Office of the **Queensland Mine Rehabilitation Commissioner**

Options for Native Ecosystem Mine Site Rehabilitation in Queensland

Stakeholder Survey Report

Queensland Government

Prepared by: Office of the Queensland Mine Rehabilitation Commissioner

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Executive Summary

In the Queensland mining industry, when native ecosystems are proposed as a post-mining land use (PMLU), there is currently ambiguity about what constitutes best practice rehabilitation outcomes, what is possible, and how to achieve them. In some ways this ambiguity is a natural outcome of the diverse views and experiences of stakeholders; it is also a function of the inherent uniqueness and complexity of mine site-specific conditions, and of legacy rehabilitation efforts and past guidelines impacting what is possible in the present and future. There are diverse understandings on what native ecosystem outcomes would be of most benefit for post-mining sites, i.e., what ecosystem attributes are of most value, and therefore, what to focus on in guiding decisions such as species selection and rehabilitation trajectories. This is particularly the case where the restoration of the pre-clearing ecosystem is not practicable due to geomorphic, hydrologic, soil chemistry, mine tailing toxicity and other changes brought about by mining and/or legacy rehabilitation efforts.

Given the range of these variables, rehabilitation of native ecosystems in highly disturbed landscapes may result in *natural* ecosystems (restored to the extent of historic succession trajectory), *hybrid* ecosystems (having some but not all characteristics of the natural/historic landscape, and some novel attributes, that could become natural with management effort), or *novel* ecosystems (new assemblies of abiotic and biotic attributes resulting in a stable alternative ecological form that does not resemble historic native ecosystems and that have crossed an ecological threshold beyond feasible return; Doley et al., 2012; Doley and Audet, 2013).

In order to better understand these issues, the Office of the Queensland Mine Rehabilitation Commissioner (OQMRC) is currently developing technical guidelines to inform mine site native ecosystem rehabilitation in Queensland. Understanding current stakeholder perspectives is an important starting point for improved outcomes for native ecosystem rehabilitation.

Stakeholder perspectives were accessed through a stakeholder survey conducted between 18 May and 8 June 2022. Stakeholders directly involved in rehabilitation activities as consultants, regulators, mining professionals, researchers or environmental groups were invited to participate. The link to the survey was also available via LinkedIn and was accessible to the general public. Stakeholders that responded to this survey primarily included environmental practitioners/managers within mining companies (30.5%), consultants (24.4%), academic researchers (14.6%) and state government employees (12.2%). Other perspectives included traditional owners, local community members, members of environmental organisations and other special interest groups. Nineteen questions were developed covering a variety of formats – multiple choice, ranking and open ended.

Despite offering no reward incentive, being quite detailed and taking an average of 40 mins to complete, the survey achieved 82 responses, highlighting that the issues entailed in the broader project are of significant interest and importance to stakeholders. The level of detail and thoughtfulness characterising the insights shared demonstrate the widespread importance of the issues covered in the minds of stakeholders and highlight the value of this industry-wide dialogue.

Key results include:

a. **Stakeholder perspectives on native ecosystem rehabilitation assessment methodologies**

The majority of respondents (55%) reported that benchmarking against a reference site was their preferred methodology for assessing native ecosystem rehabilitation. “Mine-specific custom methods” was the next most common first-preference method (12% of respondents’ first choice). BioCondition score and ecosystem or landscape function analysis were common second or third preference responses from stakeholders surveyed.

In a follow up question, regarding the selection of reference sites for planning or assessment, the key considerations were identified by stakeholders surveyed as: “Reference community matches the anticipated end land use” and “Reference community occurs on a landform that is analogous to post-mining landform”. This response highlights, as an ongoing theme, the importance of the PMLU objectives and geomorphic state in determining rehabilitation decisions.

b. **Stakeholder perspectives on native ecosystem rehabilitation outcomes (i.e., novel, hybrid, natural system outcomes)**

Native ecosystem rehabilitation can mean different things to different people. In the context of mine rehabilitation, when asked: “Which of the following most closely aligns with their understanding of, or aspirations for, ‘native ecosystem rehabilitation’ for their organisation or current site/s?”, most stakeholder respondents selected “Establishment of an ecosystem using plants from a specific

Regional Ecosystem" (39%) and "Establishment of an ecosystem using local or bioregional plant species, but not necessarily targeting a specific naturally occurring Regional Ecosystem" (29%). This response highlights the value stakeholders place on native floristics.

