaptive management.

Information Stantec received to complete this review included the draft ERD and data of rehabilitation performance related to assessment of vegetation parameters (in particular, species diversity and tree, legume and ‘recalcitrant’ densities). While an assessment of vegetation establishment against agreed completion criteria are provided below, Stantec was unable to complete a thorough assessment of success of the rehabilitation against all agreed completion criteria, such as those for creation of fauna habitat structures, timber production, water catchment and recreation values, but these are discussed more broadly in section 3.

2.1 Monitoring approach

Alcoa typically undertake monitoring in rehabilitation areas 9 and 15 months after establishment, allowing rapid feedback on rehabilitation performance and providing the opportunity for timely remediation and enabling improvements to procedures for future years. The density of jarrah, marri, total Eucalypts and legumes are monitored in rehabilitation at 9 months. Subsequently, species richness is monitored in a total of 80 m^2 in each rehabilitation area at 15 months. The density of ‘recalcitrant’ obligate re-sprouter species has also been required to be monitored at 15 months since 2016.

On-ground monitoring is undertaken using representative quadrat sampling. Species richness plots comprise five 4 m x 4 m quadrats (80 m^2) inside a 20 m x 20 m plot. These are termed ‘temporary plots’. Presence / absence of all living vascular plant species is recorded within in each of the five quadrats. The survey intensity is set at a rate equal to one plot every five hectares (50,000 m^2) rounded up such that pits less than 5 hectares are allocated at least one plot, while pits between 5 and 10 hectares will have two plots and so on. This represents a minimum sampling intensity of 0.16% of the land area. While this area that is monitored in detail on-ground is a small proportion of the total, it is a reasonably standard sampling intensity in the context of monitoring programs within the Western Australian mining industry. For rehabilitation pits where legume remediation has taken place, the total count of legumes in each quadrat is also recorded.

Approximately one in every ten 20 m x 20 m plot is established as a ‘permanent plot’. Each of the five 4 m x 4 m quadrats in permanent plots are further split into four 2 m x 2 m quadrats, resulting in 20 total quadrats per permanent plot. In each of the 20 permanent plot quadrats, density and cover are also recorded for each living vascular plant species. In addition to being used for 15-month richness, permanent plots form the basis of Alcoa’s long term rehabilitation monitoring program, whereby these plots are established to track long-term rehabilitation trajectory. As such, every third year, a subsample of the monitoring plots become part of the long-term successional monitoring program that re-examines all plots at 1, 6, 15, 30 and 50 years of age (Grant and Koch 2007). While the permanent plots are utilized for the 15-month monitoring, a different methodology is applied at the 9-month monitoring involving using both transects (Eucalypts) and quadrats (legumes), at a subsampling intensity of 6% of the land area.

Forest control or reference plots are established in appropriate site vegetation types (SVTs) adjacent to mining areas, based on the proportion of each SVT to be impacted by future mining. Plots of 20 x 20 m are established within these areas. Within these plots, five 4 m x 4 m quadrats are established for measurement of plant numbers and cover of all vascular plant species (Koch 2007). A total of 124 of permanent vegetation monitoring plots have been established around Huntly and Willowdale operations in the un-mined forest and are used as reference sites to which the rehabilitation is compared.

2.2 Native plant diversity

The most basic composition attribute for a vegetation community is species richness, which is often conflated with species diversity, but which technically is a different measure (Young et al. 2019). Diversity takes into account both richness, and the relative evenness of abundance of the species present. Various indices can be used to provide a simple measure that takes into account richness and evenness, such as the Shannon-Weiner diversity index. While diversity indices are commonly used in ecology, they are rarely used in completion criteria, as richness has been considered the most important aspect to capture in the concept of diversity (Young et al. 2019). Analysis reported by Koch (2007) suggested that species richness correlated well with Shannon-Weiner diversity in restored and intact forest using data from 49 plots in forest and rehabilitation sites. However, the correlation coefficient of $R^2 = 0.5$ suggests reasonable variability existed around the linear relationship, and it was not explored how or whether this relationship was different in rehabilitation compared to unmined forest.

The following sections contain data, as received from GHD, for species richness assessed in rehabilitation at 15 months after establishment as it relates to completion criteria.

2.2.1 Species richness at 15 months in relation to completion criteria

Forest reference plot mean richness data provided from 15-month monitoring for assessment against completion criteria ranged from 44 species to 59 species, therefore the resulting criteria standards ranged from 26 to 31 species between 1992 and 2021 (**Table 2-1**). Note, plot level variability in species richness is shown in **section 2.2.2**.

Table 2-1: Species richness means from forest reference plots used to develop completion criteria standards.

Rehabilitation Year	Species richness in forest reference plots*	Completion criteria standard	
		Proportion	Species richness
1992 – 1996	59	60%	35
1997 – 2002	54	60%	32
2003 – 2004	52	60%	31
2005 – 2010	52	60%	31
2011 – 2013	44	60%	26
2014 – 2019	50	60%	30
2020 – 2021	49	60%	29

*Provided data - mean values

Over the 30 years from 1992 to 2021, rehabilitation was carried out annually across Alcoa's mine sites of Jarrahdale, Huntly and Willowdale. On average 99% of the total rehabilitated area (15,480 ha), monitored using on-ground plots, was deemed to have met the species richness target at 15 months of age. Noting that the minimum threshold for species richness changed from 50% of that in forest reference plots from 1992 to 2003, to 60% of forest reference plots from 2004 onwards (**Table 2-1**). There were 20 years where all of the rehabilitation conducted in that year was assessed as meeting the richness target.

There was 33 ha of rehabilitation carried out in 2010, 2016 or 2017 that did not achieve the richness criterion at 15 months but remedial works were undertaken (which involved in-fill planting of seedlings). It is noted that success of these remedial works was not actually monitored due to the fact that the survival of replanted species is considered to be fairly well known and planting rates for remediation take into account a conservative survival rate (pers. comm. Tristan Sleigh, May 4, 2023).

For planting of recalcitrant re-sprouter understorey species, such as *Tetaria capillaris* (Hair sedge), survival rates have been based on research conducted on the factors affecting the long-term survival and growth including grazing and competition (Daws and Koch, 2015). Alcoa have advised that there are also dedicated plantings each year monitored for survival in subsequent years and that data from these monitoring events support management decisions on species selection, pot types, grazing intensity, and lateral spread (for re-sprouter species) (pers. comm. Andrew Grigg, June 28, 2023).

There was a total of 70 ha of rehabilitation carried out in 1992, 1998, 2004, 2005, 2009, 2011 or 2021, that did not meet the richness criterion and have not had remedial works. However, it is noted that records of remedial in-fill planting prior to 2005 are scarce and it is possible that some was carried out. In addition, remedial work for 2021 rehabilitation is scheduled for mid-2023 (pers. comm. Tristan Sleigh, May 4, 2023).

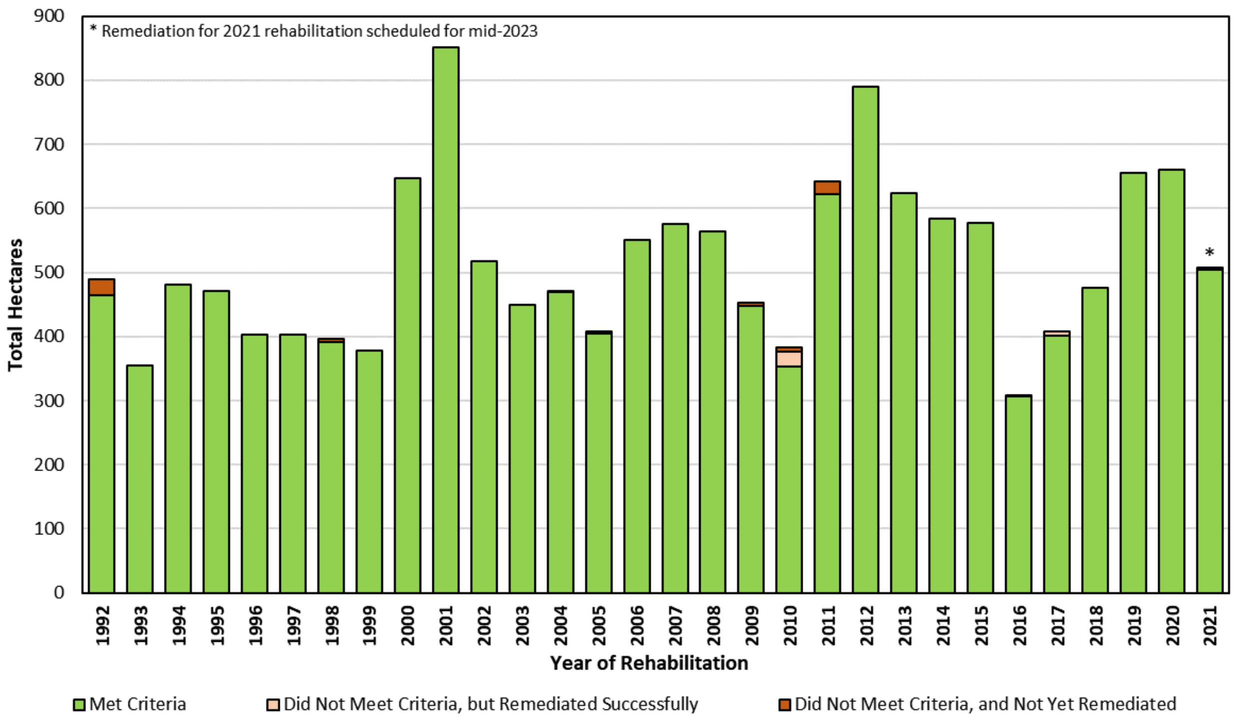

Figure 2-1: Provided data showing the extent of rehabilitation assessed at 15 months as meeting the criteria for species richness. * Remediation planting works scheduled mid-2023

2.2.2 Species richness at 15 months in relation to forest vegetation types

Native forest in the Northern Jarrah Forest (NJF) has been classified into 21 site vegetation types (SVTs) based on a suite of canopy and understorey indicator species ("Havel" classifications; Koch 2007). Jarrah and marri-dominated forest communities are typically P, S and T site vegetation types (**Table 2-2**) and are those most impacted by Alcoa's mining activities (Koch 2007).

There has been substantial variability in species richness between different forest reference plots monitored in different years from 1992 to 2021 within many of the SVTs, as well as some variation between SVTs (**Figure 2-2**). However, the mean species richness over time for forest plots in P, S and T vegetation types was similar at around 40 to 42 species.

Table 2-2: Brief description of selected northern jarrah forest SVTs (extract from Koch 2007)

Site Vegetation Type	*Description*	*Key Indicator Species*
A	Stream zone and swamp heath with small tree emergents.	*Melaleuca preissiana, Banksia littoralis, Hakea varia*
C	Woodland along creeks and swamp margins.	*E. patens, E. megacarpa*
P[b]	Mid- and lower slope forest of *Eucalyptus marginata* with occasional *Corymbia calophylla*. Second story of *Allocasuarina fraseriana*.	*E. marginata, A fraseriana*
S[b]	Mid-slope to upland forest of *E. marginata* with *C. calophylla* and *Banksia grandis*.	*E. marginata, C. calophylla, B. grandis*
T[b]	Ridge top and upper slope forest of *E. marginata* with *C. calophylla*.	*E. marginata, Pteridium esculentum, Leucopogon verticillatus*
W[b]	Lower slope and valley floor forest.	*E. marginata, C. calophylla, E. patens*

[a] Adapted from Havel (1975) and Bell and Heddle (1989). Due to the gradient of vegetation communities, there are often combinations of these site vegetation types.
[b] Impacted by Alcoa's mining activities.

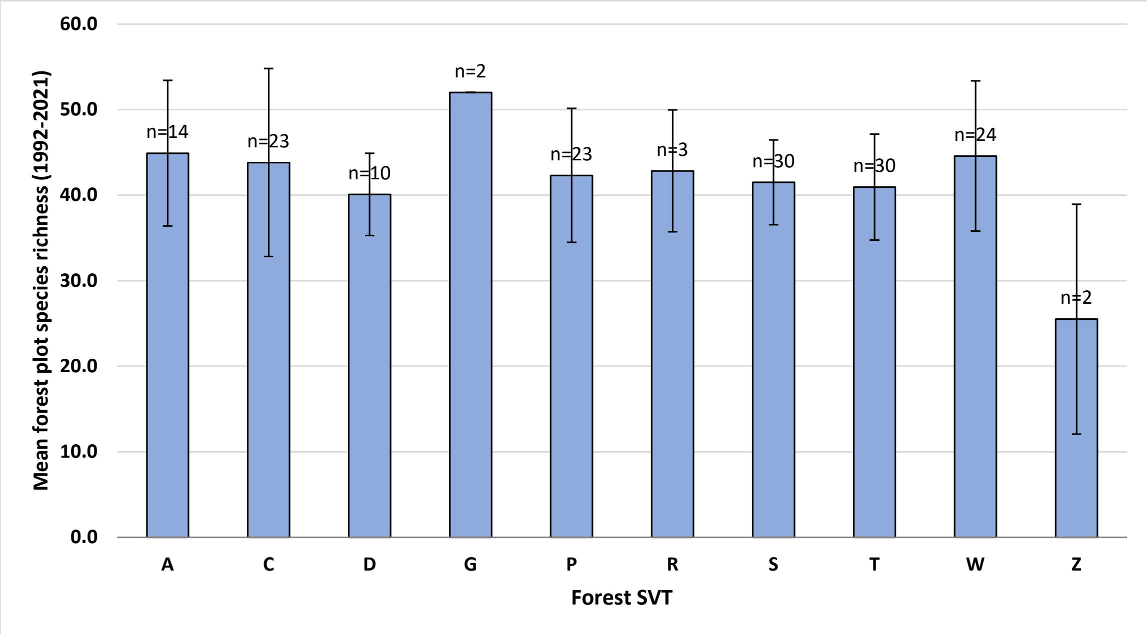

Figure 2-2: Mean species richness monitored forest control plots between 1992 and 2021, by SVTs (provided data). Column labels show the number of times a forest plot of each SVT was established and monitored. Error bars show standard deviation.

Forest reference plots are used to provide the basis for calculating a species richness target that is specific to a given mine region. In general, new forest reference plots are established ahead of a move to a new region. New plots are not necessarily established every year and established plots are not necessarily monitored in subsequent years post-establishment. Consequently, there is a sub-set of rehabilitation monitoring for which a comparison of monitoring data from a forest plot of the same SVT in the same year is available. However, the standard approach used for rehabilitation comparisons, is to use the forest data collected to establish a single species richness target (within completion criteria framework) that can be in place for many years.

A comparison of provided rehabilitation species richness data was made for the sub-set of plots with individual forest reference plots of the same SVT, as well as all rehabilitation in comparison to the completion criteria richness targets, focussed on the P, S and T vegetation types. There was some variability in the mean species richness in rehabilitation in comparison to P, S or T forest vegetation plots of the same year and SVT, but the differences were not significant by ANOVA using Tukey's pairwise comparison at 5% (**Table 2-3**). There was little variability in the species richness between P, S and T type rehabilitation in comparison to forest completion criteria targets, with a mean of 80-82% species richness return. Therefore, it appears that the success in rehabilitation, in terms of returning species richness, has not been substantially different between each of these forest types.

Table 2-3: Summary of mean species richness in rehabilitation in comparison to forest reference plots for S, T and P site vegetation types, between 1992 and 2021

SVT	Data sub-set where reference plot comparison of the same SVT in the same year available		All data with reference comparison to forest site-wide completion criteria	
	n	Mean rehabilitation richness as proportion of forest (%)	n	Mean rehabilitation richness as proportion of forest (%)
S	199	83%	1250	82%
T	57	92%	340	80%
P	39	79%	283	82%

2.2.3 Species richness beyond 15 months

The question of whether the species richness that has been established in rehabilitation persists beyond 15-months of age is not addressed specifically within the vegetation completion criteria. However, Alcoa-funded research studies have suggested that native species richness has been found to persist, but not increase, over monitoring periods of up to 20 years (Norman et al. 2006, Daws and Koch 2015, Daws et al. 2019, Daws et al.

2021). In addition, it is noted that a study by Standish et al. (2021) found that species richness of 25-year old rehabilitation was similar to that of non-mined forests. While other research indicates that species 'turnover' observed in rehabilitation also occurs over time reflective of a relay floristic model, where shorter-lived 'pioneer' species (weeds and ephemerals, Acacias and other legumes) are replaced by late-arriving species including re-sprouters and other species, including orchids (Daws et al. 2021; Grant and Koch 2003).

2.3 Native plant density

Plant density, in addition to species richness, is considered a leading indicator of rehabilitation success as it can be measured accurately at an early stage and indicates the capacity for development of vegetation cover with growth of individual plants over time. The following sections contain data as received from GHD for jarrah, marri and legume density at 9 months after establishment, and recalcitrant species density at 15 months, as it relates to completion criteria.

2.3.1 Jarrah at 9 months

From 2005 – 2014 completion criteria stipulated a minimum tree density of 600 stems/ha, with an expectation of seeding to achieve a ratio of 80% jarrah and 20% marri. The marri minimum tree density was 150 stems/ha, which implies a jarrah minimum density of 450 stems/ha. However, a specific quantitative target for jarrah tree density was not established until 2015, from which time greater than or equal to 150 stems/ha was defined as the target. Over 2015 to 2021, 98% of the total rehabilitated area was assessed as meeting this target at nine months of age, using on-ground monitoring plots (**Figure 2-4**). As a standard action, all areas that did not meet criteria were remediated, with in-fill planting assumed to be successful, based on the expected survival rate of seedlings. Infill planting of areas rehabilitated in 2021 is scheduled for completion mid-2023.

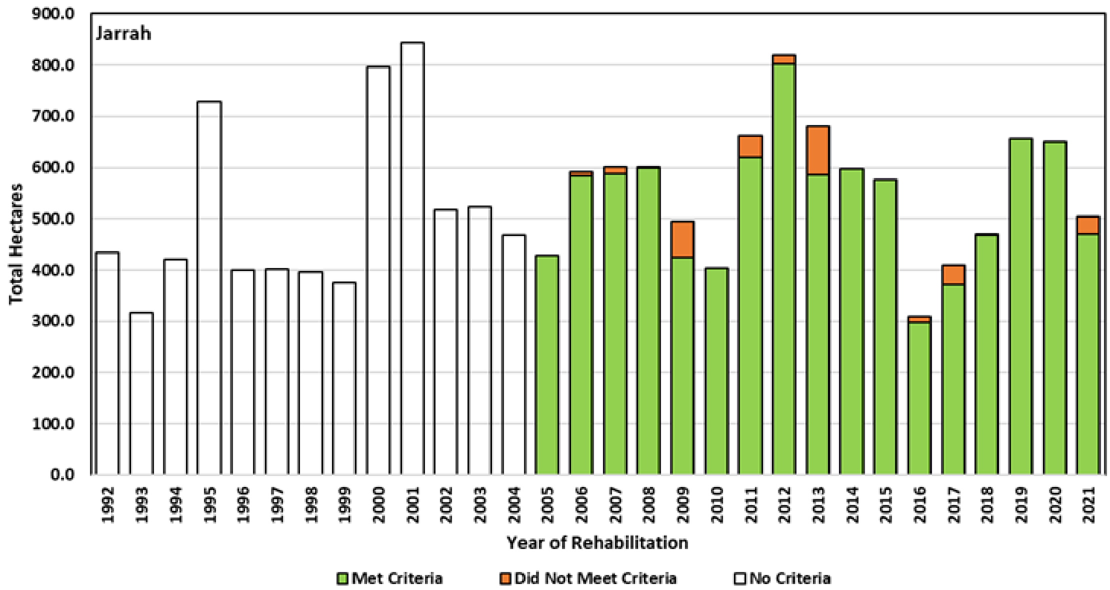

Figure 2-3: Provided data on proportion of rehabilitation by area that met the jarrah density target of 150 stems/ha from 2005 on.