When asked directly about the suitability of *novel* and *hybrid* ecosystems for native ecosystem mine rehabilitation, many stakeholders see the potential for these *no-analogue* ecosystems to have a range of PMLU options and values (e.g., ecosystem functions, services, stability), particularly where 'traditional' native ecosystems are not feasible. There is a sense in some responses that *no-analogue* ecosystems may also provide opportunities in a rapidly changing landscape while other stakeholders shared considerable concerns about the risks of *no-analogue* ecosystems as poorer substitutes for *natural* ecosystems. When asked an open-ended question on the subject, stakeholders shared a wealth of insights on the benefits and risks of *no-analogue* ecosystems in mine rehabilitation.

These stakeholder insights fell under the following general themes (some of which, were presented as both possible benefits and possible risks). Perceived benefits of *no-analogue* ecosystems were that they could be achievable and quantifiable, provide a greater range of species options, present potential habitat, long-term management and functional benefits, have a reduced recovery time, be easy to implement, be pragmatic with regards to weeds, and be of reduced cost. However, *no-analogue* ecosystems were also envisaged as creating exposure to risks, especially loss of cultural heritage integrity, "lowering the bar", loss of ecological value, long-term management risks, less integration with landscape, possible weed introduction, potential for non-beneficial outcomes, loss of previous ecosystem and habitat, lack of understanding (more research needed), and less quantifiable outcomes.

From a broad list of ecosystem attributes, the majority of stakeholders saw resilience and self-sufficiency as the key components of rehabilitation success in the long term. Research into whether and under what circumstances *no-analogue* ecosystems can provide these attributes in mine rehabilitation is still in its infancy. However, in the context of benefits and risks of *no-analogue* ecosystems, habitat value was the ecosystem aspect most commonly referred to by stakeholders (mentioned 14 times out of 71 respondents). Long term management of the rehabilitated mine site was another common theme when respondents were asked about the risks and benefits of *no*—analogue ecosystems.

Particularly in this line of questioning, but also in other instances in the survey, results overlap was apparent between native ecosystem and grazing in the minds of stakeholders with regards to rehabilitated PMLUs. It is important to note that there is a distinction between *novel* ecosystems and agricultural systems, and agricultural systems are not considered to be *novel* native ecosystems for the purposes of mine rehabilitation; they are considered to be grazing systems. Some of this confusion/overlap understandably has arisen from the 'mixed ecosystem-grazing PMLU', which is an objective for rehabilitation at some mine sites.

c. Stakeholder perspectives on factoring in the regional context (i.e., adjoining ecosystems) when considering the value of native ecosystem rehabilitation

When asked: "Is connecting native ecosystem mine rehabilitation sites with other native ecosystems in the region an important consideration for you?", 36% of stakeholder respondents replied that it was very important, while 46% selected important; only 1% responded that it was not important while the remaining 17% were neutral.

The importance stakeholders place on regional native floristics also came through indirectly in answers to other questions within the survey. For example, when asked: "In the context of mine rehabilitation, which of the following most closely aligns with your understanding of, or aspirations for, 'native ecosystem rehabilitation' for your organisation or current site/s?", "Establishment of an ecosystem using local or bioregional plant species, but not necessarily targeting a specific naturally occurring Regional Ecosystem" was the second most common statement chosen (after "Establishment of an ecosystem using plants from a specific Regional Ecosystem")

When asked: "Which of the following indicators are the most important measures of native ecosystem rehabilitation success?", "Plant species composition in the rehabilitated ecosystem reflects plant species composition in the surrounding area today" and "The rehabilitated ecosystem directly adjoins/provides for connectivity with other areas of native ecosystems in the region" were the equal third responses (after ecosystem resilience and self-sustainability). Stakeholders also identified regional context as important when describing perceived risks of novel and hybrid ecosystems, including a lack of integration/congruency with surrounding ecosystems.

The stakeholder survey also highlighted that:

- There are mixed views among stakeholders about the achievability of restoring pre-disturbance ecosystems after open cut mining. Open cut mining is an inherently disruptive process and generates greater volume of material than was present pre-mining, due to bulking and breaking up of the formerly coherent geological structure (Emmerton et al., 2018; Hancock et al., 2020). Despite these challenges, 8.5% of respondents believe that restoring open cut mine sites to a pre-disturbance ecosystem is highly achievable and 30.5% believe it is somewhat achievable. 41.5% of stakeholders felt that ecosystem restoration was somewhat difficult to achieve and 12.2% believe it to be unachievable. Only 7.3% of stakeholders remained neutral on this question.
- Sixty stakeholder supplied examples of *no-analogue* ecosystems in mining rehabilitation, with extremely varied responses and surprisingly little repetition between respondents.
- There is concern over long term management of rehabilitated native ecosystems, for example, who will manage fuel loads, weeds etc. With grazing as a PMLU it is generally expected that a landowner would provide this stewardship role, however this isn't always the case as some stakeholders raised the issue that low value pasture is not necessarily an outcome worth aspiring to.
- Resilience was the most commonly selected measure of ecosystem rehabilitation success, however only two stakeholders mention resilience as a measure being investigated in rehabilitation trials.
- When asked to describe any exotic species used during native ecosystem rehabilitation, pasture grasses were the most selected, followed by sterile grasses and then trees and shrubs.
- Topsoil testing (e.g., soil testing and improvement with amendments, green manure trials) and seed/planting trials (e.g., seed viability and functionality, tree and shrub establishment and dispersal methods) were the most common trials undertaken by respondent stakeholders.
- Unsurprisingly, given other answers, stakeholders identified pasture grazing as the most likely PMLU to combine with native ecosystem rehabilitation objectives within their organisation's rehabilitation program/s.

1. Background

In Queensland and across the globe, despite considerable effort and ongoing research, successful native ecosystem mine rehabilitation and closure remains a significant challenge, with only the minority achieving their relinquishment goals thus far (Kragt and Manero, 2021). Where the PMLU is identified as native ecosystem, genuine practical complexities are posed that intersect with a diversity of sometimes contradictory social and ecological values, and site-specific objectives and challenges. To support the resolution of relinquishment issues where considerable complexities exist, a range of options, both traditional and creative, need to be considered and dialogue fostered amongst industry groups, regulators, researchers and practitioners. Ideas of non-analogue ecosystems have been raised and reports identify they may play a role, i.e. retaining *no-analogue* ecosystems may be warranted if there is sufficient evidence that they deliver a beneficial environmental outcome (Environmental Protection Regulation 2019) and they do not cause environmental harm. In relation to *no-analogue* ecosystems, including in the mining industry rehabilitation context, it has been recognised that exploring and acknowledging the diverse perspectives of stakeholders may facilitate transparent dialogues and development of mutually acceptable management approaches, alongside being a fruitful exploration of rehabilitation objectives (Doley et al., 2012; Truitt et al., 2015). As a component of a broader project on the topic of native ecosystem rehabilitation options and best practice assessment methods, the Office of the Queensland Mine Rehabilitation Commissioner (OQMRC) sought to elucidate stakeholder perspectives on these and related matters. The results and methodology of this survey are presented below.

2. Survey details

With input from representatives of the OQMRC, consultants at Aspect Ecology Pty Ltd delivered a survey to ascertain perspectives on native ecosystem mine rehabilitation options, completion criteria possibilities, current practices, opinions around *natural*, *hybrid* and *novel* (no-analogue) ecosystems and examples of these, barriers to rehabilitation and evaluation of monitoring options. The survey period was between May 18–June 8, 2022. The survey was released online via Microsoft Forms and emailed across relevant networks to garner anonymous responses from a range of relevant stakeholders. Stakeholder contacts were accessed through departmental contact lists, mailing lists and social media platforms, as well as professional networks of the project staff.

Despite offering no reward incentive, the survey received 82 responses, with stakeholders taking an average of 40 minutes to complete the questions entailed. The level of detail and thoughtfulness in the responses and insights shared indicate the widespread relevance of the issues covered in the minds of stakeholders and highlight the importance of this industry-wide dialogue. Nineteen questions were asked in total, including multiple choice, ranking and open-ended formats. These questions captured both qualitative and quantitative data to better understand stakeholder perspectives and to maximise opportunities for stakeholders to share their insights with the project team. This data is intended to assist the development of the native rehabilitation guidelines. Appendix 1**:** Survey supplies the comprehensive list of survey questions.