2.3.2 Marri at 9 months

Marri is the co-dominant tree in the jarrah forest, is not susceptible to *Phytophthora* and is an important species for black cockatoos. Alcoa (2022; Chart 4-1) states that Alcoa has achieved the minimum stocking rates for marri in 29 out of the most recent 30 years. Although, from 2015 onwards, on area-based data provided to Stantec, marri tree density criteria (200 stems/ha) was only met at 61% of the total rehabilitated area (calculated from provided data; **Figure 2-5**). As a standard action, all areas that did not meet criteria were remediated, with in-fill planting assumed to be successful based on the expected survival rate of seedlings. In-fill planting in 2021 rehabilitation is scheduled for mid-2023.

It is worth noting that in more recent years, such as 2019 to 2021, data provided to Stantec indicated that marri establishment has not been as successful as the longer-term average, with between 22% and 58% of pits meeting the 200 stems/ha target, equating to a total area of 991 ha over three years that did not meet the marri density target at nine months of age. It is unclear why marri establishment has been less successful in more recent years, though Alcoa have indicated that this is the subject of active research and that seed quality has already been investigated and ruled out as a possible cause of poor survival (pers. comm. Andrew Grigg, 28 June 2023). Given the size of the area requiring in-fill planting with marri, and the importance of marri as a food source for black cockatoos, some follow-up monitoring of the success of the remedial actions could be warranted, particularly in larger remediated areas.

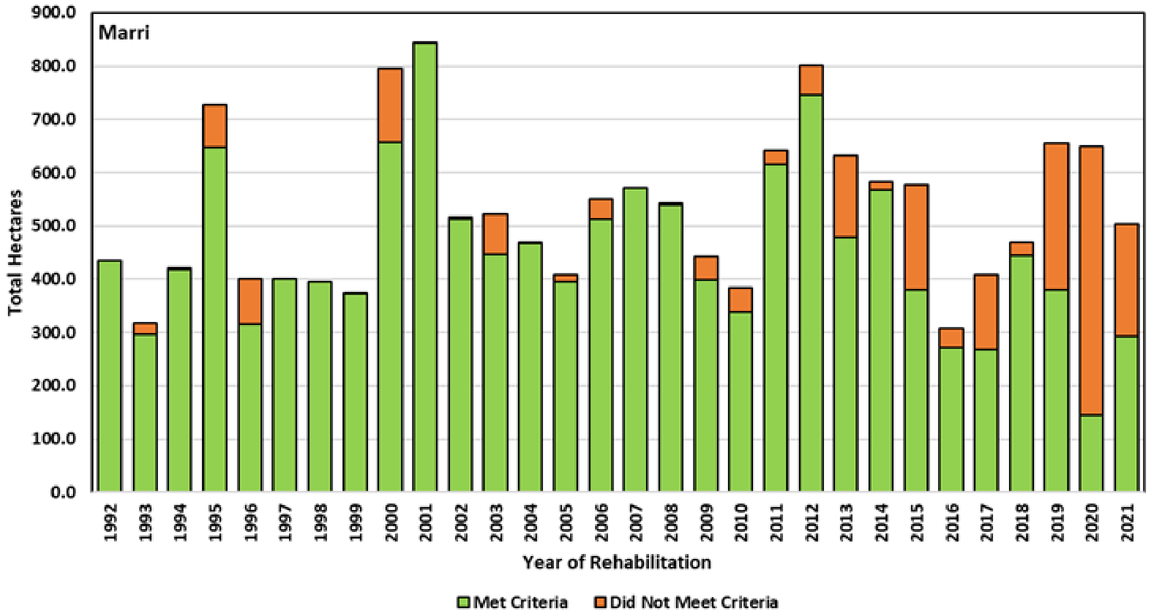

Figure 2-4: Provided data on the proportion of rehabilitation by area that met the marri density target of 150 stems/ha (2005-2014) or 200 stems/ha (1988-2004 and 2015 onwards)

2.3.3 Total Eucalypts at 9 months

The criteria for total Eucalypt density was updated in 2004 to the target range of 600 – 2,500 stems/ha. Prior to 2004, the criterion specified an "average of 1,300 stems/ha over 65% of the pit" which was deemed not possible to make an "pass" or "fail" assessment on collected data, and therefore not included in the below figure provided to Stantec (pers comm. Tristan Sleigh, May 4, 2023; Grigg 2012). The maximum stem density target set in 2004 of 2,500 stems/ha was then reduced to 1,400 stems/ha from 2015 on, with a minimum of 600 stems/ha.

The range specified in the criterion for total Eucalypt density was met at over 80% of the total rehabilitated area between 2004 and 2021, although it is not clear what proportion of the rehabilitation not meeting criteria was due to being over the maximum, or under the minimum (**Figure 2-6**; **Figure 2-7**). Noting again that the proportion of area that met the criterion over 2019 – 2021 was between 47% and 60%, consistent with low marri stem densities over that period.

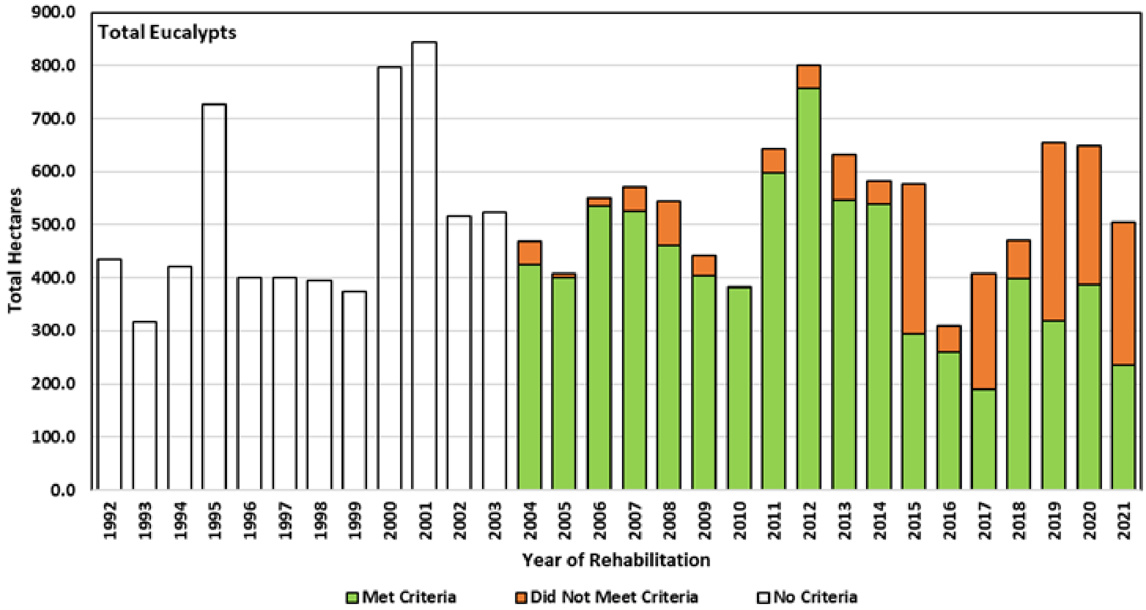

Figure 2-5: Provided data on the proportion of rehabilitation by area that met the total Eucalypt density target from 2004 on.

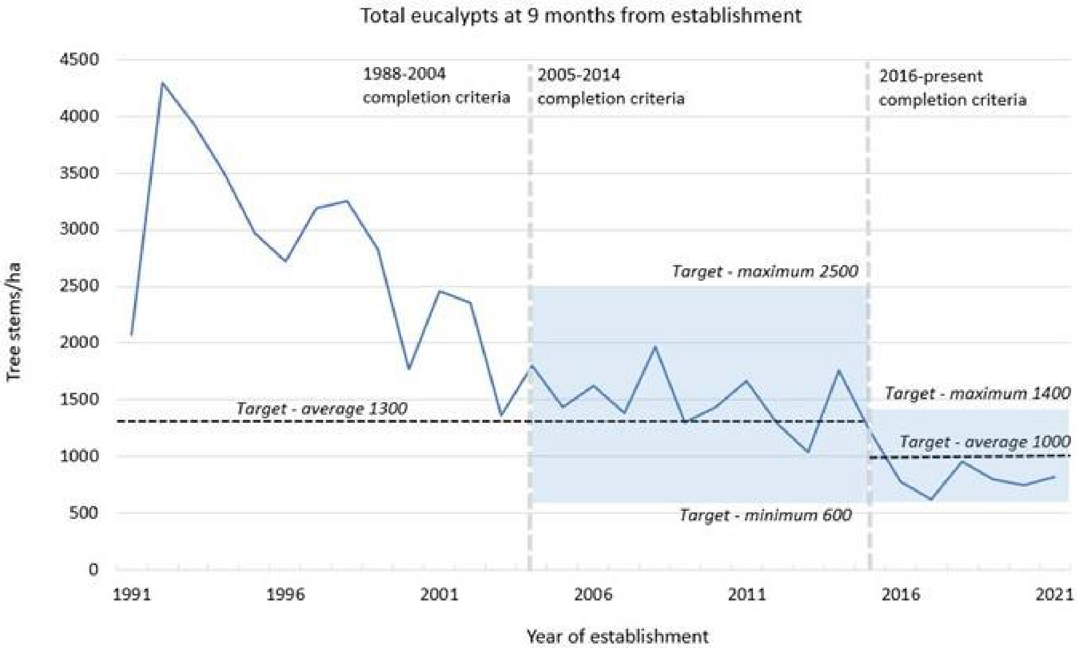

Figure 2-6: Extract of figure from the draft Environmental Review Document (Alcoa 2022) showing mean total Eucalypt stem densities in relation to changing completion criteria targets.

2.3.4 Legumes at 9 months

From 1992 to 2021, approximately 78% of the total rehabilitated area was assessed as meeting the relevant legume density target (**Figure 2-8**). The target was decreased from ≥ 1 plant/m^2 to ≥ 0.5 plant/m^2 in 2004, which equates to a decrease from 10,000 to 5,000 plants/ha.

As a standard action, remedial seeding was typically undertaken in pits that did not meet the target. Monitoring is undertaken to confirm whether legume remediation was successful, however, this data has not been recorded in the primary database (pers. comm. Tristan Sleigh, 4 May 2023) and therefore was not able to be reviewed. It is not clear why 401 ha of rehabilitation in 1997 was reported as ‘not assessed’, however given data was collected for trees in 1997 and that tree and legume monitoring are conducted simultaneously, it is likely that assessment was completed but not added to the database.

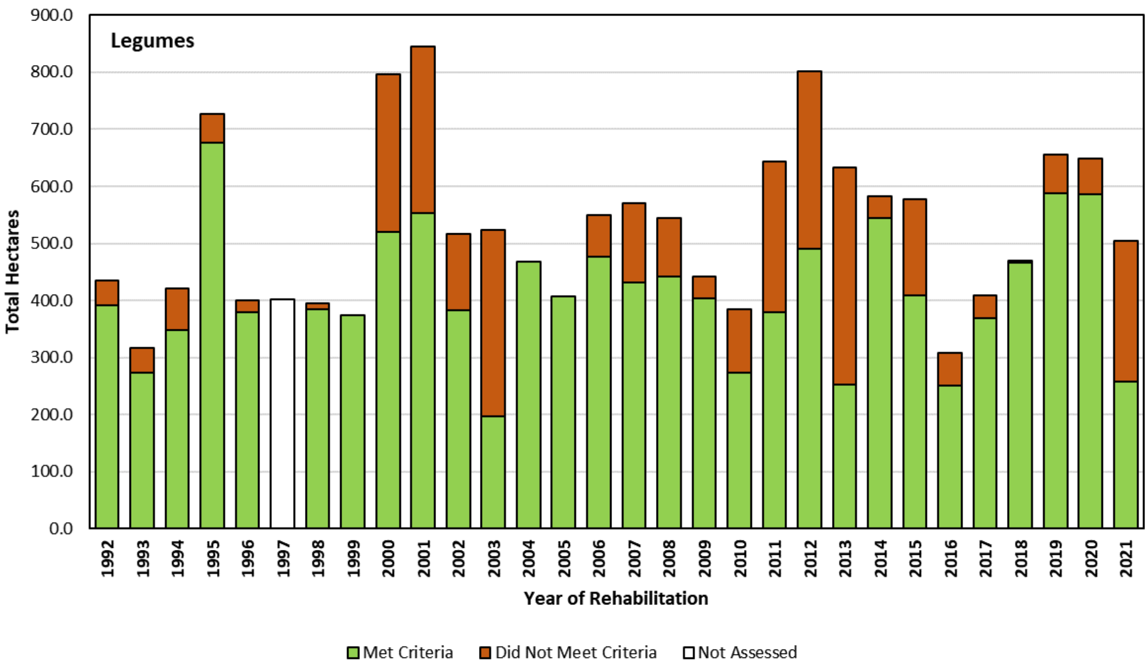

Figure 2-7: Provided data on the proportion of rehabilitation meeting legume density targets.

2.3.5 Recalcitrant species at 15 months

Rehabilitation monitoring in the era leading up to the 1990s indicated a shortage of those species which have very low seed production and are therefore difficult to restore from the soil seedbank or from collected seeds (Alcoa 2022). From 1999-2005, obligate re-sprouter species were propagated and nursery-grown seedlings planted in rehabilitation at densities of approximately 200 to 300 plants/ha, comprising 15 to 28 species (Koch 2007). Most of these are graminoids, from the sedges (*Cyperaceae*), rushes (*Restionaceae*), and certain species of lily (*Anthericaceae*) and lomandras (*Dasypogonaceae*) (Koch 2007). Currently, approximately 15 species are propagated (pers. comm. G. Mullins, April 2023) and planting rates, in place since 2006, are approximately 800 plants/ha for all species combined (Alcoa 2022). Not all recalcitrant species are obligate re-sprouters.

The completion criteria for 2016 onwards include the standard to establish 'recalcitrant' species at a minimum of 200 plants/ha in the 'Early establishment – first 5 years' phase. This is monitored in rehabilitation at 15 months of age. Stantec did not re-assess monitoring data in this review, but the summarised figure presented in Alcoa (2022) indicates rehabilitation has been broadly successful at meeting this target (**Figure 2-9**).

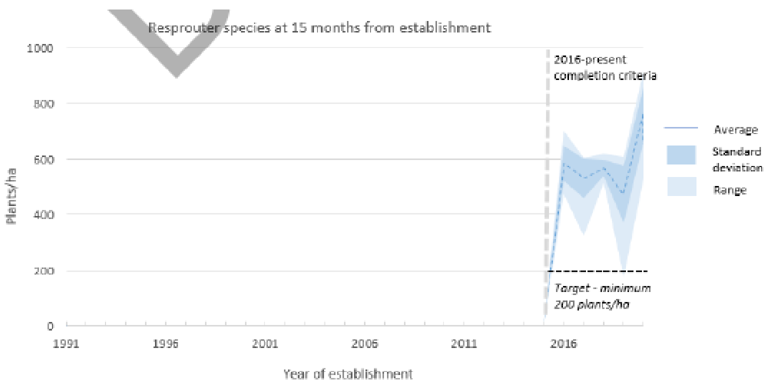

Figure 2-8: Extract of Environmental Review Document (Alcoa 2022, Chart 4-2) of rehabilitation performance (15 months) against re-sprouter (recalcitrant) species density target of 200 plants/ha, from 2016 on.

2.4 Native plant cover

The underlying assumption in the rehabilitation process is that the establishment of a native overstorey is the main indicator of eventual vegetation cover and ultimately, the primary productivity of the forest ecosystem (Alcoa 2022). Research studies have used Leaf Area Index (LAI) as an indicator of combined overstorey and understorey vegetation cover and shown that historic LAI of rehabilitation was higher than the unmined forest range, as a result of higher stem densities, consistent with the assumption regarding development of long-term cover (Bradshaw 2015; Alcoa 2022). While for contemporary rehabilitation with lower tree density targets, even the oldest sites of the current prescription (rehabilitated in 2016) are too young to verify that current prescriptions result in a lower equilibrium LAI than rehabilitation established under earlier prescriptions. However, using the results of a 2017 study, Alcoa have developed an annual (summer) LAI timeseries dataset for the period 1973 to 2022 that covers 28,000 km^2 and encompasses all of Alcoa's mining operations (rehabilitation and non-mined forest areas) in order to monitor changes in LAI (Macfarlane et. al. 2017).

Provided LAI summary data for rehabilitation at Huntly and Willowbrook since 2016 indicates that the LAI of contemporary rehabilitation (2016 onwards) is trending towards that of non-mined forest but on average remains substantially lower at 6 to 7 years of age (**Figure 2-10**). However, it should be noted also that the LAI for young rehabilitation up to 6 to 7 years of age will be dominated by understorey rather than trees. While lower density targets for trees were introduced in 2016, the legume target has remained at 0.5 plants/m^2 since 2004. Legume seeding rates have been relatively stable over that time but their contribution to cover may vary as a function of the contribution from the seedbank in returned topsoil (pers. comm. Andrew Grigg, 28 June 2023).

The completion criteria for 2016 onwards, for vegetation 12 years and older, include a criterion for the management of understorey (4.2.3) with the standard to be achieved "*Evidence from permanent monitoring plots and research trials that understorey cover, density and richness are within the respective ranges observed in forest reference sites*". Alcoa indicate that understorey cover monitoring data is routinely collected from permanent monitoring plots in rehabilitated areas over time. The summarised data presented in **Figure 2-11** was provided to Stantec and indicates that while on average understorey cover at 12-year old rehabilitation has been greater than that of non-mined forest, understorey cover decreases (notable exception 17 years of age) such that at 25 years old understorey cover of rehabilitation was approximately half that of the average understorey cover recorded in non-mined forest areas. Peaks and subsequent decreases in understorey between 12 and 17 years of age are likely related to the growth and then senescence of 'seeder' species (including longer-lived, nitrogen-fixing legumes) (Daws et al. 2021).

In a further study of understorey cover development, Daws et al. (2023) analysed data on understorey richness and cover in rehabilitation established in 1988, at 15 and 32 years of age. This study demonstrated a significant negative effect of increasing stand basal area of jarrah trees on understorey plant cover and species richness. Understorey cover values in the study ranged from approximately 20% to 120% (cover estimates were by species and not bound by 100%), though were not compared to understorey cover data from permanent forest reference plots.