The voices of stakeholders have been brought to the fore in this survey and, as such, have been woven through this report as often as possible and as unfiltered as possible, although occasionally editing is required for clarity and summarisation, or for synthesis of multiple similar comments. Direct stakeholder quotes are italicised within quotation marks for identification.

3. Survey results

3.1 Stakeholder details

Environmental practitioners/managers within mining companies, consultants advising the mining industry and academic researchers were the most represented stakeholder respondents. Other respondent groups were State government employees, traditional owners, local community, members of environmental organisations, other special interest groups and those who did not select one of the available categories (other); see Figure 1 below.

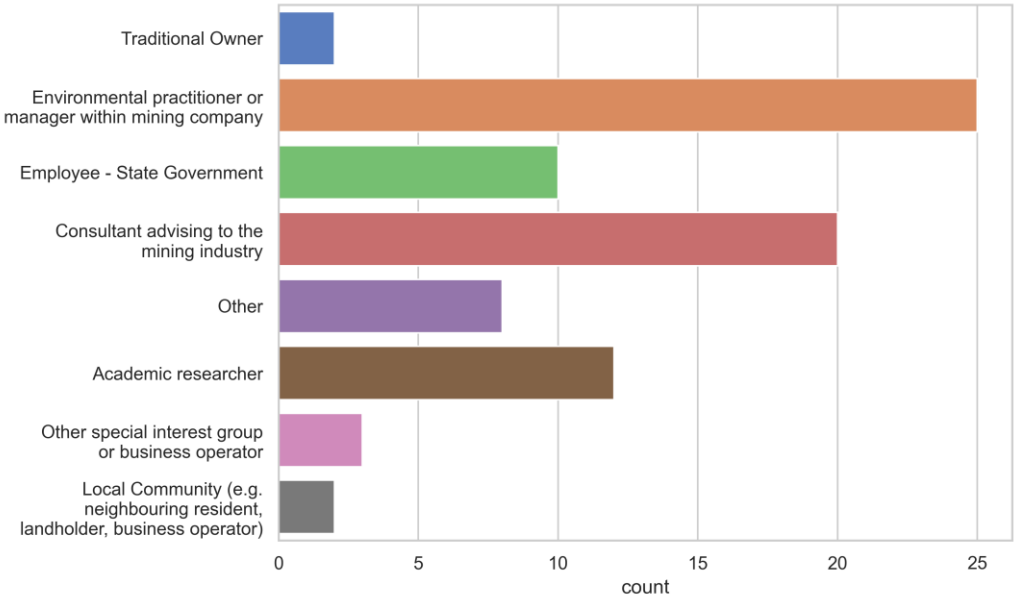

Figure 1. Distribution of stakeholders surveyed on native ecosystem rehabilitation outcomes and assessment methods. Count is the number of responses (n=82). For the 'other' category, stakeholders described themselves using a variety of role descriptions including: "*industry body representative*", "*environmental lawyer – coal mining and human rights*", "*consultant advising to a mining company but also the undertaker of relevant rehabilitation & associated works*", and "*research manager*".

The severity of disturbance imposed by mining activities varies considerably among mining operation types (Gwenzi, 2021). For the purposes of this survey, mining operations were categorised into four groups, based on the nature of their disturbance and how this effects the progression of rehabilitation:

Coal mining – Open cut or underground coal mining operations that initially require deep excavation (in the case of open cut) but then predominantly progress in a horizontal direction, such that land can be rehabilitated progressively.

Base and precious metal mining - Major metal mining operations that progress predominantly in a vertical direction, such that land cannot be rehabilitated progressively. Typical commodities - copper, zinc, lead, gold.

Strip and dredge mining - Major mining operations that progress predominantly in a horizontal direction (i.e., shallow deposit or pre-strip operations), such that land can be rehabilitated progressively. Typical commodities - bauxite, vanadium, mineral sands.

Other mining - Medium/major operations that don't fit among strip mining, metals mining or coal mining. Typically, these operations are more bespoke in operation context and may progress horizontally, vertically or both. Typical commodities - sandstone, clay/bentonite, limestone, phosphate, silica.

Stakeholders directly involved in the mining industry were asked: "**What mining process/es is your work/organisation or community associated with? (Select all that apply.)"**. Coal mining (open cut and underground) was the most represented mining process, however "bauxite, vanadium, sand mining", "base and precious metal mining (excluding vanadium)" and "other mining (e.g. phosphate, clay and limestone)" were also strongly and quite evenly represented. Respondents were able to select multiple processes, which accounts for the total > 82; see Figure 2.

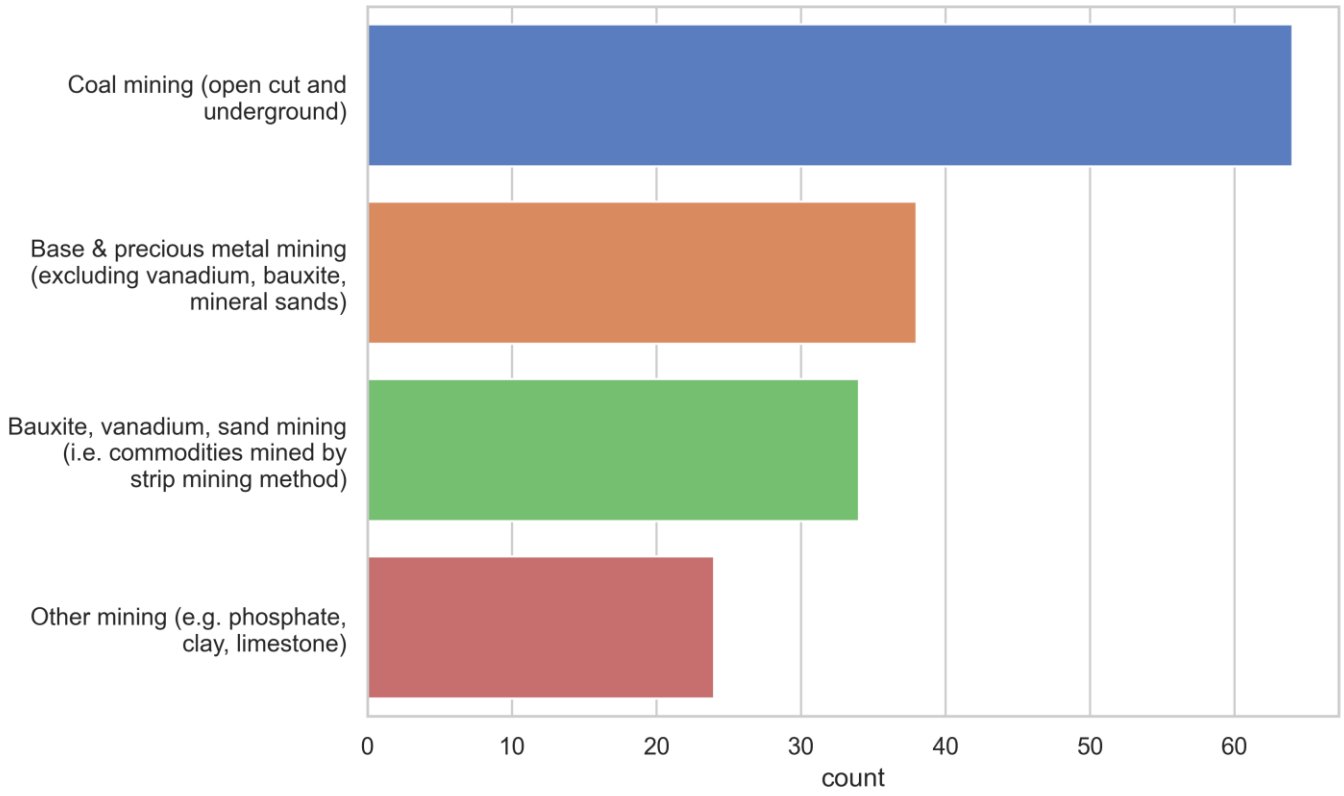

Figure 2. Mine industry stakeholders' mineral resource association. Count is the number of responses (n=160); multiple selections were allowed.