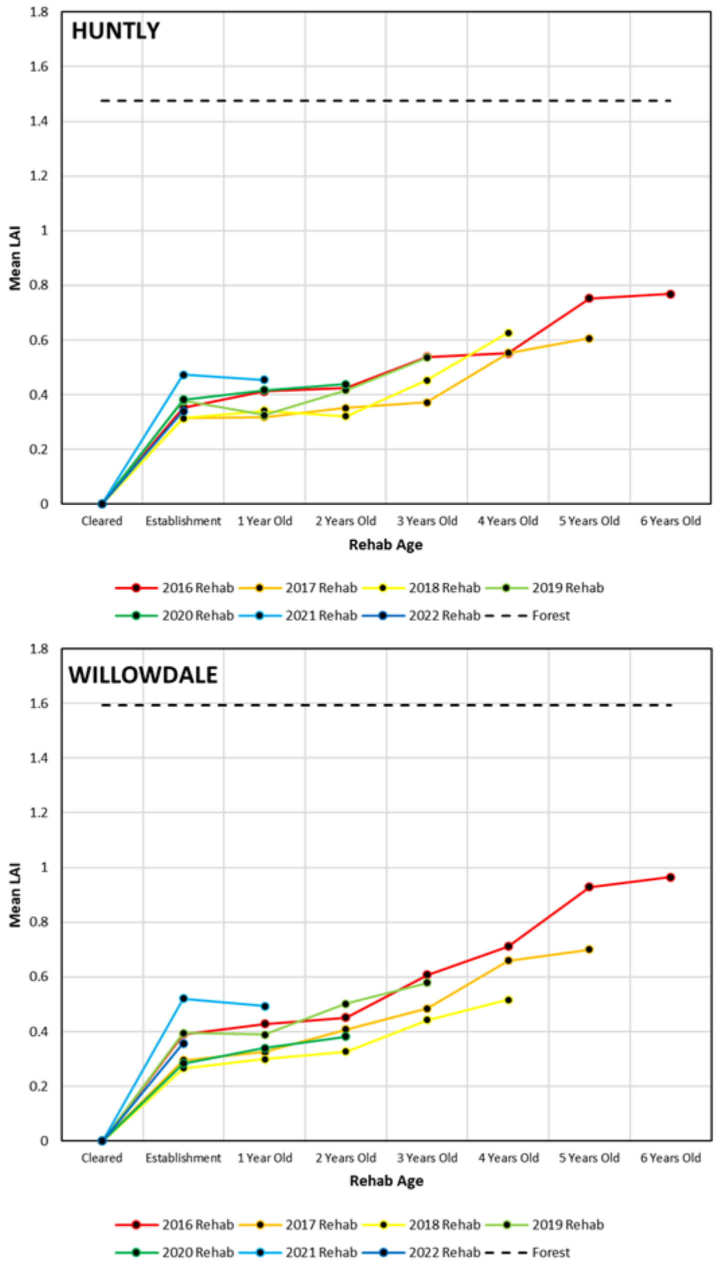

Figure 2-9: Weighted mean LAI of rehabilitation pits established in 2016 through 2022. The Forest LAI value is calculated as the mean of forest LAI within 200 m of the same rehabilitation, for the same years (source: Alcoa)

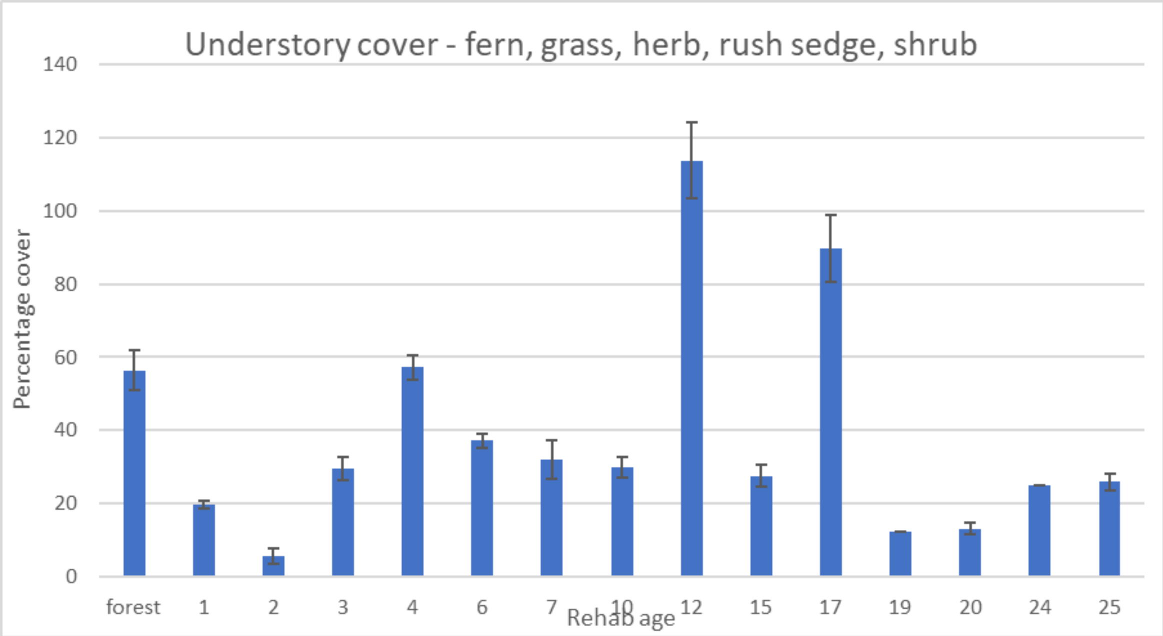

Figure 2-10: Understory cover percentage for permanent forest plots, and rehabilitation plots over time. Trees and sub-trees were excluded, so only fern, grass, herb, rush, sedge and shrubs are included. Note that the number of plots is <15 for years 2, 7, 12, 17, 19, 25 (Source: Alcoa).

2.5 Weeds

All eras of completion criteria have had a requirement relating to weed establishment and potential competition with native species. The completion criteria for 2016 onwards states that within the phase 'Early Establishment – first 5 years' there is "*no evidence that significant introductions of new weed species (environmental and declared) are persisting or that weed competition is restraining sustainable development of native species*".

Weeds are recorded in the 9-month and 15-month rehabilitation monitoring, but this data has not been assessed by Stantec in this review. However, qualitative statements provided in Alcoa (2022) would suggest that this criterion has been broadly met.

2.6 Floristic compositional similarity

Community composition is infrequently quantified as a rehabilitation target, despite broad closure objectives often including expressions relating to "returning a similar vegetation community" (Young et al. 2019). However, when it is important that a similar vegetation community is returned, such as in the case of jarrah forest rehabilitation, then it is reasonable to expect that variation in community composition is measured through similarity metrics. Metrics such as Bray-Curtis similarity, which is commonly used for biological data, can compare the relative similarity in a list of species (i.e. multivariate data) between sites or groups of sites, both with and without taking into account relative abundance measures such as density or cover (depending on the similarity measure or data transformation used).

Known difficulties in achieving compositional similarity to unmined forest have been highlighted in Alcoa (2022) and various research papers, resulting in modifications to the rehabilitation methodology over time. Specifically, there has historically been a lower representation of re-sprouter and ephemeral species, and lower diversity in rehabilitation compared to unmined forest (Alcoa 2022; Norman 2006). Greater success with re-sprouter establishment has been achieved through protection from herbivory and delayed planting to reduce competition (Daws and Koch 2015). Historically there was higher tree species relative abundance (i.e. stand density) in rehabilitation, and lower understorey species richness compared to unmined forest – which has also resulted in changes in the rehabilitation prescription and completion criteria over time.

Floristic similarity at a broader level, and understanding which species' presence, absence or difference in relative abundance, contribute to dissimilarity between rehabilitation and unmined forest, is less explored. A summary of compositional similarity assessments was described under the heading "Future Work" in Koch (2007). It was found at that time that on average Bray-Curtis similarity between rehabilitation (established in 1998) and unmined forest was lower than between unmined forest plots, and did not improve with rehabilitation age (Norman et al. 2006). Therefore, unassisted recruitment of native plant species was deemed extremely slow or non-existent. However, 2001 rehabilitation showed greater similarity to unmined forest than 1988 rehabilitation, consistent with modifications in rehabilitation practices (Koch 2007).

Further compositional similarity analyses have been published by Tibbett et al. (2020) and Daws et al. (2021). Both these studies showed a negative impact of addition of phosphorus on species richness and compositional similarity of rehabilitation to reference forest plots. Daws et al. (2021) concluded that unassisted recruitment of re-sprouter species may actually be retarded by the elevated soil phosphorus. This study involved three phosphorus fertiliser treatments established in four replicate mine pits which were seeded in 1994, with comparison to 18 forest reference plots. A Sorensen's dissimilarity matrix, which uses presence/absence data (Hao et al. 2019), was used for multivariate statistical analysis at 1, 6, 13 and 20 years of age. Similarity between experimental plots and forest reference plots, expressed as a proportion of the overall forest to forest plot similarity value, ranged from approximately 30% to 70% of forest-to-forest similarities, and improved with rehabilitation age (although underlying rehabilitation to forest similarity values were not provided; Daws et al. 2021; **Figure 2-12**). Koch (2007) previously reported forest-to-forest Sorensen similarity of 60% on average and rehabilitation-to-forest Sorensen similarities of 34% on average.

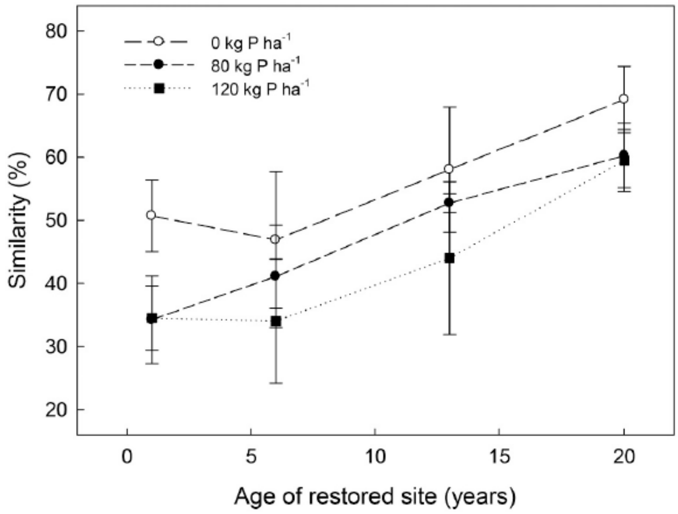

Fig. 6. Effects of P-fertiliser application rate on the similarity of species composition between the fertiliser treatments and adjacent reference forest plots over time. Similarity values for the treatment plots are expressed as a percentage of the average value of forest plot: forest plot similarity. Error bars ±1SE of the mean.

Figure 2-11: Figure extract from Daws et al. 2021 showing similarity of rehabilitation trial plots to forest plots, as a proportion of forest-to-forest Sorensen similarity.

Additional recent research has also explored compositional similarity, drawing on long-term permanent plot datasets (i.e. repeated measures of rehabilitation as it ages) which removes some of the difficulties in space-for-time substitution studies due to changing rehabilitation protocols over time. For example, Standish et al. (2021) demonstrated increasing Bray-Curtis similarity of rehabilitation over time to forest references. However, similarity of 25-year-old rehabilitation was significantly lower than similarity of reference forest to itself. Continued further assessments of similarity will be required to understand the achievable similarity of current rehabilitation protocols as they age. Arguably, these types of compositional analyses are required to provide greater confidence around broad questions and knowledge gaps regarding the maintenance of ecological integrity.

While richness targets from unmined forest reference plots are derived from all species present (and the majority of species will come from understorey and midstorey strata), specific compositional targets are only considered within the completion criteria for plant density. These plant density targets are for selected species or functional groups only, namely jarrah and marri overstorey species, leguminous species (not clear how many species fall within this category) and from 2016 onwards 'recalcitrant species', which may comprise 15 to 28 species (Koch 2007). Other species that may be abundant in unmined forest but do not fall within these categories are therefore not represented by a specific target.

There are other species abundant in certain northern jarrah forest vegetation types that are not currently considered in compositional targets but have important functional roles. Examples include mid-storey species *Banksia grandis*, *Allocasuarina fraseriana* and *Xanthorrhoea preissii* (Koch 2007). *Banksia grandis* (Bull banksia) belongs to the Proteaceae family, which can regenerate from seed but also develops a lignotuber and can regenerate by vegetative means if the upper plant is destroyed by fire (ANSPA 2023). *Xanthorrhoea preissii* (grass tree) reproduces from seed but is known for its ability to withstand fire and can resprout in response to fire. These are recorded in rehabilitation monitoring data and additional data supplied to Stantec indicated that the frequency of *Xanthorrhoea preissii* presence in a selection of rehabilitation plots (2019, 2020 and 2021) was similar or higher than forest reference plots. However, frequency is not equivalent to density, as applied in the completion criteria targets for eucalypts and legumes.

Another study provided to Stantec, indicated that the main plant species contributing to dissimilarity between rehabilitation and forest references overall were the lower abundance of the recalcitrant species which were all identified as re-sprouters in their ecological response to fire, and prevalence of annuals and shorter-lived 'pioneer' species in younger rehabilitation (Ducki 2020). Research by Standish et al. (2021) also explored changes in functional diversity indices with rehabilitation age. Functional traits assessed included plant life forms, seed mass, fire response (seeder or re-sprouter), seed storage (canopy or soil) and nutrient acquisition strategy. All functional indices were different, to varying extents, between forest references and 25-year old rehabilitation. A further finding of this research was that these indices did not correlate with species richness, suggesting a risk of over-reliance on richness as a metric of rehabilitation performance.

3 Alignment of rehabilitation methods and success with proposed NJF post-mining land use

For the purposes of an assessment of alignment of rehabilitation with proposed post-mining land uses, we considered rehabilitation success at a general level, rather than in a strict statistical sense, such as applied in Section 2 above. Therefore, rather than rehabilitation success, we have considered it more broadly as alignment of rehabilitation outcomes with post-mining land uses or values of the NJF described in past and current Forest Management Plans (FMPs) (Conservation and Parks Commission, 2013).

Currently more than 27,000 ha have been disturbed by mining or rehabilitation as part of Alcoa's operations, with a further 14,084 ha to be disturbed as part of the ongoing operations post 2020 and the implementation of the Huntly mine transition proposal from 2025/2026, representing a total of more than 2% of the NJF (Alcoa 2022). When considered together with other mining operations in the NJF, the total area of mining or rehabilitation in 2020 was 37,804 ha which is expected to exceed 66,000 or approximately 3.5%, of the NJF in the future. The scale of this disturbance emphasizes the importance of considering alignment of rehabilitation with proposed NJF post-mining land uses.

Rehabilitation has consistently aimed to re-establish a self-sustaining jarrah forest ecosystem that meets the requirements of the applicable FMP (Alcoa 2015; Alcoa 2023). The forest values outlined in past and present FMPs represent the range of post-mining land uses and have been broadly consistent across all eras of Alcoa's rehabilitation, as reflected in the sequence of completion criteria over those periods (DoIR 2007, Alcoa 2014, Alcoa 2023). The current FMP (2014-2023) states that forests will be managed for the purposes of conservation, recreation, timber production on a sustained yield basis, water catchment protection or other purposes prescribed by regulations (Conservation and Parks Commission, 2013). As a reflection of the requirements of the FMP, Alcoa's broad rehabilitation objective is to:

'Establish a self-sustaining jarrah forest ecosystem, planned to enhance or maintain water, timber, recreation, conservation and other nominated forest values. Rehabilitated areas must become amenable to similar management practices employed in the surrounding jarrah forest'.

Specific rehabilitation goals include (Alcoa 2022):

- Water values: to ensure that mined areas provide acceptable water quality and quantity.
- Timber: to grow a forest that has the potential for sawlog production.
- Recreation: to maintain existing recreational values where possible and to provide increased opportunities for forest based recreational activities in accordance with DBCA district and regional recreation plans.
- Protection: to conserve the residual soils, to control dieback spread and to manage potential fire hazards.
- Landscape: to create a rehabilitated landscape visually compatible with the adjoining indigenous forest.
- Conservation: to encourage the development of floral, faunal and soil characteristics of the indigenous jarrah forest ecosystem.
- Long-term Management: to produce a rehabilitation system that can flourish (in the short term) and become self-sustaining (in the long-term) without continual applications of management resources greater than those needed by the unmined forest (e.g. fertiliser applications).

A draft FMP for the 2024-2033 period that will replace the current plan (2013-2023) is currently under review and expected to be in force in January 2024 (Conservation and Parks Commission, 2022). While forest values of the current FMP are broadly retained in the draft FMP, the aim will be to facilitate the management of the multiple values and uses of south-west forests, including biodiversity conservation, customary practices, recreation and tourism, and other forest-based industries, excluding large-scale commercial timber harvesting (Conservation and Parks Commission, 2022). The exclusion of timber production as a potential future land use from the draft FMP reflects the WA government's stated position on logging in native forests (WA Govt 2023), while the increased focus on the value of traditional knowledge and customary practices reflects in part the commencement of the *Noongar (Koorah, Nitja, Boordahwan) (Past, Present, Future) Recognition Act 2016*, and the South West Native Title Settlement.

Alignment of Alcoa's rehabilitation past, current and proposed methods and outcomes with each of the key forest values or post-mining land uses as described in the current FMP are considered below.

3.1 Conservation values

Conservation of the biodiversity values of the south-west forests is a key focus of both the current and draft FMP (Conservation and Parks Commission, 2013, 2022). In order to conserve biodiversity, it is recognised that representation of the full array of habitats and ecological processes is required at various spatial scales (Conservation and Parks Commission, 2022). To support this key forest value, Alcoa's rehabilitation aims to *'encourage the development of floral, faunal and soil characteristics of the indigenous jarrah forest ecosystem'* (Alcoa 2022).

3.1.1 Biodiversity of flora and vegetation

Prior to 1978, the objective of Alcoa's rehabilitation was to support timber production through establishment of plantations of tree species not indigenous to the south-west, with no requirement to establish understorey species (DoIR 2007). Rehabilitation conducted between 1978 -1987, has a broader range of floristic characteristics established by seeding understorey species (mostly legumes) but still with few overstorey *Eucalyptus* species native to the Darling Range. This rehabilitation aimed to establish a functioning and self-sustaining eucalypt forest. Reflecting this, completion criteria up to 1988 do not address restoration of diversity/richness of local forest species. Assessment of overstorey was strongly in terms of timber production (e.g. tree density, health and form) and was completed using silviculture guidelines.

After 1988, direct seeding of indigenous species was introduced, with jarrah as the dominant *Eucalyptus* species. The objective of the rehabilitation became to restore a self-sustaining jarrah forest ecosystem (DoIR 2007). Associated with this was the introduction of completion criteria relating to species richness. The initial level of 50% of forest reference plots, increased to 60% from 2005 rehabilitation and this remains the minimum standard.

Genetic diversity is maintained through use of local provenance seed for rehabilitation, based on provenance zones established in 1991. The provenance zones are considered conservative given the relative uniformity of jarrah forest vegetation. Since 2000, Alcoa has commissioned Kings Park and Botanic Garden to carry out a series of studies on the degree of genetic differentiation of a range of jarrah forest species and determine the extent of provenance zones within a study area from approximately Jarrahdale to Collie. Outcomes from this research were not reviewed for this report.

In addition to the direct seeding of indigenous species, changes in other rehabilitation methods over time have led to improved species richness outcomes such as, enhanced site preparation, topsoil management (direct-return), propagation and planting of nursery-grown recalcitrant species, seed germination treatments, reduction in tree and legume densities, and in the quantity of inorganic fertiliser applied.

Despite the sequential improvements in rehabilitation methods, differences in compositional similarity between rehabilitation and unmined forest remain (see section **2.6**). Furthermore, rehabilitation does not aim to reinstate the specific upland SVTs that were cleared (P, S and T), as the subtle differences in soil profile and landscape that defined the vegetation types are lost with the mining and rehabilitation process (Koch 2007). Accordingly, while rehabilitation achieves comparable species richness and cover, it is expected to cause a partial loss in the diversity of vegetation types compared to native jarrah forest.

Opportunities remain for continuing improvement of flora and vegetation biodiversity outcomes through ongoing refinement of elements such as fertilizer inputs (specifically with respect to phosphorus), tailored seed mixes / planting according to the new topographical features in each rehabilitated mine pit and continued focus on the return of species that remain poorly represented in rehabilitation compared to unmined forest.

3.1.2 Biodiversity of fauna

The goal to return a native jarrah forest is cited as a key consideration for rehabilitation, addressing the principle of conservation of biological diversity and ecological integrity (Alcoa 2022). Alcoa have recognised that given the scale of their mining operations, if clearing is not minimized and rehabilitation does not restore a forest ecosystem that meets habitat requirements, there is the potential for significant local impacts and loss of fauna and ecological integrity over the medium to long term (Alcoa 2022).

In addition to disturbance from mining, fauna of the NJF have been subject to a series of significant disturbances over a long period of time, including clearing for agriculture and predation by introduced species, particularly the fox, that have resulted in changes to populations. These cumulative disturbances have resulted in a number of vertebrate species being listed as Endangered or Vulnerable under the EPBC and BC Act. A total of 16 conservation significant fauna species have been identified through database searches as likely to occur in the vicinity of the proposed mine expansion area (Alcoa 2022). Six of the conservation significant species known or likely to occur in the proposed mine development envelope are listed under the EPBC Act and as such comprise matters of national environmental significance (MNES). These include:

- three black cockatoo species:
  - Baudin’s cockatoo (Calyptorhynchus baudinii) – Endangered;
  - Carnaby’s cockatoo (Calyptorhynchus latirostris) – Endangered;
  - Forest red-tailed black cockatoo (Calyptorhynchus banksii naso) – Vulnerable;
- Woylie (Bettongia penicillata ogilbyi) – Endangered;
- Quokka (*Setonix brachyurus*) – Vulnerable; and
- Chuditch (*Dasyurus geoffroii*) – Vulnerable

For all conservation significant fauna, the NJF represents important remnant breeding and foraging habitat (Nichols and Nichols 2003) and the loss of habitat for such species as the Baudin's cockatoo, has been identified as a primary threat to their persistence (Chapman 2008). As mining will remove further potential breeding and feeding habitat, developing an understanding of how conservation significant species utilise rehabilitation areas as habitat is important (e.g., Doherty et al. 2016, Craig et al. 2017).

The completion criteria relating to the re-establishment of biodiversity of fauna have varied slightly over time but have remained focused on creating habitat structures during initial rehabilitation works. These constructed habitats are generally a collection of coarse woody material, rocks and soil. For rehabilitation completed since 2005, at least one constructed habitat is required to be installed per two hectares (Alcoa 2014; Alcoa 2015; Alcoa 2023). Habitat construction is documented in the Rehabilitation Assessment Sheets and Rehabilitation Checklists that are reviewed by DBCA following completion of rehabilitation works at the end of the rehabilitation season. No remedial actions are listed in the completion criteria if failures are reported through this process. Stantec was not able to verify if completion criteria relating to constructed habitats have been met across all rehabilitation conducted to date though it is noted that deficiencies in constructed fauna habitats should be noted by the DCBA during their assessment. It is also noted that Alcoa has conducted several research projects investigating the appropriate/desirable quantities, spacing/configuration and condition of coarse woody debris (CWD) and this has informed the development of a standard operating procedure for construction of these habitats (e.g. Craig et al. 2011; Craig et al., 2012; Craig et al. 2014).

While completion criteria have not required monitoring of recolonization by fauna, Alcoa have undertaken numerous (some unpublished) surveys and research programs related to ecosystem development and the ecology of fauna since 1978 to understand the impact of mining operations and level of post-mining recolonization (Nichols and Grant 2007; Alcoa 2022). A Long-term Fauna Monitoring Program (LTFMP) was developed in 1991 and involved the establishment of survey plots in rehabilitated pits and unmined forest at the Jarrahdale, Huntly, McCoy and Orion mining regions between 1992 and 2004. The program was designed to monitor fauna every three years at each established monitoring plot between 1992 and 2001 and then every five years. Rehabilitation assessed as part of the LTFMP program has included areas at various stages of succession starting at 2-year-old at McCoy (established 2011) and 8-year-old rehabilitation at Orion mining region (established 2002). In addition, Alcoa have undertaken research programs targeting recovery of specific groups of animals (e.g., short range endemic (SRE) invertebrates) and conservation significant species including the woylie, chuditch, quokka and several bats (Glen et al. 2008; McGregor et al. 2014; Craig et al. 2017; Burgar et al. 2015), birds including Forest red-tailed black cockatoos (Doherty et al. 2016) and reptiles (Nichols and Grant 2007; Craig et al. 2012).

Synthesis studies conducted in both 2003 (Nichols and Nichols 2003) and 2007 (Nichols and Grant 2007) indicated that all mammal species re-colonize mined areas within 10 years of restoration (Nichols and Nichols, 2003), though the rate of recolonisation varied, with some species returning relatively quickly (Grey kangaroo, mardo) and others, dependant on larger trees for example, taking longer (Brushed-tailed Phascogale, Forest red-tailed black cockatoos) (Nichols and Grant 2007). Previous research has also indicated that the recovery of floristic diversity (>80 percent) in past prescriptions of rehabilitation was likely a key attribute supporting recolonisation of fauna including invertebrates, mammals (e.g. woylie) and reptiles (Glen et al. 2008). However, research has also indicated that persistent differences between rehabilitation and non-mined forest, particularly lower density of coarse woody debris (CWD), higher overstorey stem density, and lack of large tree hollows can impact recolonisation and persistence of some species over the long-term, particularly reptiles and SREs (Glen et al. 2008; Craig et al. 2012; Christie et al. 2012; 2014). It has also been recognised that some microhabitat features, such as CWD which is critical habitat for some of these species, may take more than a century to accumulate in mine rehabilitation (Craig et al. 2018; Phoenix 2021, as reported in Alcoa 2022) and that rehabilitation practices could include an emphasis on the use of larger (>30 cm) logs, stumps and rocks, increased densities of CWD and use of single large logs to maximize probabilities of recolonization and of CWD persisting through multiple wildfire events (Grigg and Steele, 2011).

Based on survey and research programs on past prescriptions, Alcoa have concluded with a high level of confidence that the effectiveness of rehabilitation under past prescriptions (e.g. 1980s-1990s) has been demonstrated in relation to fauna return (Alcoa 2022). However, only a moderate level of confidence has been assigned to the ability of contemporary rehabilitation prescriptions to improve fauna habitat values (e.g. for black cockatoos and reptiles) relative to past prescriptions (Alcoa 2022). This moderate level of confidence could be expected given the lack of studies on recolonisation of fauna in current era rehabilitation. However, Alcoa indicate this risk will be partially offset by the expectation that current era rehabilitation will establish a floristic diversity and vegetation structure closer to that of un-mined forest relative to earlier prescriptions (Alcoa 2022). While this may be true for some groups, recent studies still highlight the need for caution if assuming that revegetation will lead to the establishment of appropriate faunal communities (Craig et al. 2015; Anderson et al. 2022). While some studies have been completed that have investigated recolonisation of fauna groups associated with ecosystems functions including pollination (Tudor 2019, unpublished thesis), Consideration should continue to be given to the fundamental role animals play in many key ecological processes required for restoration including pollination, soil development and establishment of vegetation (e.g. through seed dispersal) (Anderson et al. 2022).

While ongoing support by Alcoa for fauna research and monitoring in rehabilitation is clear, and there is recent evidence of adaptive management responses, including trials of placement of additional CWD in pits close to non-mined forest to encourage reptile recolonisation (Christie et al. 2014) and retention of known and potential black cockatoo breeding trees during clearing (Alcoa 2022), there are no specific fauna standards or targets to return particular taxa or groups of fauna to rehabilitation in current completion criteria, though this is broadly reflective of the industry at large. The requirement to install constructed CWD habitat structures appears to act as a surrogate for faunal return, though research indicates that substantial increase in the density of CWD habitats per hectare like the unmined forest would encourage faster recolonisation from surrounding non-mined forest and improve the biodiversity value of rehabilitated areas (Craig et al. 2014). While CWD habitat structures are directly related to habitat creation for ground dwelling fauna, they do not address the need for habitat creation or retention of habitat structures (e.g. known breeding, roosting or foraging trees) critical for other groups of animals (e.g. Forest red-tailed black cockatoos, bats). However, Stantec acknowledge that other measures and programs Alcoa undertake or contribute to, including avoidance of specific habitat features and implementation of large-scale feral predator management, are additional approaches within the Mitigation Hierarchy that offer synergistic benefits to fauna recolonisation.

For endangered Forest red-tailed black cockatoos, loss of large diameters trees with suitable nesting hollows remains the biggest threat to persistence (Chapman 2008). Alcoa have committed to retaining known or potential breeding trees within the proposed mine development envelope (Alcoa 2022), though there is currently no requirement to retain large diameter (>60 cm) trees likely to provide breeding hollows in the future or foraging habitat. Stantec understands the practice of retaining large diameter trees for protection is part of standard mining procedures and wherever possible during the design of haul road alignments. Protected trees are GPS located and in 2014-2015, a dedicated study was initiated to investigate the long-term survival/attrition rates of protected trees in the mining area. The study includes more than 100 nest trees located in pit edge and ‘far from edge’ locations (reference or baseline areas). However, Stantec has not reviewed any data related to this study. Alcoa have indicated that this study and other current and past studies (e.g. Mastrantonis et al. 2019) investigating the use of retained trees by Forest red-tailed black cockatoos will be used to inform and improve management practices of these protected nesting tress including determination of effective buffer distance around these trees. However, it is encouraging to note that feeding activity of cockatoos in rehabilitation has been recorded on proteaceous (*Banksia*) and myrtaceous (marri, jarrah) trees within four to ten years, indicating that rehabilitation has the potential to provide an ongoing food resource for these birds over time (Lee et al. 2010; Lee et al. 2013; Doherty et al. 2016). This research underlines the importance of understanding potential constraints to development of marri in rehabilitated jarrah forest ecosystems.

The quantity of quantitative data collected by Alcoa over the past 45 years through ongoing surveys and high-quality research programs suggest development of specific standards related to fauna in rehabilitation may be possible, broadening the historically vegetation-centric standards to also consider faunal community composition and physiological and behavioral responses. While Alcoa have completed a variety of studies in line with this, indeed more than other mine operators in Australia (Cross et al. 2019), an updated review of existing research knowledge that builds on previous reviews (Nichols and Nichols 2003; Nichols and Grant 2007) and contemporary literature on this subject in the context of climate change and its impacts of fauna habitat would be helpful. Although most existing data relates to earlier rehabilitation prescriptions, Alcoa have indicated that additional long-term monitoring plots in have been established in current era rehabilitation over the past two years (2022-2020), though Stantec has not reviewed any data from these plots.

3.1.3 Soil

In terms of re-creating a suitable substrate or growth medium to support vegetation establishment, current rehabilitation practice includes creating an approximately 1.5 m thick, friable layer of topsoil, overburden and ripped substrate which Alcoa indicate provides a comparable, stratum to support root growth as prior to mining (Alcoa 2022). Deeper-rooted vegetation, such as jarrah and larger shrubs establishing in this friable layer are expected to exploit pre-existing root channels (Dell et al. 1983) in the underlying regolith materials. Although a partial loss of soil water-holding capacity is expected due to the removal of the friable bauxite layer, especially in areas of shallow bauxite, Alcoa indicate that this has not constrained vegetation development in rehabilitation, citing establishment and persistence of LAI comparable to unmined forest and resistance to canopy die-off following the 2020/2011 drought and heat waves (Alcoa 2022). Based on this assessment, Alcoa conclude the current standard of a 1.5 m friable soil substrate over intact regolith is an effective growth medium, and that vegetation in rehabilitation is expected to demonstrate resilience to the drying and warming impacts of climate change, comparable to that of non-mined forest (Alcoa 2022). Following on from this, the development and persistence of vegetation under these conditions will offer protection to soil erosion and hence stream and reservoir water quality.

Given the acknowledged importance of pit floor ripping for long-term rehabilitation performance, it is a concern that there have been occasions where this has not occurred. For example, during a recent visit to Huntly mine site, it was acknowledged by Alcoa that a substantial proportion of the rehabilitation completed at Huntly in 2018 had not had pit floor ripping and that this had in some areas led to erosion in rehabilitated areas (e.g. Manning 15 pit), and importantly, has potential to constrain vegetation growth over the long term. In the Rehabilitation Checklist for this particular pit, pit floor ripping was signed off by Alcoa and DBCA as being completed appropriately. It is a concern that potentially substantial areas of rehabilitation at Huntly in that year may have been incorrectly prepared, without internal certification processes detecting the issue. An additional concern is that apparently no remedial action has occurred yet. This discrepancy highlights vulnerability in the self-certification process and the importance of effective monitoring and evaluation by regulating agencies.

Current topsoil management practices involve topsoil being either stockpiled separately for later re-use or re-used immediately (direct return) for rehabilitation (Alcoa 2022). To reduce the amount of vegetation clearing, the preference is to stockpile topsoil on ore bodies. Stockpiles at Alcoa's mining operations are generally large and constructed by scrapers, leading to substantial compaction of the soil in the process and thus creating very unfavourable conditions for soil biological components. Wherever possible, it is recommended that stockpiles should be loosely placed and at shallower depths, to maximise the potential for vegetation to establish on the surface, maintaining soil biological function and eventually adding to the soil seed bank.

Where stockpiled topsoil is used in current rehabilitation, some direct-return soil is also spread as a final layer (pers. comm. A. Grigg, April 2023). Soil stockpiles are required to be managed to meet key objectives of rehabilitation success including seedbank survival, *Phytophthora* Dieback hygiene and sediment control. Stripping of topsoil leads to an immediate dilution of organic matter and loss of microbial biomass carbon (Banning et al. 2008), but immediate re-spreading offers clear benefits for subsequent rehabilitation outcomes, due primarily to higher levels of soil-stored seed, and also to the presence of beneficial soil microbial populations (Sawada, 1996; Jasper 2007; Daws et al. 2022). Recent research also highlights the importance of not only direct return but also the combined benefits of direct return and depth of soil returned on soil seed bank viability (Daws et al. 2022). Re-spreading direct return topsoil over stockpiled topsoil has been shown to produce a vegetation composition most similar to unmined forest in the long term (45 years) (Daws et al. 2022). Maximising the proportion of topsoil that is directly returned to areas being rehabilitated should be a key objective of future rehabilitation.

Soil invertebrates and microbiota are also fundamentally linked to the restoration of degraded ecosystems, helping to underpin ecological functions and plant communities. Alcoa have undertaken a series of research programs to understand the recovery of soil processes in rehabilitation at various stages of succession along with assessments of resilience to disturbances such as prescription burning and thinning in comparison to non-mined jarrah forest (e.g. Morley et al. 2004; Lalor et al. 2007; Cookson et al. 2008; Banning et al. 2011a; Banning et al. 2011b; Liddicoat et al. 2022). Broadly, these studies have demonstrated that soil organic matter and microbial biomass re-establishes over time in these rehabilitation sites, although recovery of organic matter (as measured by total organic C) is slower than the recovery of microbial biomass and in 18–26 years old rehabilitation remains below that of the non-mined forest mean (Banning et al. 2008; Jasper 2007). However, as rehabilitation practices have changed over time, the future trajectory of current-era rehabilitation, may not be accurately predicted by these chronosequence studies of older sites.

In addition to long-term fauna monitoring studies that included assessment of invertebrates in rehabilitation, there has been one small study on an experimental pit, on the effect of 'snipped' wood treatments (coarser than mulch) on invertebrate populations 3-4 years post rehabilitation (2008 rehabilitation). The findings indicated that a rate of 100 t/ha applied at the time of rehabilitation works, equating to approximately 30% wood cover, may contribute to improved richness and abundance of invertebrate communities, potentially facilitating more rapid development of favourable soil conditions, without compromising the establishment of plants (Lythe et al. 2017). However, given the limited scale of the trial, it was recommended it be replicated across several pits and include comparison of communities in unmined forest (Lythe et al. 2017). It is not known if this recommendation has been implemented.

3.2 Timber production (prior to 2024 rehab)

Timber production has a been a primary post-mining land use for rehabilitation since commencement in the 1970s. Rehabilitation to date has been required to meet standards associated with timber production that have been informed by monitoring and research into the relationship between seed application rates and establishment and survival of seedlings, the risk of the soil-borne pathogen *Phytophthora cinnamomi* (dieback) to jarrah trees, and the impacts of initial densities on tree form (Grigg 2012).

Prior to 1988, rehabilitation practice aimed largely to reinstate a productive forestry land-use, utilising eastern Australian eucalypt species (Gardner and Bell, 2007; Grigg 2012). In response to monitoring and targeted experimentation that revealed a reduced risk of dieback to the health of jarrah trees, the objective of returning a sustainable jarrah-dominant forest ecosystem supporting a range of forest uses was introduced in 1988 (Gardner and Bell, 2007). In general, the completion criteria for overstorey reflect the desire to have appropriate species and form for timber production with completion criteria for 2005 to 2014 rehabilitation requiring a minimum of 300 trees/ha while for rehabilitation established in 2016 onwards, the minimum is 250 trees/ha. Other completion criteria including those related to topographical features focused on ensuring accessibility for forest management practices, including timber production.

From 1988 to 2004, rehabilitated areas were required to have an average of 1,300 stems per hectare at 9 months, over 65% of each pit (Alcoa 2014). At least 200 of these total stems were required to be marri, as a protection against dieback devastation. However, a lack of certainty around success of direct seeding led to high seeding rates (1.5–3.7 kg/ha). During this time, tree densities at nine months after sowing averaged around 3,000 stems/ha, with mean densities in the early-mid 1990s being higher (Grigg 2012), far exceeding the 300 stems with sawn timber potential required per hectare for late-stage rehabilitation of this era.

In response to high tree stem numbers, seed application rates were reduced to less than 2 kg/ha by 1997 and then to less than 1 kg/ha in 2000 (Grigg 2012). Based on the outcomes of monitoring at 9 months post seeding, completion criteria relating to tree density were updated in 2002 to include a target for average tree density of 1,300 stems/ha with an upper limit of 2,500 stems/ha. Alcoa reported in 2012, that between 2003 and 2010, establishment of eucalypt densities was close to the target, averaging 1,490 trees/ha (Grigg 2012). However, it was also estimated that high densities in rehabilitation completed between 1988-2002 had resulted in a legacy of over 6,000 ha of rehabilitation with a pit mean establishment density of about 2,800 stems/ha (Grigg 2012). As this is an average, some individual pit densities are likely to be much higher.

Alcoa’s rehabilitation prescription has largely evolved over time to reduce tree stocking densities to 1000 stems/ha, reflecting a balance between biodiversity, timber harvesting and water yield. However, Alcoa have acknowledged that the WA Government’s announcement to end native forest logging from 2024 onwards and the update of the FMP in 2024 coupled with ongoing adaptation to climate change, will likely change the future post-mining land use objectives for State Forest, and that this will likely influence rehabilitation objectives and completion criteria related to overstorey establishment (Alcoa 2022). The management of these legacy areas in the context of current and proposed post-mining land uses under a drying climate presents a unique forest management challenge which is discussed in relevant sections below.