3.2 Understanding of and aspirations for native ecosystem rehabilitation

In Australia, notions of 'nativeness' (endemicity) in relation to ecological restoration are complex (Trigger et al., 2008) and native ecosystem rehabilitation' can mean different things to different people. In the context of mine rehabilitation, when asked: "**Which of the following options most-closely aligns with their understanding of, or aspirations for native ecosystem rehabilitation for your organisation or current site/s?"**, most stakeholder respondents selected the option "Establishment of an ecosystem using plants from a specific Regional Ecosystem" (39%) and "Establishment of an ecosystem using local or bioregional plant species, but not necessarily targeting a specific naturally occurring Regional Ecosystem" (29%) see Figure 3. Other responses offered by respondents included "*vegetation cover similar to surrounding area*", "*fits in with surrounding vegetation*", "*self-sustaining vegetation communities*", and "*native trees and exotic grasses with potentially native grasses (unfortunately exotic grass are dominant in many of our native areas now so are very difficult to exclude from rehabilitation areas)*" (see Appendix 2: Responses to understanding of 'native ecosystem rehabilitation' open-ended question).

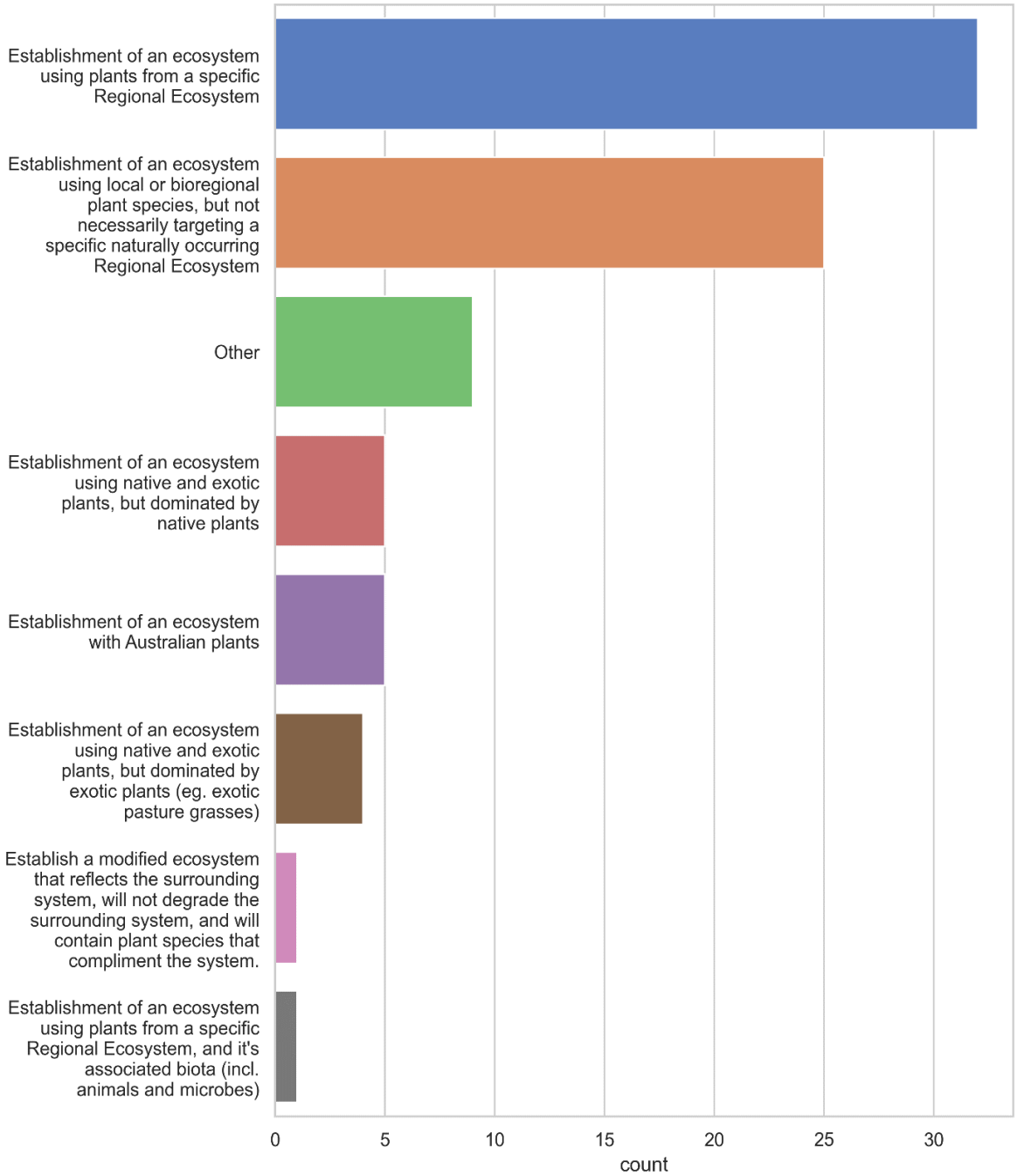

Figure 3. Stakeholder aspirations for native ecosystem rehabilitation. Count is the number of responses (n=82). Major stakeholder groups that formed the 82 responses were mining professionals (30.5%), consultants (24.4%), academics (14.6%), state government (12.2%).

3.3 Rehabilitation of ecosystems similar to pre-disturbance in open cut mining situations

Every mine site presents unique hydrological, landform and geochemical conditions that influence the target native ecosystem and its rehabilitation. As mining operations tend to disturb the whole ecosystem, they may produce biophysical limitations in the mining area which could inhibit native ecosystem rehabilitation. When asked about the achievability of rehabilitation to an ecosystem similar to the pre-disturbance ecosystem in an open cut mining situation, most stakeholders thought this would be somewhat difficult to achieve (41.5%), and a smaller percentage thought it was unachievable (12.2%). 