3.3 Water catchment

3.3.1 Water quality

Completion criteria for Alcoa’s rehabilitation relating to protection of water catchments have largely focused on planning and implementation of rehabilitation works that, facilitate creation of safe, stable and non-polluting landforms, re-establishment of suitable growing conditions, maintaining streamflow and water quality in affected catchments and access for forest management. A key element is avoidance of mining near stream zones.

Completion criteria have recognised the fundamental importance of landscape design and accurate implementation (e.g. slope <18 degrees, deep and contour ripping) for effective management of surface water and limiting the potential for erosion (Alcoa 2014, 2015). Holding water within the mined pit through the use of in-pit sumps and contour ripping minimises sediment transport and turbid drainage that could compromise water quality. However, while there are requirements relating to initial design and implementation in each pit, the requirement to monitor water quality has not been stipulated in completion criteria, but rather is outlined in the Working Arrangements.

In recognition of the importance of vegetation cover on the surface stability of landforms, completion criteria include elements to encourage sustainable growth and development of vegetation, such as ensuring the majority of caprock was broken (no area greater than 0.1 of a hectare with unbroken caprock), topsoil to be spread over a minimum of 90% of the rehabilitation area and criteria relating to vegetation establishment. Measures of success have included extent of erosion, vegetation growth and water quality. Where unacceptable erosion was observed, corrective actions have been required.

Vegetation establishment is largely through measurement of plant density (e.g. no area greater than 0.1 hectare with less than 0.5 native plants per m^2) as measured by aerial photography or ground truthing (5 yearly in the case of rehabilitation completed from 2016 onwards) (Alcoa 2015). However, where plant densities have been higher than the maximum standard, remedial action has involved spraying with herbicide. Stantec understands Alcoa have internal procedures and standards for the safe use of these herbicides which aim to ensure surface water quality is protected, and that pits are designed to retain surface. Alcoa (2022) have indicated that long term research, water quality monitoring and numerical modelling, indicates that mining and rehabilitation is unlikely to substantially increase salinity or turbidity, nor substantially reduce inflows into drinking water reservoirs.

3.3.2 Hydrology

The hydrological effects of mining on a catchment scale initially involve increases in streamflow because of clearing and subsequent return to pre-mining streamflow levels as rehabilitation matures (Croton and Reed 2007, cited in Grigg 2012). For example, a study of streamflow response in a catchment mined in the late 1990s (Lewis catchment), showed mining resulted in an initial increase in streamflow, peaking approximately four years after mining, followed by a return to pre-mining streamflow after around 11 years (Grigg 2017).

Observations of continuing declines in flows in some catchments where density of rehabilitation exceeded that of pre-mining forests have led to trials of various rehabilitation prescriptions to reduce competition between trees and also developing rehabilitation approaches that result in less plant-available water within the soil profile in mine pits (Grant et al. 2007; Grigg 2012). Trials have manipulated either initial seeding rates or stand density of older rehabilitation through thinning and burning. For example, the 'Hydrologically Considerate Rehabilitation (HCR)' rehabilitation trial areas were established in 2009 and treatments included reduced application rates of tree and understorey seed. Monitoring of vegetation at these pits at 9 months indicated lower establishment densities of overstorey trees, consistent with lower seeding rates (Grigg 2012).

In addition, a number of experiments and related studies have been conducted since 2007 to determine the effects of thinning on streamflow in mined catchments and investigate the effects on a range of ecosystem attributes including vegetation growth and composition, and animal and soil characteristics (Grigg, 2012; Daws et al. 2022). In a study of two catchments rehabilitated in the early 1990s with high mean tree stocking densities of 2,300 trees/ha, thinning treatments (notching) combined with a controlled burn (in one catchment) resulted in increased streamflow in subsequent years in those catchments. While Croton et al. (2013) suggested lowering the LAI of rehabilitation to less than 1.0 may buffer both rehabilitation and forest to the climate-change impacts. As for any thinning practice, ongoing management of coppice stems from the stumps of felled trees and of seedling recruits, is likely to be important to maintain the effect of thinning (Grigg 2012). It is unclear if monitoring of these trials has continued over time.

Current targets for eucalypt numbers at establishment provide for natural attrition of trees over time, with the acceptable initial range of 600 - 1,400 trees/ha typically decreasing to about 400 - 1,100 trees after 32 years (Alcoa 2015, Alcoa 2022). As detailed in Section **2.3.3**, the target range was met at over 80% of the total rehabilitated area between 2004 and 2021, however the proportion of area that met the criterion over 2019 – 2021 was only between 47% and 60%, presumably a reflection of low Marri stem densities. Recent research suggests that a further reduction in establishment targets toward the lower end of the current range may be more appropriate, particularly in comparison to old growth, non-mined forest where average tree density is 155 stems/ha, though the impact on the growth of trees, streamflow and understorey richness has not been quantified (Daws et al. 2022).

The legacy of rehabilitation with excessively dense tree stands (approximately 6,000 ha) (Grigg 2012), has implications for existing and future rehabilitation as well as on the surrounding forest and raises questions about what the best management options will be to meet competing forest values including stream flow and water catchment (Wardell-Johnson et al. 2015). An update on the status of existing long-term trials of management including thinning and burning and in comparison, to non-mined forest would assist in predicting long-term impacts on streamflow. Under the proposed arrangements outlined in the draft Forest Management Plan 2024-2033 (FMP), ecological thinning of rehabilitation areas would occur in areas where full management responsibility has not yet been returned to the State. Operational thinning under the FMP, expected to be in effect from 2024, is envisaged to involve Alcoa, the DBCA, the Forests Products Commission (FPC) and forestry contractors under Forest Product Commission's supply contract arrangements. Specific treatment areas and rates of treatment each year will be subject to the finalisation and formal adoption of the FMP and other considerations such as planning of prescribed burns.

As proposed in the draft FMP, thinning would be undertaken in areas of densely-stocked mining rehabilitation of more than 20 years of age (i.e. those areas established prior to 2001). An interim *Guideline for First Thinning at Age 25 or Older of Bauxite Rehabilitation Areas Established with Native Species* (DBCA, 2020) has been developed to guide treatment and support the FMP. In addition, Alcoa have indicated that operational-scale demonstration trials to understand operational approaches and working arrangements, cost-efficiencies and silvicultural outcomes of thinning practices were established in rehabilitation areas at Huntly mine in 2020-2022. These trials build on earlier thinning activities in the Banksiadale Dam catchment and plot-scale thinning trials established in 2001 (Grant and Norman, 2006; Grigg and Grant, 2009).

3.4 Recreation values

The jarrah forest provides for diverse cultural ecosystem services through recreation and tourism offerings including both formal and informal trail networks and historic character that provide a range of benefits and contributes to a sense of place for residents and visitors (Alcoa 2022; Rosa et al. 2020).

Between 1988 and the current era, rehabilitation has been required to meet agreed plans for recreation or access, while ensuring final landforms meet accessibility requirements of forest management operations and public safety. In addition, there have been requirements for visual compatibility such that the final topography blends in with surrounding landscape (Alcoa 2014; Alcoa 2023). Stantec has not reviewed any recreation or access plans or been able to assess compliance with landscape design criteria including maximum slope parameters.

The visual amenity of rehabilitation can be very different to non-mined forest as mine rehabilitation typically results in fast growing, single age stands in former mine pits that are clumped but scattered within a matrix of non-mined forest (Wardell-Johnson et al. 2015). This contrasts with surrounding non-mined forest where silviculture and disturbances have resulted in a mosaic of different ages and structures (Wardell-Johnson et al. 2015). When Rosa et al. (2020) asked bushwalkers and mountain bikers, who use the jarrah forest region affected by mining, about the extent to which mine rehabilitation restores recreation services, most respondents expected “a restored area as natural as it was before mining” and were sceptical about the ability of rehabilitation practices to return pre-mining benefits. However, use of rehabilitated forests was related to the activity, with bushwalkers favouring non-mined forest to a greater extent than mountain bikers. While rehabilitation will eventually mature into ‘a’ jarrah forest it will not be ‘the’ jarrah forest’, and its relative quality in terms of future recreation is dependent on the successful return of key unique features including large mature trees. Some rehabilitation practices such as ripping of the final surface make the landform seem ‘not natural’ and less ‘walkable’ than non-mined forest, even many years after establishment (Rosa et al. 2020). These results suggest there may be a disconnect between current rehabilitation objectives and public perceptions of success and as such warrant further investigation. Specifically, flattening the peak-and-trough soil surface that results from ripping, in areas where control of surface water is not imperative, may be easily achieved and would provide an immediate benefit for walkability.

3.5 Heritage values

Heritage values have only been included in completion criteria for the current era, though all previous eras refer to the requirement to meet the broad requirements of FMPs relating to that era, and these have included acknowledgement of heritage values of the jarrah forest.

Noongar knowledge of plants, animals, ecosystems and seasons is noted in the current and draft FMP as contributing to biodiversity conservation, just as the protection of biodiversity helps conserve and protect Noongar cultural values (Conservation and Parks Commission 2013; 2022). Recognition of the importance of integrating the cultural value of the forest to the Noongar people is largely missing from Alcoa's current long-term goals. The goal related to landscape creation such that the rehabilitated landscape becomes visually compatible with the adjoining indigenous forest is likely to be the most closely aligned and it is recognised that returning biodiversity may in part reflect forest values important to indigenous people. However, it has not been possible to establish to what extent Noongar values have been incorporated into the design and ongoing adaptive management of rehabilitation procedures to date. Determining mine rehabilitation success requires assessment against both quantitative and qualitative indicators of mine completion. As indigenous peoples' expectations have rarely been considered or adequately addressed in site clearing activities or mine completion criteria, the next review of the completion criteria provides an opportunity to strengthen the link with biodiversity indicators and Noongar knowledge and values.

3.6 Resilience to further disturbance, regional pressures and climate change

Climate change is expected to be a persistent, escalating stressor on all ecosystems in the Northern Jarrah Forest with the main anticipated or predicted changes over the coming decades expected to be drier and warmer conditions (Conservation and Parks Commission, 2022). These drier and warmer conditions will interact with other pressures affecting south-west forests, such as fire, disease, weeds and pest animals. The outcomes of these interactions are difficult to predict but are anticipated to include changes to hydrology, vegetation structure, critical fauna habitat, carbon carrying capacity and forest productivity by altering evapotranspiration, soil moisture and infiltration and runoff (Conservation and Parks Commission 2022). Rising temperatures and prolonged hot spells are predicted to lead to an increase in the frequency and intensity of bush fires.

Alcoa (2022) provides an assessment of the ability of rehabilitation to adapt to future needs, and suggests that success to date in developing and adapting the rehabilitation program allows for confidence in the ability to adapt to changing rehabilitation objectives, such as the planned cessation of timber harvesting and the requirement for resilience to climate change. However, this potential to adapt is largely limited to establishment of vegetation communities in future rehabilitation, and does not consider how each era of existing rehabilitation is likely to respond to climate change. An assessment of the key threats to long-term performance of rehabilitation including potential increase in frequency and severity of fires and droughts and potential impacts for forest disease and weeds, is provided below.

3.6.1 Fire

Understanding the long-term success of rehabilitation must necessarily involve consideration of the inter-related cycles of vegetation succession and fire. Completion criteria over time have focused on the requirement of rehabilitation to be as resilient to fire as the non-mined jarrah forest, and able to be integrated with existing forest management practices such as prescribed burning (Grant 2003). In relation to this, Alcoa have conducted a series of studies investigating the resilience of various aspects (e.g. vegetation growth, soil function) of pre- and post-1988 rehabilitation, in response to both prescription burning and wildfire, to determine an appropriate age for integration into surrounding forest management practices. Prescribed burning of rehabilitation forests of 12–15 years of age is desirable to reduce high fuel loads including a mid-storey of senescent legume species (Grant et al. 2007; Morley et al. 2004). Rehabilitated forest burnt at this age is resilient, in terms of vegetation structure soil seed stores and its capacity to restore LAI, and the recommended practice is now to carry out low to moderate-intensity spring burns in 13–15-year-old rehabilitation (Grant et al. 2007).

While Grant (2003) demonstrated that spring burning resulted in development of fuel loads, vegetation structure and understorey composition that were similar to non-mined jarrah forest in pre-1988 rehabilitation. The timing of burning of rehabilitated forests can be used to manipulate the encourage transition toward the characteristics of non-mined ecosystems. Choosing an appropriate fire regime that will encourage development of desirable species and discourage weeds and continued high densities of *Acacia* understorey species, is critical (Grant 2003).

Changes to rehabilitation methods over time have led to lower legume densities, which should enhance resilience to fire by reducing fuel accumulation in the understorey. However, further research is required to understand the long-term implications of differences in community composition in rehabilitation compared to unmined forest (such as lower abundance of obligate or opportunistic re-sprouter mid-storey and understorey species, and development of soil seedbanks). In addition, the NJF more broadly requires greater understanding of the long-term ecological impact of wildfires versus intensively managed fire regimes, particularly on floristic diversity (Bradshaw et al. 2018).

3.6.2 Forest disease

3.6.2.1 Phytophthora Dieback

In general, the effects of dieback in jarrah forest include a loss of floristic diversity and a change in community structure and function (Shearer and Tippett, 1994). Typically, once a jarrah dominated forest with a diverse understorey is impacted by dieback the community will be replaced by an open marri dominated woodland with an understorey dominated by sedges (Alcoa 2022). Dieback of jarrah is associated with loss of other susceptible species, particularly in the *Proteaceae, Ericaceae* and *Xanthorrhoeaceae* (Alcoa 2022). Within these families, genera representing key components of the jarrah forest floristic diversity including *Banksia, Isopogon, Adenanthos, Persoonia, Petrophile, Xylomelum, Andersonia, Astroloma, Leucopogon* and *Xanthorrhoea* have demonstrated high susceptibility (Glevan 2021, cited in Alcoa 2022). The majority of infested areas are in low lying valleys and swamps, while upland areas are less impacted owing to the movement of the disease in soil water (Colquhoun and Hardy 2000).

While the spread of dieback due to mining has been estimated to be very low, at 0.006-0.007 ha per hectare cleared (Colquhoun and Kerp 2007), this is in part dependant on the execution of rehabilitation practices as per agreed management and access plans (Colquhoun and Hardy 2000). As part of previous rehabilitation prescriptions, Alcoa have been required to meet the criteria established in Dieback Forest Rehabilitation programs as agreed to under the Working Arrangements. An intensive dieback research and management program has been operating since 1990 at Huntly though Stantec have not independently reviewed compliance with management programs.

A review of early monitoring of survival of 5- and 16-year-old rehabilitation (1979 to 1990 rehabilitation) and effectiveness of the dieback management procedures completed in 2000 revealed tree mortality coincided with areas of water ponding, and that the use of soil infested with dieback did not significantly decrease species richness, particularly in comparison to stockpiling of topsoil which had a larger effect (Colquhoun and Hardy 2000). Dieback mapping prior to mining is conducted routinely, but it is unclear if Alcoa have quantified the extent of dieback in rehabilitation or risk of dieback infestation in various rehabilitation prescriptions and landscape positions in recent years. An understanding of the proportion of historical rehabilitation located in upland areas, coupled with a contemporary study quantifying the risk of forest disease to rehabilitation survival and floristic diversity in the context of climate change, may provide a more accurate estimation of the susceptibility of rehabilitation and thus the implications for the ecological integrity of the NJF.

As marri is known to be less susceptible to dieback than jarrah (Colquhoun and Hardy 2000), completion criteria for rehabilitation have required a minimum number of marri stems/ha at 9 months of age to support resilience to dieback in older rehabilitation (over 12 years) (Alcoa 2015). Marri is also likely to be increasingly important in the context of climate change as research suggests it has a physiology more resistant to drought (Szota et al. 2011) and is a preferred foraging tree for Forest red-tailed black cockatoos. Recent research indicates that the ongoing impact of climate change is expected to increasingly limit, over time and space, access to food resources during the breeding season for cockatoos, further threatening their persistence (Mastrantonis et al. 2019). While Alcoa has achieved the minimum stocking rates for marri in the majority of rehabilitation at establishment, recent establishment rates of marri have been below the target establishment rate and have required or have planned corrective action which would benefit from re-monitoring to confirm success (see **section 2.3.2.1**). There are no indications in the literature of any issues with long term survival of marri, but it is unclear if this has been studied specifically.

3.6.2.2 Other forest diseases and pests

Completion criteria relating to other forest diseases and insect pests has largely focused on determining if rehabilitation is being preferentially attacked by non-dieback forest diseases or insects, and that this should be no greater than in the non-mined forest (Alcoa 1989, Alcoa 2014, Alcoa 2015). The guideline for acceptance has largely been based on an assessment of the extent and severity of any damage and whether rehabilitation is being selectively damaged (Alcoa 2015).

There is no published data on the occurrence of marri canker within the mine development envelope or Huntly Mine, nor on whether rehabilitation is susceptible to this disease. However, it is noted that the disease has been demonstrated to occur along roadsides in high rainfall areas of the southwest region (Alcoa 2022). The mine development envelope lies in a high rainfall zone of the NJF and accordingly there may be potential for the Proposal to introduce and/or spread marri canker. While Alcoa note that mining as part of the proposed mining area expansion (Alcoa 2022) may result in the spread of armillaria root disease (ARD) and marri canker; a lack of information on the ecology and spread of these diseases in the jarrah forest or in rehabilitation, limits the ability to predict the magnitude of impact on existing or future rehabilitation in the context of climate change (Alcoa 2022). No information was provided to Stantec on the extent and/or severity of any insect damage in rehabilitation sites.

3.6.3 Weed invasion

Mining and rehabilitation activities have the potential to result in introduction of weeds or spread of existing weed infestations. Weeds are expected to be present in the NJF adjacent or downstream of disturbed areas (e.g. towns, roads and tracks or recreational areas accessible by vehicle). This would suggest that mining activities closer to regional towns may increase the risk of weed spread. However, it is noted that there is a lack of data on the presence of weeds in the NJF subregion (Alcoa 2022).

A new rehabilitation site, which has topsoil applied but no vegetation established typically has an increased risk of weed infestation due to the lack of competition (for space and resources) with native vegetation. However, it has been reported that from establishment, native vegetation gradually outcompetes the ephemeral exotic species and that mine rehabilitation has limited and declining weed cover and is therefore developing resilience to further weed spread or invasion (Daws et al. 2021; Alcoa 2022;).

3.6.4 Dust

It is not clear if dust from surrounding mine operations is impacting rehabilitation success and there are currently no completion criteria that relate to control for the impact of dust. However, the Alcoa (2022) notes that mining may result in residual impacts of elevated dust deposition with the mine development envelope and that there is uncertainty regarding the susceptibility of jarrah forest vegetation to dust deposition, particularly for the understorey, over the summer and autumn periods. Dust issues are most likely adjacent to major haul roads, and given the general pattern of mining activity continually moving away from existing rehabilitated areas, then it appears likely that dust is not likely to be a factor in the long-term integrity of rehabilitation.

3.6.5 Ecological thinning

Under increased atmospheric CO_2 scenarios, rainfall is expected to continue to decline in the southwest region. Modelled mean streamflow from the tributaries entering the Swan River (approximately 80 km north of the mined jarrah forest area) decreased by 12 and 24% with 1.5 CO_2 and 2 CO_2 scenarios (Evans and Schreider 2002). This has implications for the capture of drinking water for metropolitan Perth. Paired catchment studies and modelling have demonstrated that increases in streamflow volumes following vegetation removal during the mining phase can be followed by decreases with rehabilitation age, below that of non-mined forest (Croton and Reed 2007) but not always (Grigg 2017). From 2024, timber harvesting will be limited to forest management activities that improve stand health, such as thinning. Current era completion criteria state that stands above the required minimum may be thinned to 300 stems hectare at any time after the age of 15 years old. These stands will be preferentially targeted for management actions including both prescription burning and thinning. However, if one of the objectives of forest thinning would be to improve streamflow, it is likely to be unachievable without being both intensive and costly, given that it would need to be maintained indefinitely (Wardell-Johnson et al. 2015).

It has been reported that since 2004, rehabilitated sites with early stem densities above 2,500 stems/ha have been thinned at 9 months of age by herbicide spraying (Grant 2006). However, it has been estimated that around 6,000 ha of rehabilitated forest has more than 2,500 stems/ha (Grigg 2012), and this would require manual thinning (Grant 2006). While thinning is expected to increase individual tree and either maintain or decrease overall stand growth relative to untreated stands (Grigg and Grant 2009), an increased fuel load following thinning can result in increased risk of higher intensity fire, though findings of Grigg et al. (2010) suggest that in the absence of fire immediately after thinning, fuel loads can return to unthinned loads within 5 years. Changes to soil nitrogen cycling as a result of thinning have also been observed (Banning et al. 2011a).

3.6.6 Drought/water stress

Over the past 40 years, groundwater levels in the NJF have declined at rates up to 0.5 m year (Macfarlane et al. 2018). To understand the impact of a falling water table on the persistence (survival and growth) of rehabilitated forest, Alcoa have supported studies to quantify the physiological response of vegetation to water stress and use of available water (soil and groundwater) relative to non-mined forests. The studies have investigated these dynamics for different prescriptions of rehabilitation and stages of development (Szota et al. 2007; Szota et al. 2011; Standish et al. 2015; Macfarlane et al. 2018).

The effect of climate variability on species richness at 15 months, for rehabilitation completed between 1992 and 2010 (including the severe drought of 2010), has been reported to be less than that of rehabilitation practice, particularly topsoil handling (Standish et al. 2015). Species richness and assemblage composition were relatively consistent each year, and the study concluded 15-month rehabilitation demonstrated resistance to climatic variations and attributed this in part to the reliability (as opposed to the amount) of winter rainfall (Standish et al. 2015). It was suggested that rainfall reliability may provide a more accurate assessment of potential impacts of projected climate change on establishment of vegetation in rehabilitation. However, it was also acknowledged that further investigations that more accurately assess response of rehabilitation to long-term disturbances such as climate change are required (Standish et al. 2015). Note, this study did not include assessment of 15-month monitoring data of rehabilitation from the current era (2016-onwards).

Macfarlane et al. (2018) investigated whether depth to groundwater and altered hydrology after mining affect overstorey transpiration rates of 8- and 30-year-old rehabilitation and post-harvest (logged) non-mined forests. They concluded that jarrah forests are likely to be facultative phreatophytes, meaning they will use groundwater where it is available but are not reliant on it, particularly where groundwater is within 10 m of the surface. In addition, both rehabilitation and non-mined forests were conservative in water use characteristics where access to deep groundwater was limited and as are likely to be resilient to declines in groundwater levels (Macfarlane et al. 2018). As there was no discernible difference in transpiration rates per unit leaf area between rehabilitation and post-harvest jarrah forest, it was concluded that both forest types could be managed consistently.

In additional studies on water stress, field observations and aerial reconnaissance after the 2010/11 drought and heatwaves recorded tree deaths in both non-mined forest and in rehabilitation (Davison 2011). Many of the dying trees in non-mined forest had insect borers, while trees in some rehabilitation sites had obvious fungal cankers, both indicating that the trees had been under moisture stress for several months before the foliage had died (Davidson 2011). While Matusick et al. (2013) noted that tree death after drought was more prevalent close to rock outcrops and higher in the landscape and in soils with low water holding capacity. While rehabilitation is typically situated mid slope, and frequently has a substrate of deep-ripped clay soils, research has also highlighted the importance of rehabilitation practices, particularly deep ripping of pit floors, on water availability and growth and survival of trees in mid to late-stage rehabilitation (Szota et al. 2007). Szota et al. (2011) demonstrated that 13-year-old jarrah and marri grown on 'low quality' areas of rehabilitation, where deep ripping had been inadequate to break the cemented subsoil, had smaller and fewer trees relative to areas where the subsoil was accessible to roots, and that poor survival and growth was the result of severe water stress. The severity of the water stress indicated that long-term survival may be impacted in areas receiving sub-optimal deep ripping (Szota et al. 2011), highlighting the importance of initial rehabilitation practices, for long-term survival and resilience to climatic variability. The study also found that marri may be more drought tolerant at suboptimal root conditions than jarrah, and that increasing the proportion of marri in rehabilitated areas, particularly where water availability is perceived or expected to be sub-optimal, may increase drought resistance of these areas (Szota et al. 2011), whilst having biodiversity benefits including providing additional critical foraging habitat for endangered forest black cockatoos (Lee et al. 2013).

Current completion criteria require rehabilitation at late stage (12 years of age) to not show any evidence of being more affected by drought (water stress) relative to non-mined forest. Prior to the current era, there had been no specific criteria relating to drought tolerance. Based on increased confidence in seedling survival and rehabilitation practices that aim to improve water retention and root penetration, Alcoa suggest that rehabilitation in the current era is likely to exhibit reduced competition for water resources and hence demonstrate greater resilience to drought than in previous eras (Alcoa 2022). The ongoing trend of less trees established in rehabilitation, and thus an emphasis towards the understorey, is likely to improve the water balance at the subcatchment level (Wardell Johnson et al. 2015).

There is no published data that provides an assessment of resistance or resilience of current era rehabilitation to drought or water stress and it will be several years before an assessment of late-stage rehabilitation would be possible. Further, this expectation is underpinned by the assumption that deep ripping and initial site preparations have been adequate. However, on a landscape level it is unclear how much of the rehabilitation to date would be classed as ‘low quality’ (poor growth and survival at mid-late stage), whether remediation works including re-ripping or other remedial works (re-planting with marri) have been undertaken in these areas, and whether these remedial actions have positively impacted growth and survival of trees. Inclusion of species from drier areas of the NJF into the rehabilitation seed mix is a potential option to enhance resilience to climate change, but this has not occurred to date (pers. comm. G. Mullins, April 2023).

4 Consistency with ongoing ecological integrity of the Northern Jarrah Forest

As part of the EPA assessment of the amendment to the current Proposal to increase production at the Pinjarra Alumina Refinery (Refinery) (GHD 2023), the EPA required Alcoa to supply additional information to its Environmental Review Document (ERD) under section 40 (2)(a) of the EP Act. This additional information was requested to ensure the EPA was able to adequately consider, understand and assess cumulative, and holistic impacts of the current Proposal.

In particular, the EPA required Alcoa to develop adequate and scientifically robust Biodiversity Indicators (BIs) and a supporting detailed monitoring framework that could be used to assess whether impacts of and environmental outcomes from the Proposal are likely to be consistent with the ongoing ecological integrity of the Northern Jarrah Forest (NJF). Specifically, Alcoa were required to:

"*Identify the key biodiversity indicators (relevant to all applicable key factors, i.e., not just flora and vegetation) which are adequate, scientifically robust and appropriate to assess whether the impacts of, and environmental outcomes resulting from, the proposal are likely to be consistent with the ongoing ecological integrity of the Northern Jarrah Forest (NJF). Key biodiversity indicators must take into account the impacts of the proposal, cumulative impacts from past, current and reasonably foreseeable future activities, and ongoing pressures such as fire, water resource availability and climate change*."

This EPA requirement regarding BIs, was also included as part of their request for an independent peer review (this document). Specifically, a task identified for the peer review was: "*Taking into account the key biodiversity indicators, assess whether ongoing rehabilitation for the Proposal is likely to be consistent with the ongoing ecological integrity of the Northern Jarrah Forest".* That task is addressed in this section.

The conservation of biological diversity and ecological integrity is a key principle guiding the EIA process under the EP Act 1986 (EPA 2023) and the EPA objectives define ecological integrity as "*the composition, structure, function and processes of ecosystems, and the natural range of variation of these elements*" (EPA, 2016). The extent to which Alcoa's rehabilitation is able to contribute to and maintain ecological integrity in the long-term and adapt to the impacts of climate change, can be considered in terms of the Environmental Factors developed by the EPA (2023). These factors were also considered in the development of the BIs, with five factors identified as relevant to their proposal: Flora and Vegetation, Terrestrial Environmental Quality, Terrestrial Fauna, Inland Waters and Social Surrounds (GHD 2023). We understand the BIs have also been developed with regard to the principles outlined in the Draft FMP (2024-2033), specifically Foundation 2 (Biodiversity Conservation) and Foundation 3 (Forest Health & Climate Resilience). In these principles, maintenance of ecological integrity is implicit, with their recognition that, in order to conserve biodiversity and forest health, the full array of habitats and ecological processes at various spatial scales are required. Other guidance documents referenced in the BIs include the NSW Biodiversity Indicator Program (OEH & CSIRO 2019) and the Montreal Process (GHD 2023).

A draft document setting out the BI rationale and monitoring framework was provided to Stantec (GHD 2023) and in brief twelve BIs have been proposed as follows:

1. Areas with a Protective Mechanism within the NJF within the ML1SA, lasting for at least the State Agreement lease period
2. Disturbance to vegetation communities of conservation significance
3. Ecological condition of native vegetation (upland vegetation)
4. Ecological condition of native vegetation (stream and swamp vegetation)
5. Waterway health
6. Ecological connectivity of vegetation
7. Avifauna
8. Ground fauna presence/absence – threatened mammal species
9. Forest red-tailed black cockatoo population estimates
10. Inappropriate fire regimes
11. Feral predators and invasive species
12. Dieback infection

Assessment of rehabilitation using proposed BIs

Alcoa's current and proposed mining operations are expected to cover a total of approximately 2% of the NJF. Though when considered with other mining operations, the total area of mining or rehabilitation is expected to exceed 66,000 ha in the future, or approximately 3.5% of the NJF (Alcoa 2022). This does not factor in the impact of fragmentation of the surrounding non-mined areas. The scale of this disturbance emphasizes the importance of considering how the Proposal fits with ensuring the ongoing ecological integrity of the NJF.

As identified in earlier sections of this review, there are knowledge gaps relating to the severity, duration and scale of the potential impact that may remain as a result of the Proposal and whether these impacts can be realistically and credibly managed through rehabilitation. As the aim is for Alcoa to use the proposed BIs to assess and monitor potential impacts (from mining operations or other threatening processes) across the whole of life of the Proposal and to provide input into ongoing and adaptive management (GHD 2023), we have limited our consideration as to whether the BIs (Table 3, GHD 2023) and associated monitoring approach (Table 4, GHD 2023):

i. adequately address gaps in knowledge identified in sections 2 and 3, and
ii. what additional value the BIs may provide to the rehabilitation process and the overall goal of ensuring ongoing ecological integrity of the NJF.

Remedial action and outcomes

Accurate monitoring and evaluation are fundamental to ensuring an effective adaptive management system. A critical element in judging success of rehabilitation is the frequency and scale of failures to meet agreed early-stage completion criteria, given that initial establishment can affect the rehabilitation vegetation community for decades. Timely remediation of areas of inadequate rehabilitation relies on the accuracy of monitoring and the self-certification process. During this review we identified opportunities for improvement to the monitoring and evaluation process, particularly for remedial or corrective actions that would be critical to reducing vulnerabilities, provide a strong evidence-base to support adaptive management and allow a more robust and credible evaluation of rehabilitation success including:

- early identification of potential non-compliances and causes during rehabilitation works;
- provision of accurate information to DBCA during the onsite Checklist process;
- completion of remedial work within the designated timeframe, to facilitate long-term success;
- improved record keeping and database management of all remedial actions;
- early evaluation of the success of remedial works;
- incorporation of findings from remedial evaluations into rehabilitation planning and ongoing management strategies;
- holistic, catchment-wide assessment of rehabilitation success that includes a quantitative assessment of rehabilitation classified as ‘low quality', and possible causes; and
- regular, robust and transparent auditing of rehabilitation performance.

Addressing these issues requires accountability to be embedded into the monitoring framework at various points and ensuring that appropriate internal and external knowledge systems are integrated. Ensuring the optimal functioning of the monitoring and evaluation framework is fundamental to ensuring ongoing ecological integrity and Alcoa’s social license to operate. We also suggested that consideration could be given to incorporating these improvements into DBCA working arrangements and completion criteria.

We reviewed the BIs for evidence of mechanisms that may support improved verification of remedial actions and make the following observations. The rationale for the BI framework indicates that the outcomes of the monitoring of BIs will inform the formulation of management strategies which will in turn, mitigate risks to the ecological integrity of the NJF. The key outcome of an exceedance of a BI will be a causal analysis to determine the nature and source of the exceedance, which will then inform the appropriate action/s to reduce the risk of an exceedance occurring in the future. Figure 1 of the BIs provides a schematic of the monitoring framework process. Here, ‘corrective actions’ are identified as a key part of the overall process. The schematic lists three possible outcomes stemming from corrective actions including revision of the Mine Plan, revision of the BIs or revision of the completion criteria. We have assumed these outcomes are the proposed management strategies. However, based on the potential improvements identified in this review, an additional outcome or management strategy associated with corrective actions could be their audit and evaluation against the response target or another determined target. This would ensure that an assessment of any corrective action is captured in the overall BI framework.

Despite the rationale providing an aspiration that the monitoring of BIs will inform management strategies we did not find explicit evidence in either the BIs or the monitoring framework indicating *how* this will occur. While it is recognised that the first response is primarily a causal investigation, consideration could be given to providing more detailed information regarding how Alcoa plans to use information gained during initial evaluations of target exceedances to inform corrective actions, including a timeframe.

As discussed above, Figure 1 of the BI document does set out a pathway for monitoring and analysis, potentially leading to corrective actions, but we found the process diagram to be excessively convoluted, and recommend that it is simplified wherever possible, to assist understanding. As a specific observation, it is surprising that of the three potential corrective actions, only one (Revision of Mine Plan) appears likely to result in a change to mining or rehabilitation practice. Although, it is not clear if, or how, revising the mine plan will lead to changes in rehabilitations strategies. The other two actions are to either revise the BIs or revise the completion criteria. Both of which have connotations of potential lowering of standards, if monitoring finds that current targets are not being achieved. As part of revising the process diagram we recommend that this potential interpretation is clarified.

It is proposed in the BI monitoring framework that monitoring outcomes will be reported in the Annual Environmental Report, but it is also not clear if all target exceedances, causal investigations and corrective actions will be reported. This should be made explicit in the monitoring framework. It is noted that measurement of BIs will mostly be done on an annual basis and largely through existing monitoring programs, however, it would be helpful to clarify how the measurement and evaluation of proposed BIs will interact with existing reporting frameworks.

In the following, we discuss issues identified earlier in this review in relation to the proposed BIs.

Marri establishment

The successful establishment of marri trees in rehabilitation is an important factor in ecological resilience and development of fauna habitat. Recent monitoring data indicate inadequate seeding success rates of marri in rehabilitation completed between 2019 and 2021 against established completion criteria, with a large area of rehabilitation (approximately 991 ha) requiring remedial infill planting in coming seasons. While Alcoa have commenced an investigation into the reasons for this, it is unclear how information from this investigation will inform remedial actions or changes to the rehabilitation method.

A sub-indicator under BI 3 – Ecological condition of native vegetation, identifies overstorey (tree) species richness as a measure of the establishment of overstorey species during rehabilitation. Alcoa have identified that in order to maintain ecological integrity of the NFJ, species richness of the overstory in rehabilitated areas should be comparable to non-mined forest. The monitoring method proposed for this sub-indicator is biennial image capture and analysis, coupled with annual on-ground vegetation plot monitoring. The response trigger would be a statistical reduction in overstorey species richness greater than two standard deviations, with the initial response being on-ground assessment of areas where exceedances occurred to investigate potential causes. However, it remains unclear in the BI monitoring framework whether there is a commitment to use the results of initial causal investigations to inform corrective actions and management strategies and how assessment of the BIs are linked to the existing environmental closure risk assessments. As such, the link between initial response (investigation), corrective action and adaptive management to ensure ongoing ecological integrity remains deficient.

Understorey cover

A diverse and productive understorey is an important element of rehabilitated forest, as reflected in late-stage completion criteria of the current era, which indicate richness, density and cover as key elements for acceptance. In section 2 we identified the possibility of undertaking more detailed monitoring of understorey performance to determine if recent-era rehabilitation was on track to achieving cover targets. However, there is no reference to understorey cover measurement in the BI framework.

Vegetation structure and composition

There are two proposed BIs in Group 2 that relate to measurement of changes in ecological condition or integrity of native vegetation (upland, and stream and swamp) as a result of mining impacts relative to nonmined references. Sub-indicators propose to capture both on ground site level data (annual) and remote sensing data (biennial) of overstorey (tree) species richness, tree density, canopy cover and understorey species richness (GHD 2023). These are in line with current metrics used for vegetation completion criteria in rehabilitated areas.

The rationale for the BIs was to assess "structure and composition metrics". However, as discussed in section 2 of this review, while species richness is a widely-used diversity index within mine rehabilitation monitoring programs, it does not provide compositional similarity comparisons. For example, the BI framework specifies an understorey species richness target of returning 60 – 80% of unmined forest species in rehabilitation. Assuming this is achieved, a knowledge gap still exists around the ecological condition or integrity of the rehabilitation as it depends, to some extent, which of the 20 - 40% of forest species are missing, and whether or not it is the same species, genera or functional groups, that are consistently not returned in rehabilitation. Richness metrics also do not address potential changes in the abundance of the species that are returned in rehabilitation, relative to unmined forest, which may also affect ecological condition and fauna usage. (Note, Stantec recommends that the BI framework clarifies whether species typically described as "mid-storey" in unmined forest would be captured within the overstorey (tree) or understorey species richness indicators for rehabilitation assessments).

While the species-level identity (i.e. composition) of all vegetation is routinely collected within the existing on-ground monitoring program, specific compositional targets are only included in the completion criteria framework by having density targets for jarrah and marri trees, legumes and more recently, 'recalcitrant' species. The proposed BI framework currently states "tree densities (stems per ha)" as the indicator and therefore is not a compositional metric. The rationale for the BIs acknowledge that changes in species composition could indicate a vulnerability to the impacts of invasive species, forest disease and fragmentation and generally ecological condition. However, given that the proposed BIs do not directly assess broad-scale compositional metrics, the knowledge gaps already highlighted in this report regarding compositional changes would remain.