30.5% of respondents believe that rehabilitation to an ecosystem similar to pre-disturbance is somewhat achievable and 8.5% believe such an outcome is highly achievable, while 7.3% were neutral (Figure 4). Taking this and the previous question together, it can be inferred

that stakeholders value the aspiration for *natural* rehabilitation, despite a view that it may be challenging to achieve in practice, at least in the context of open cut mining.

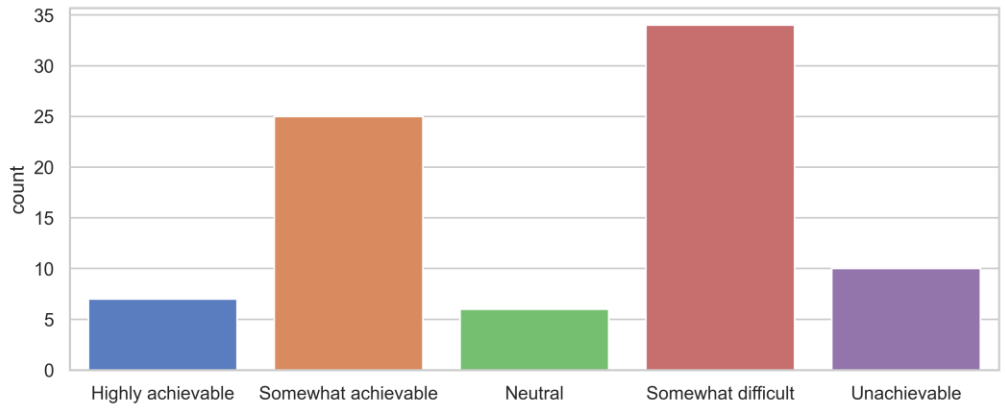

Figure 4. Stakeholder perspectives on achievability of rehabilitation to a pre-disturbance ecosystem, at open cut mine sites. Count is the number of responses (n=82). Major stakeholder groups that formed the 82 responses were mining professionals (30.5%), consultants (24.4%), academics (14.6%), state government (12.2%).

3.4 Stakeholder perspectives on *no-analogue* ecosystems

In relation to *no-analogue* ecosystems, the survey provided the following definition and background:

> *The nature and extent of environmental disturbance associated with mining commonly can result in completely new and challenging combinations of hydrology, lithology and landform. Consequently, the outcomes of ecological processes associated with the recovery or restoration of ecosystems can vary from previously known associations between their physical and biological components. For radically disturbed sites, it is not always feasible to aim for the restoration of historical ecosystems. However, there is debate that hybrid (reversibly different) or novel (irreversibly different) ecosystems comprising new combinations of physical and biological components, including both native and non-native species, might theoretically provide levels of stability and functionality acceptable to some stakeholders and within feasible management regimes, adapted from Doley and Audet* (2013).