It is not typical in mine closure planning for compositional metrics to be specified as quantified targets and instead are usually referred to in a qualitative sense (Young et al. 2019). Nonetheless, Alcoa's own research programs have explored the use of compositional similarity metrics (such as Bray-Curtis) and have been able to examine how similar rehabilitation is to forest references, how this similarity changes with rehabilitation age or changing rehabilitation protocols (such as topsoil return, fertilizer use or seed mixes) or time since fire and which species (presence, absence and can also be used for differences in relative abundance) are most significant drivers of dissimilarity between rehabilitation and unmined forest. Species composition data has also been used to create functional diversity indices (Standish et al. 2021) which can be used to measure whether improvements have been made regarding known difficulties in rehabilitation, such as the return of species with a "re-sprouter" ecological response to fire as well as other potential broad-scale shifts in functional traits in response to mining and rehabilitation.

It is worth considering whether the knowledge base built from Alcoa's research studies could be applied more broadly into a BI framework. Arguably, these type of compositional similarity analyses are required to provide greater confidence and address knowledge gaps regarding the maintenance of ecological integrity, including fauna habitat values, of the NJF.

Fauna utilisation

Our review identified the need for continual focus on faunal community composition. The BIs proposed in Group 3 (BI 7, 8 and 9) largely address this aspect through measurement of changes in avian assemblages and threatened species populations, with causal investigations required following identified changes in assemblages and/or declines in populations. The indicators selected are broadly appropriate and relevant to understanding return of species in rehabilitation and how populations and ecosystem condition and integrity may be impacted by rehabilitation. However, a key requirement for developing indicators for biodiversity is that they should be inclusive of all levels of biological organisation: diversity within and between species and diversity of ecosystems (within the meaning of the Biodiversity Conservation Act 2016). Therefore, evaluation of threats and extinction risk should be extended beyond those species and ecological communities currently listed as threatened or conservation significant. This is partly addressed by selection of avifauna assemblages and presence/absence of selected bird species are proposed to be measured triennially across the MDE as a surrogate for structural and compositional changes to habitat that may result from mining (GHD 2023). In general, the measurement of biodiversity surrogates is an accepted approach in biodiversity conservation to reduce knowledge gaps (OEH & CSIRO 2019) and can be derived through the selection of a set of species representative of entire group. However, the rationale does not detail why certain indicator species have been selected.

In section 3 of this report, we highlighted the importance of enhancing understanding of how conservation significant species utilise rehabilitation areas as habitat. Alcoa propose to monitor the presence/absence of threatened mammal species through continuation of the Long-Term Fauna Monitoring Program (LTFMP). The response trigger is identified as when changes in presence of individual species from monitoring sites are recorded. As indicated in section 5, given the extent of quantitative data on fauna return collected by Alcoa over the past 45 years, development of specific standards related to fauna in rehabilitation may be possible. This would broaden the historically vegetation-centric standards to include faunal community composition and physiological and behavioral responses to mining impacts. In addition, as research has highlighted the benefit of returning larger (>30 cm) logs, stumps and rocks, along with higher densities of other coarse woody debris to maximize probabilities of recolonization, monitoring of development of these habitat characteristics could be considered for inclusion in assessment of ecological condition.

Vulnerable Forest red tailed black cockatoos have been included as an avifauna indicator species, reflecting their sensitivity to reductions in breeding habitat and foraging areas. Assessment of the impact of the proposal on the population of this species has been selected as a standalone BI (BI 9) given there will be losses in its foraging and breeding habitat as a result of the Proposal and that the population may be limited by regional availability of watering habitats. However, it is not clear why this species was selected over the Endangered Baudin's and Carnaby's black cockatoo. Further, measurement of population numbers over time should be linked to measurement of changes in key factors in ecosystem quality that are important for maintaining populations of these and other forest dwelling animals, particularly the presence of large DBH trees suitable for breeding and foraging. While it is recognized that a monitoring program for Forest black cockatoos is yet to be developed and will include comparison with ecological condition and other faunal indicators interactions, it will be important to ensure that monitoring is able to accurately capture information about how mining may be impacting local habitat conditions along with landscape level changes such as the extent, shape and quality of available habitat in the region and the effectiveness of local scale management actions to reduce impacts (OEH & CSIRO 2019). For example, as outlined in section 5, a more detailed understanding of the use of large DBH trees by Forest black cockatoos in the MDE and the effectiveness of management practices to ensure survival of retained large DBH should be considered for inclusion in monitoring and reporting programs.

In addition, the mitigation hierarchy identifies avoidance and minimisation strategies as the most effective ways to reduce environmental impacts and that these strategies should be prioritised over rehabilitation and offsets (ICMM 2015). Given the existing gaps in knowledge relating to populations of conservation significant Forest black cockatoos and the lack of up-to-date Species Recovery Plans, clear articulation of how the mitigation hierarchy and Precautionary Principle have been applied in regard to protection of endangered species and how these BIs would interact with Proposal's Offset Strategy should be considered.

Thinning and streamflow

Tree density in rehabilitation is a factor influencing understorey development, the water-use of vegetation in rehabilitated areas, and streamflow. Given that there is currently a legacy of overly dense rehabilitation, understanding the impact on water movement (groundwater and streamflow) and the integrity of the surrounding forest matrix is important, particularly in the context of climate change. While not explicitly addressed as part of the BI framework, assessment of thinning practices on tree density and how this interacts with the surrounding forest will likely be addressed through measurement of forest ecosystem indicators (BI 3 to 6), particularly the ecological condition of native vegetation (BI 3). In addition, the BI framework includes an assessment of the ecological condition of stream and swamp vegetation in water dependent Site Vegetation Types (BI 4) using the same metrics and response triggers as BI 3.

In addition to considering vegetation health in shallow groundwater zones, the proposed BIs include monitoring of water quantity and quality in waterways, both upstream and downstream of active pits and rehabilitated areas less than 5 years old (BI 5). Both BIs are broadly appropriate to assess the impact of rehabilitation on water dependent vegetation and water quantity and quality, however consideration could be given to providing a rationale for restricting this BI to rehabilitated areas less than 5 years old. The assessment of waterway health (BI 5) also does not relate to past rehabilitation activities.

Resilience to further disturbances – fire, forest disease, drought

Alcoa identifies three key threats to the ecological integrity of the NJF: inappropriate fire regimes, extent and impact of invasive species and dieback infection, with each having a corresponding BI. The drier and warmer conditions expected in the southwest forests are likely to interact with these key threats to the NJF, though the outcomes of these interactions are difficult to predict (Conservation and Parks Commission 2022a). Furthermore, extreme climate-related events may amplify the impact of other threats at the species and ecosystem level. In the development of biodiversity indicators for ecological integrity of the NJF, it is therefore important to identify those indicators that can assess resilience of the forest to changes or disturbances that may be associated with climate change (OEH & CSIRO, 2019). It has also been acknowledged that more accurate assessments of the response of rehabilitation to disturbances resulting from climate change are required (Standish et al. 2015).

Choosing an appropriate fire regime that will encourage development of desirable species and floristic diversity in rehabilitation but discourage weeds and continued high densities of *Acacia* understorey species is critical. An annual monitoring method is reported to be under development (based on fuel age) in collaboration with DBCA to assess the impact of rehabilitation on the NJF's resilience to fire, in the context of a drying climate (GHD 2023). No timeframe for development of this monitoring program was provided.

In regard to invasive species, monitoring of native plant species, and density and distribution of weed species, will be completed annually through existing vegetation plot monitoring and compared at different spatial and temporal scales to determine changes. Statistical increases in weed species richness or cover will act as triggers for remedial actions including initiation of a comparison with ecological condition and connectivity indicators to investigate interactions. This approach appears commensurate with the level of risk posed by weeds, though effective preventative weed management will be key to reducing the initial establishment and subsequent spread of weed species. For feral animal predation and vegetation disturbance, Alcoa indicate that a biennial on-ground monitoring program will be developed in conjunction with DBCA and proposed monitoring aligns with existing feral animal management program (Western Shield) conducted in collaboration with DBCA. Existing fire and feral animal management programs represent examples of public-private collaborative land management and lessons learnt from the implementation and evaluation of these programs could be useful during development of additional monitoring programs proposed to measure broad ecological integrity of the NJF.

Phytophthora dieback is recognised as the most significant plant disease affecting ecological values in the planning area (GHD 2023). The proposed BI 12 will aim to assess the extent of change (hectares) in infected areas within the ML1SA. However, in section 5 we identify that in order to fully assess the susceptibility of rehabilitation to forest diseases, there was a need to determine the proportion of historical rehabilitation located in upland areas and to complete a contemporary study of the risks of forest disease to rehabilitation survival and floristic diversity in the context of climate change. Consideration should also be given to incorporating the outcomes of investigations into the resilience and long-term survival of marri also identified in section 5.

Drought which may induce water stress in vegetation in rehabilitation and non-mined forest is an additional threat to the ecological integrity of the NJF that has not been included in the BI framework. However, the proposed BIs relating to measurement of ecological condition of native vegetation are broadly appropriate to assess the potential impact of drought on survival of rehabilitation. As identified above, if causal investigations stemming from the annual review of on ground and remote sensing data reveal water stress as a possible cause of poor growth, there should be a commitment to corrective actions. Current completion criteria require rehabilitation at late stage (12 years of age) to not show any evidence of being more affected by water stress relative to non-mined forest. While there is an expectation that current era rehabilitation will be more drought tolerant than previous prescriptions, this expectation assumes that deep ripping and initial site preparations have been adequate to allow adequate root exploration. Further, there is no published data indicating resistance or resilience of current era rehabilitation to drought or water stress.

The addition of a BI dedicated to the assessment of ecological connectivity of vegetation (BI 6) recognizes the importance of minimising habitat fragmentation that can lead to the isolation and loss of species and genetic diversity, degrade habitat quality and reduce ecosystem resilience (GHD 2023). A fragmentation index is proposed to be applied for areas within the MDE, adapted from the NSW biodiversity indicator program (OEH & CSIRO 2019). The index will use on-ground and disturbance mapping to assess changes in ecological connectivity. At a local scale, fragmentation is expected to decrease with the age of rehabilitation. While the index provides a broad assessment of ecological connectivity in the MDE, it could be coupled with assessments of vegetation condition described above, to assess the extent to which rehabilitation fits into the surrounding forest matrix.

Ongoing rehabilitation research and general comments

In previous sections we highlighted the need for a more holistic landscape-scale assessment of rehabilitation performance over time and the need to continually examine how rehabilitation practices can be adapted to support both sustainability of rehabilitation and ecological integrity of the surrounding forest matrix. Biodiversity indicators can be expressed at different scales; geographic, taxonomic and temporal (OEH & CSIRO 2019). While it is acknowledged that any direct impacts of Alcoa's Proposal are more likely to be associated with the MDE and ML1SA, the BIs explicitly aim to provide an assessment of the ecological integrity of the whole NJF bioregion and as such wherever appropriate, indicators should reliably report status and trends at this scale (OEH & CSIRO 2019). Although most of the BIs propose to measure changes at the scale of the MDE or ML1SA, more consideration could be given to clarifying how the different approaches proposed in the BI framework will support understanding of potential impacts at the bioregional scale. For example, several years of direct assessments of species presence/absence or assemblages of fauna are required to confidently assess change and then such information may only apply to a specific location. However, use of appropriately-calibrated remote sensing approaches and models may allow generalisation over multiple locations to support assessments of ecological integrity over larger scales (OEH & CSIRO 2019). The BI framework proposed here could foster novel approaches to environmental modelling using site level, remote sensing and fragmentation assessments to identify and report on 'good quality' and 'low quality' areas of rehabilitation at the landscape level as well as whether remediation works have been successful, thus supporting the ongoing ecological integrity of the NJF.

It is acknowledged that there has not previously been clearly defined BIs for the NJF, separate from the objectives of the Draft FMP. Given that there are other forest users, including South32 and Boddington Gold Mine, with ongoing rehabilitation programs, prior to implementation of the framework, clarification from regulating agencies regarding how the BI framework proposed here aligns with those of other forest users, and how the BI framework will be integrated into existing compliance reporting and biodiversity monitoring programs within the whole NJF.

5 Conclusions on current and proposed rehabilitation methods

Alcoa's rehabilitation practices after bauxite mining in the NJF, together with a substantial program of related research published in peer-reviewed journals, remain as sophisticated and comprehensive as for any mining operation globally. In addition, the process of development and sequential refinements of publicly-available completion criteria, commencing more than 30 years ago, exceeds that of other operations in WA, if not globally.

The nature of the rehabilitation approach and extent of supporting research at Alcoa's operations reflects the sensitive environment in which the mining has taken place over the last 50 years. Given the substantial area of the NJF that is currently disturbed or rehabilitated, together with additional areas proposed, continued focus on rehabilitation outcomes and potential improvements is critical. In this section, we have assembled a synthesis of conclusions and recommendations as an outcome of this peer review.

5.1 Assessment of rehabilitation success to date

Rehabilitation standards and practices, and stakeholder expectations have increased over time such that continuing improvements in biodiversity outcomes and ecological integrity are required. Adaptations and improvements have been reflected in changes in completion criteria over time. In the following, we raise aspects to be considered for improvement.

Documenting remedial actions and outcomes

Monitoring and evaluation is fundamental to adaptive management. A critical element in the success of rehabilitation methods is the frequency and scale of failures to meet agreed early-stage completion criteria, given that initial establishment can affect the rehabilitation vegetation community for decades. Identification and opportunities for cost-effective subsequent remediation rely on the accuracy of monitoring and the self-certification process. The Rehabilitation Checklist used in this process has been developed to record the status of rehabilitation establishment in the field in agreement with DBCA. The assessment of vegetation establishment criteria is largely to ensure corrective actions can be carried out in a cost-effective and timely manner. Typically, if a rehabilitation area does not meet one of the criteria, it is reviewed with Parks and Wildlife to determine the need for corrective action and the extent of remedial work required to improve the site.

Alcoa have indicated that rehabilitation rarely fails to meet vegetation establishment criteria (9 and 15 months) (Alcoa 2022) and that where incidences of failures are identified, these are reported to DBCA via the Rehabilitation Checklist process and recorded and reported on internally through Alcoa's safety management system. While Stantec have received some information relating to frequency of failing to achieve early-stage vegetation completion criteria, no information of failures against other key completion criteria were provided. Stantec is unaware of how often these checklists are audited by Alcoa or DBCA and this information is not publicly available.

While the majority of rehabilitation completed in the 30 years between 1992-2021 has met species richness targets, some areas that were assessed as not meeting the richness criterion (70 ha) have not yet had remedial works (planned to be completed during 2023 rehabilitation season) and it is noted that records of remedial in-fill planting prior to 2005 are scarce. Where remedial works have been undertaken, such as in-fill planting of seedlings, success of these remedial works is not monitored, but instead is based on results of trials of survival rates that have been conducted annually since 2017, along with data from some earlier trials (pers. comm., C. Blackburn, 26 June 2023). As such, there is an assumption that all supplementary plantings of seedlings are successful. Follow-up monitoring of a selection of remediated areas to verify success would be useful in providing confidence in overall rehabilitation outcomes and could help identify areas for improvement in the rehabilitation process.

While monitoring is done to determine the success of remedial seeding to improve legume densities, we understand that this data has not been recorded in the primary database and there are no consistent records regarding remediation efforts for failed legumes densities. In addition, while assessment of remediation efforts is provided in annual reports, the data has not been collated, making review of remediation success difficult. Alcoa have acknowledged their data collection process for remediated areas requires improvement.

Given the relatively small area of rehabilitation not meeting richness targets over time, overall, the ability of rehabilitation procedures to achieve richness appears reasonable. However, monitoring success of all remedial actions that may impact the long-term success of rehabilitation as a standard practice, as well as conducting a holistic, catchment-wide assessment of rehabilitation success that includes a quantitative assessment of rehabilitation classified as ‘low quality', where growth and survival has been retarded including possible causes, would provide a strong evidence-base to support adaptive management.

Marri establishment

The successful establishment of marri trees in rehabilitation is an important factor in ecological resilience and development of fauna habitat. It is worth noting that in recent years, such as 2019 to 2021, data provided to Stantec indicated that marri establishment has not been as successful as the longer-term average, with a total 991 ha over three years that did not meet the marri density target at nine months of age. Given the size of the area requiring in-fill planting with marri, and the importance of marri as a food source for black cockatoos, some follow-up monitoring of the success of the remedial actions is warranted, particularly in larger remediated areas. Alcoa have commenced an investigation into the reasons for relatively low success rates in recent years. This information will be important for future rehabilitation outcomes.

Understorey cover

A diverse and productive understorey is an important element of rehabilitated forest, as reflected in late-stage completion criteria of the current era, which indicate richness, density and cover as key elements for acceptance. Stantec, has not received or reviewed any monitoring data related to understorey cover. More-detailed monitoring of understorey performance could be undertaken to determine if recent-era rehabilitation was on track to achieving cover targets.

Compositional similarity

Current monitoring and related completion criteria rely on measures of species richness for diversity assessments and compositional targets are applied only to densities of jarrah, marri, legumes and recalcitrant species (from 2016 onwards). The success of the return of midstorey and understorey non-legume, non-recalcitrant species is only partially captured within the overall richness target, which does not assess abundance or composition directly. It is important to acknowledge this gap and consider whether amendments are warranted in future completion criteria.

Analyses on floristic compositional similarity do exist in a variety of Alcoa rehabilitation focussed research publications over a number of years. Further compositional similarity analyses and associated multivariate statistical analyses will be required to assess the influence of more recent changes in rehabilitation practices as the rehabilitation ages. Arguably, wide-scale application of these type of compositional and functional diversity analyses is required to provide greater confidence around knowledge gaps regarding the maintenance of ecological integrity.

Monitoring and self-certification process vulnerabilities

Completion Criteria (CC) and the Working Arrangements (WA) Checklist focus on landscaping, soil return and fauna habitats, contour ripping, seeding and planting, including recalcitrant species. Monitoring, reporting and verification of rehabilitation outcomes are essential elements of ensuring rehabilitation is established appropriately, and also in ensuring stakeholder confidence in the process. Alcoa has indicated that an internal database tracks rehabilitation activities that occur across their operations. However, inaccuracies in reporting, and subsequent lack of remediation, could result in rehabilitation that does not meet post-mining land use objectives. Appropriate completion of rehabilitation earthworks (landscaping, soil return, fauna habitats, contour ripping), and seeding and planting are currently self-certified by Alcoa, and then reviewed and signed off by DBCA, via the Completion Criteria (CC) and Working Arrangements (WA) Checklist. However, this process can be vulnerable to inaccuracies.

Lack of pit floor ripping over a substantial proportion of rehabilitation completed at Huntly in 2018, is likely to have led to erosion (e.g., pit Manning 15) and perhaps more importantly has the potential to constrain vegetation growth over the long term on all affected pits. In the Rehabilitation Checklist for the Manning 15 pit, pit floor ripping was signed off by Alcoa and DBCA as being completed appropriately. It is a concern that potentially substantial areas of rehabilitation at Huntly in that year may have been incorrectly prepared without internal certification processes detecting nor reporting the issue. An additional concern is that apparently remedial action has not occurred. This highlights vulnerability in the self-certification process and the importance of effective monitoring and evaluation by regulating agencies.

It is important that the monitoring and certification process is rigorous, identifying areas that do not reach defined standards, that remedial action is taken as promptly as possible, and in turn it is monitored and reported appropriately. For example, effective monitoring and reporting protocols relating to remedial works including area (ha) of failures, contributing causes and details of remediation works completed are important for quality assurance and stakeholder confidence. Consideration could be given to incorporating this into working arrangements and completion criteria.

5.2 Alignment of rehabilitation methods and success, with proposed Northern Jarrah Forest post-mining land use

5.2.1 Conservation

Opportunities remain for continuing to improve flora and vegetation biodiversity outcomes through ongoing refinement of elements such as fertilizer inputs (specifically with respect to phosphorus), tailored seed mixes / planting according to the specific topographical features in each mined pit, further consideration of seed provenances, and continued focus on the return of species that remain poorly represented in rehabilitation compared to unmined forest.

Fauna utilisation

For all conservation significant fauna, the NJF represents important remnant breeding and foraging habitat and the loss of habitat for such species as the Baudin's black cockatoo, has been identified as a primary threat to their persistence. As mining will remove further potential breeding and feeding habitat, enhancing understanding of how conservation significant species utilise rehabilitation areas as habitat is important.

Only a moderate level of confidence has been assigned to the ability of contemporary rehabilitation prescriptions to improve fauna habitat values (e.g. for black cockatoos and reptiles) relative to past prescriptions (Alcoa 2022). This moderate level of confidence could be expected given the lack of studies on recolonisation of fauna in current era rehabilitation. However, Alcoa indicate this risk will be partially offset by the expectation that current era rehabilitation will establish a floristic diversity and vegetation structure closer to that of un-mined forest relative to earlier prescriptions (Alcoa 2022). However, recent studies highlight the need for caution when assuming that revegetation will lead to the establishment of appropriate faunal communities. Continuing emphasis is recommended on understanding fauna return and habitat requirements given the fundamental role animals play in many key ecological processes required for restoration including pollination, soil development and seed dispersal.

Retaining large diameter trees within mined pits, together with a surrounding buffer of unmined soil, is part of current mining procedures in order to maintain potential habitat for black cockatoos. While Alcoa have indicated that a dedicated study investigating the long-term survival/attrition rates of protected trees in the mining area is underway (established in 2014-2015), Stantec has not reviewed any data related to this study. It will be important to understand how effective the current protection practices are at ensuring long-term tree survival and tree use and should include an assessment of the amount of undisturbed soil around each tree required to ensure long-term survival. However, it is encouraging to note that feeding activity of black cockatoos in rehabilitation has been recorded on proteaceous (*Banksia*) and myrtaceous (marri, jarrah) trees within four to ten years, indicating that rehabilitation has the potential to provide an ongoing food resource for these birds over time. This research underlines the importance of understanding potential constraints to development of marri in rehabilitated jarrah forest ecosystems.

The continued focus on faunal community composition and physiological and behavioral responses will be important in informing current and future rehabilitation practices. As a specific example, constructed fauna habitats are a key element encouraging fauna return to rehabilitation. In addition, further research on the adequacy of the current density requirements of CWD stipulated in the completion criteria (number per pit), and investigations into how to incorporate more CWD would be useful. In addition, an updated review of recent fauna research that builds on previous reviews would be valuable, particularly in the context of climate change and its potential impacts for fauna and fauna habitat would be helpful. Finally, as most existing data relates to previous rehabilitation prescriptions, establishment of monitoring programs in current era rehabilitation could now be considered.

Topsoil management

Topsoil is a key element of successful rehabilitation because of the soil stored seed, and beneficial soil microbial population that it contains. A substantial proportion of topsoil is direct-returned, but some is also stockpiled. Topsoil stockpiling practice appears to have changed little over the life of Alcoa's operations, resulting in large stockpiles that are constructed by scrapers, likely leading to heavy compaction. As a result, survival of soil-stored seed will be compromised. Avoiding stockpiling by maximising the proportion of topsoil that is directly returned to areas being rehabilitated should be a key objective of future rehabilitation. When stockpiling is required, wherever possible it would be beneficial if stockpiles were loosely placed at shallower depths, to maintain soil biological function, maximise the potential for vegetation to establish on the surface and eventually add to the soil seed bank.

5.2.2 Thinning and streamflow

Tree density in rehabilitation is a factor in understorey development and in water-use and streamflow. Plans to undertake broadscale thinning of established rehabilitation areas are being developed as part of the draft FMP 2023-2026. As for any thinning practice, ongoing management of coppice stems from the stumps of felled trees and of seedling recruits, is likely to be important to maintain the effect of thinning. Therefore, if forest thinning aims to improve streamflow, it is likely to be intensive and costly, given that it would need to be maintained indefinitely. Given that there currently exists a legacy of overly dense rehabilitation, understanding the impact on water catchment (groundwater and streamflow) and the integrity of the surrounding forest matrix in the context of climate change is important.

5.2.3 Recreation and heritage

Some rehabilitation practices such as ripping of the final surface make the landform seem ‘not natural’ and less ‘walkable’ than non-mined forest, even many years after establishment. Flattening the peak-and-trough soil surface that results from ripping, in areas where control of surface water is not imperative, may be easily achieved and would provide an immediate benefit for walkability. More generally, research suggests there may be a disconnect between current rehabilitation objectives and public perceptions of success and as such warrant further investigation.

It has not been possible to establish to what extent Noongar values have been incorporated into the design and ongoing adaptive management of rehabilitation procedures to date. As indigenous peoples' expectations have rarely been considered or adequately addressed in site clearing activities or mine completion criteria, the next review of the completion criteria provides an opportunity to strengthen the link with biodiversity indicators and Noongar knowledge and values.

5.2.4 Resilience to further disturbance, regional pressures and climate change

Fire

Further research is required to understand the long-term implications of differences in community composition in rehabilitation compared to unmined forest (such as lower abundance of obligate or opportunistic re-sprouter midstorey and understorey species, and development of soil seedbanks). In addition, the NJF more broadly requires greater understanding of the long-term ecological impact of wildfires versus intensively managed fire regimes, particularly on floristic diversity.

Dieback

An understanding of the proportion of historical rehabilitation located in upland areas, coupled with a contemporary study quantifying the risk of forest disease to rehabilitation survival and floristic diversity in the context of climate change, may provide a more accurate estimation of the susceptibility of rehabilitation and thus the implications for the ecological integrity of the NJF.

Drought tolerance

Current completion criteria require rehabilitation at late stage (12 years of age) to not show any evidence of being more affected by drought (water stress) relative to non-mined forest. There is no published data that provides an assessment of resistance or resilience of current era rehabilitation to drought or water stress and it will be several years before an assessment of late-stage rehabilitation would be possible. The expectation that current era rehabilitation will be more drought tolerant than previous prescriptions is underpinned by the assumption that deep ripping and initial site preparations have been adequate. However, on a landscape level it is unclear how much of the rehabilitation to date would be classed as ‘low quality’ (poor growth and survival at mid-late stage), whether remediation works including re-ripping or re-planting with marri have been undertaken in these areas, and whether they have positively impacted growth and survival of trees. Inclusion of species from drier areas of the NJF into the rehabilitation seed mix is a potential option to enhance resilience to climate change, but this has not occurred to date. Remote sensing techniques, supported by field validation may be an appropriate approach to provide an overview of current rehabilitation status.

Although research has shown marri to be less susceptible to dieback, more drought resistant and an important food source for black cockatoos under a changing climate, it is unclear if survival has been investigated in long-term rehabilitation trials. Although Alcoa has achieved the minimum stocking rates for marri in the majority of rehabilitation at establishment and there are no indications of any issues with long term survival of marri, evidence demonstrating long-term survival coupled with an investigation of lower establishment rates in recent years would be helpful.

5.2.5 Rehabilitation research

Alcoa's environmental research program has been operating since the 1970s and has focused on establishment, sustainability and management of rehabilitation areas of their bauxite mine (Alcoa 2022). The extent and quality of this research in mine rehabilitation ecology is unparalleled globally. The program has involved collaborations with universities, CSIRO, government departments and others. The research generated has in part been used to refine the planned approach to rehabilitation and support development of appropriate completion criteria and guidelines to assist the DBCA with longer-term management of rehabilitation areas including fire management. A full review of the research funded by Alcoa over the past 40-50 years is outside the scope of this report.

Although Stantec has not independently verified the methods and outcomes of each research program, outcomes have been published widely in credible scientific journals with robust peer review processes. While there is a wealth of research on various aspects of rehabilitation it has largely been published as discrete papers (some behind paywalls) with few review and synthesis papers. An exception being the 2007 dedicated supplementary edition of Restoration Ecology. An updated synthesis of recent research would be useful in informing understanding of rehabilitation practice.

Based on past vegetation and fauna monitoring and research, Alcoa have indicated a high degree of confidence in the rehabilitation of previous eras, however the lack of research on current era prescription that was available for review, coupled with uncertainty surrounding the impacts of climate change, has made assessment of current and proposed rehabilitation practices difficult. While rehabilitation procedures have remained focused on the return of a self-sustaining jarrah forest over time, the drying climate reinforces the need to continually examine how rehabilitation practices can be adapted to support both sustainability of rehabilitation and the surrounding forest matrix.

Furthermore, while the research program has provided an assessment of specific aspects of rehabilitation success under previous prescriptions, a holistic, landscape-scale approach to assessment of rehabilitation integrity would be useful. Approximately 10,000 ha of rehabilitated forest has been reported to be potentially suitable for final sign-off based on agreed completion criteria. However, in the context of a drying climate, reassessment may be justified and as previously stated, remote sensing approaches may provide a useful tool.

5.3 Consistency with ongoing ecological integrity of the Northern Jarrah Forest

Ongoing ecological integrity of the NJF was considered in the context of the issues raised in earlier sections and taking into account the draft Biodiversity Indicators provided. The rationale for the BI framework indicates that the key outcome of an exceedance of a BI will be a causal analysis to determine the nature and source of the exceedance, which will then inform corrective actions to mitigate risks to the ecological integrity of the NJF. Three possible corrective actions include revision of the Mine Plan, revision of the BIs or revision of the completion criteria. We consider that, based on the potential improvements identified in this review, an additional outcome or management strategy associated with corrective actions could be their audit and evaluation against the response target or another determined target. This would ensure that an assessment of any corrective action is captured in the overall BI framework.

As a further specific observation regarding the BI process, it is surprising that of the three potential corrective actions, only one (Revision of Mine Plan) appears likely to result in a change to mining or rehabilitation practice. Although, it is not clear if, or how, revising the mine plan would lead to changes in rehabilitations strategies. The other two actions are to either revise the BIs, or revise the completion criteria. Both of which have connotations of potential lowering of standards, if monitoring finds that current targets are not being achieved. As part of revising the process diagram we recommend that this potential interpretation is clarified. Finally, we found Figure 1 of the BI document, to be excessively convoluted, and recommend that it is simplified wherever possible, to assist understanding.

In the BI monitoring framework, it is proposed that monitoring outcomes will be reported in the Annual Environmental Report, but it should be made explicit if this would also include all target exceedances, causal investigations and corrective actions. In addition it would be helpful to clarify how the measurement and evaluation of proposed BIs will interact with existing reporting frameworks.

Marri establishment

As has already been highlighted, successful establishment of marri trees in rehabilitation is important factor in ecological resilience and development of fauna habitat. This aspect is most closely addressed in a sub-indicator under BI 3 – 'Ecological condition of native vegetation' where overstorey (tree) species richness is identified as a measure of the establishment of overstorey species. The monitoring method and response trigger are proposed but it remains unclear in the BI monitoring framework whether there is a commitment to use outcomes from of causal investigations to inform corrective actions and management strategies. As such, the link between initial response (investigation), corrective action and adaptive management to ensure ongoing ecological integrity remains deficient.

Understorey cover

A diverse and productive understorey is an important element of rehabilitated forest, as reflected in late-stage completion criteria of the current era, and we identified the possibility of undertaking more detailed monitoring of understorey performance to determine if recent-era rehabilitation was on track to achieving cover targets. However, there is no reference to understorey cover measurement in the BI framework.

Vegetation structure and composition

The rationale for the BIs is to assess "structure and composition metrics". However, while species richness is widely used in rehabilitation monitoring, it does not address compositional similarity. The BI framework specifies an understorey species richness target of returning 60 – 80% of unmined forest species, but there is still a knowledge gap about the ecological integrity of the rehabilitation as it depends, to some extent, which of the forest species are missing. Richness metrics also do not address potential changes in the abundance of the species that are returned in rehabilitation, which may also affect ecological condition and fauna usage. The rationale for the BIs acknowledge that changes in species composition could indicate a vulnerability to the impacts of invasive species, forest disease and fragmentation and generally ecological condition. However, given that the proposed BIs do not directly assess broad-scale compositional metrics, the knowledge gaps already highlighted in this report regarding compositional changes would remain.

It is worth considering whether the knowledge base built from Alcoa's research studies could be applied more broadly into a BI framework. Arguably, these type of compositional similarity analyses are required to provide greater confidence and address knowledge gaps regarding the maintenance of ecological integrity, including fauna habitat values, of the NJF.

Fauna utilisation

Our review identified the need for continual focus on faunal community composition. The BIs proposed in Group 3 largely address this aspect and the indicators selected are broadly appropriate and relevant. However, a key requirement for developing indicators for biodiversity is that they should be inclusive of all levels of biological organisation: diversity within and between species and diversity of ecosystems. Therefore, evaluation of threats and extinction risk should be extended beyond those species and ecological communities currently listed as threatened or conservation significant. This is partly addressed by selection of avifauna assemblages and presence/absence of selected bird species and in general, the measurement of biodiversity surrogates is an accepted approach to reduce knowledge gaps. However, it would be useful for the rationale to detail why certain indicator species have been selected.

Vulnerable Forest red tailed black cockatoos have been included as an avifauna indicator species in a standalone BI (BI 9) reflecting that there will be losses in foraging and breeding habitat and that the population may be limited by availability of watering habitats. However, it is not clear why this species was selected over the Endangered Baudin's and Carnaby's black cockatoo. Further, measurement of population numbers over time should be linked to measurement of changes in key habitat factors, particularly the presence of large DBH trees suitable for breeding and foraging. It will be important to ensure that monitoring is able to accurately capture information about how mining may be impacting local habitat, along with landscape level changes such as the extent, shape and quality of habitat in the region and the effectiveness of local scale management actions to reduce impacts.

Given the existing gaps in knowledge relating to populations of conservation significant black cockatoos and the lack of up-to-date Species Recovery Plans, clear articulation of how the mitigation hierarchy and Precautionary Principle have been applied in regard to protection of endangered species and how these BIs would interact with Proposal's Offset Strategy should be considered.

Thinning and streamflow

Tree density in rehabilitation is directly influences water-use in rehabilitated areas, and thus streamflow. There is currently a legacy of overly dense rehabilitation, and it is important to understand impacts on groundwater and streamflow and the integrity of the surrounding forest matrix, particularly in the context of climate change. While not explicitly stated in the BI framework, assessment of thinning practices on tree density and how this interacts with the surrounding forest will likely be addressed through indicators BI 3 to BI 6. In addition, the BI framework includes an assessment of the ecological condition of stream and swamp vegetation in water-dependent Site Vegetation Types (BI 4), along with water quantity and quality in waterways, both upstream and downstream of active pits and rehabilitated areas (<5 yrs) (BI 5). These BIs are broadly appropriate to assess potential impacts of rehabilitation, however consideration could be given to providing a rationale for restricting this to young rehabilitated areas.

Resilience to further disturbances – fire, forest disease, drought

Alcoa identifies three key threats to the ecological integrity of the NJF: inappropriate fire regimes, extent and impact of invasive species and dieback infection, with each having a corresponding BI. The drier and warmer conditions expected in the southwest forests are likely to interact with these and other threats to the NJF, though the outcomes of these interactions are difficult to predict. In developing biodiversity indicators for ecological integrity of the NJF, it is therefore important to identify those indicators that best assess resilience of the forest disturbances that may be associated with climate change.

Choosing an appropriate fire regime that will encourage development of desirable species and floristic diversity in rehabilitation but discourage weeds and continued high densities of *Acacia* species is critical. An annual monitoring method is reported to be under development in collaboration with DBCA, but no timeframe for development of this monitoring program was provided.

Monitoring of weed species, will be completed annually through existing plot monitoring and compared at different spatial and temporal scales to determine changes, supported by triggers for remedial actions. This approach appears commensurate with the level of risk posed by weeds, though preventative weed management will be key to reducing their establishment and spread.

Existing fire and feral animal management programs represent examples of public-private collaborative land management and lessons learnt from the implementation and evaluation of these programs could be useful during development of additional monitoring programs proposed to measure broad ecological integrity of the NJF.

Phytophthora dieback is recognised as the most significant plant disease affecting ecological values in the planning area with the proposed BI 12 aiming to assess the extent of change in infected areas within ML1SA. However, we identified that in order to fully assess susceptibility of rehabilitation to disease, the proportion of rehabilitation in upland areas should be defined, and a contemporary study of the risks of forest disease to rehabilitation survival and floristic diversity be completed in the context of climate change. Consideration should also be given to incorporating the outcomes of investigations into the resilience and long-term survival of marri.

Drought is an additional threat to the ecological integrity of the NJF that has not been included in the BI framework. However, the proposed BIs relating to ecological condition of native vegetation are broadly appropriate to assess this potential impact. If water stress is identified as a possible cause of poor growth, there should be a commitment to corrective actions. Current completion criteria require late-stage rehabilitation (12 years) to not show evidence of being more affected by water stress relative to non-mined forest. While there is an expectation that current era rehabilitation will be more drought tolerant than previous prescriptions, there is no related published date, and this assumes that deep ripping and initial site preparations have been adequate to allow adequate root exploration.

The inclusion of a BI focusing on ecological connectivity of vegetation (BI 6) recognizes the importance of habitat fragmentation in relation to potential isolation and loss of species and genetic diversity, poorer habitat quality and less ecosystem resilience. A fragmentation index is proposed for areas within the MDE, using on-ground and disturbance mapping. At a local scale, fragmentation is expected to decline as vegetation in rehabilitated areas matures. While the index provides a broad assessment of ecological connectivity, it could be coupled with assessments of vegetation condition, to assess the extent to which rehabilitation fits into the forest matrix.

Ongoing rehabilitation research and general comments

We have highlighted the need for a more holistic landscape-scale assessment of rehabilitation performance over time and the need to continually examine how rehabilitation practices can be adapted to support both sustainability of rehabilitation and ecological integrity of the surrounding forest matrix. While it is acknowledged that any direct impacts of Alcoa's Proposal are more likely to be associated with the MDE and ML1SA, the BIs explicitly aim to provide an assessment of the ecological integrity of the whole NJF bioregion and as such wherever appropriate, should reliably report status and trends at this scale. More consideration could be given to clarifying how the different approaches proposed in the BI framework will support understanding of potential impacts at the bioregional scale. The BI framework proposed could foster novel approaches to environmental modelling using site level, remote sensing and fragmentation assessments to identify and report on 'good quality' and 'low quality' areas of rehabilitation at the landscape scale, thus supporting the ongoing ecological integrity of the NJF.

It is acknowledged that there has not previously been clearly defined BIs for the NJF, separate from the objectives of the Draft FMP. Given that there are other forest users, including South32 and Boddington Gold Mine, with ongoing rehabilitation programs, it will be valuable for regulating agencies to clarify how the BI framework proposed for Alcoa aligns with those of other forest users, and how the framework will be integrated into existing compliance reporting and biodiversity monitoring programs within the whole NJF.

6 Personnel contributing to the review

The following personnel contributed to this review: Dr Natasha Banning, Dr Briony Lalor, and Dr David Jasper. The team members have appropriate experience in natural and mining-affected environments, in the relevant areas of soils and landforms, flora and vegetation, fauna, aquatic systems and climate change.

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