When asked if *novel* and *hybrid* (*no-analogue*) ecosystems are an acceptable rehabilitation objective in Queensland, 62% of stakeholders responded “yes”, 23% responded “maybe” and 14% responded “no” (Figure 5).

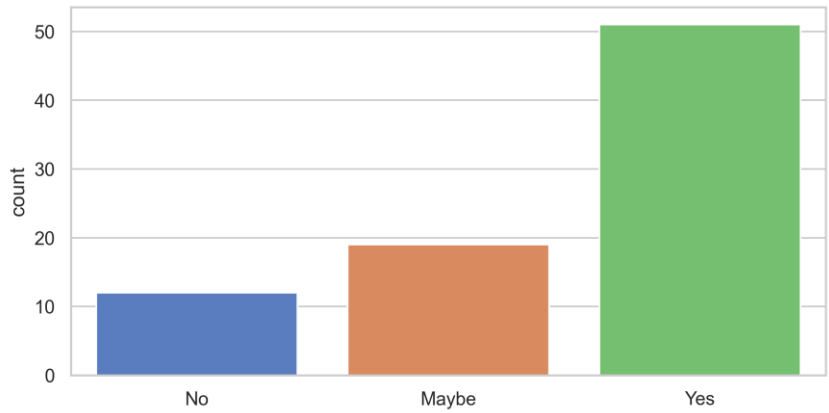

Figure 5. Stakeholder acceptability of *no-analogue* ecosystems as rehabilitation outcomes. Count is the number of responses (n=82). Major stakeholder groups that formed the 82 responses were mining professionals (30.5%), consultants (24.4%), academics (14.6%), state government (12.2%).

When answering the open-ended question: "**What are the benefits/risks you see in regard to these hybrid and novel ecosystem options?"**, stakeholders shared a wealth of insights on the benefits and risks of *no-analogue* ecosystems in mine rehabilitation and some observations fell into both benefit and risk categories:

Benefits of *no-analogue* ecosystems: achievable and quantifiable, provides a greater range of species options, potential habitat benefits, long-term management, potential functional benefits, reduced recovery time, ease, pragmatic, reduced cost.

Risks of *no-analogue* ecosystems: loss of cultural heritage integrity, "lowering the bar", loss of ecological value, long-term management, less integration with landscape, possible weed introduction, potential for non-beneficial outcomes, loss of previous ecosystem, loss of habitat, lack of understanding, more research needed.

Some stakeholders spoke to the difficulties in managing weeds in this question, while many stakeholders mention habitat as either a possible benefit of *no-analogue* ecosystems or as being at risk for these systems. The strong focus on habitat, both with regards to potential benefit and risk, does highlight that this ecosystem feature is important to a significant number of stakeholders. Concerns around long-term management of PMLUs also fall into this category. Stakeholder perspectives on *no-analogue* ecosystems are summarised in **Table 1**. Stakeholder voices have been kept as intact as possible, however some have been edited for readability and many have been compiled and synthesised when duplication occurs.

In both this question, and when asked to supply examples of *no-analogue* ecosystems in mining rehabilitation, sixty stakeholders responded to the question, resulting in varied responses, with little repetition between respondents. However, one theme that was repeated across respondents was the mention of pasture rehabilitation systems. In this context, it is important to note that there is a distinction between novel ecosystems and agricultural systems. Agricultural systems are not considered to be novel ecosystems for the purposes of native ecosystem mine rehabilitation: they are considered to be grazing systems. Some of this confusion/overlap understandably has arisen from the 'mixed ecosystem-grazing PMLU', which is an objective for rehabilitation at some mine sites.

As the focus of this report is native ecosystem rehabilitation rather than grazing, these responses have not been interrogated in detail. However, it is worth noting a few comments that directly compare grazing and novel native ecosystem PMLUs. For example:

"*Once land has been significantly disturbed, returning it to poor quality pastures with lower grazing rates than other land use may not be the best use of the land. Opting for alternative rehabilitation objectives where post-mining land use is considered and ecologically engineered to generate a new industry for the local area around the mine would be a much better outcome"*.

"[novel ecosystems are] *better than nothing and could provide more long-term sustainability, habitat, and CO_2 storage than a buffel grass monoculture".*

"Depends on the PMLU. If the PMLU is not around creating biodiversity values etc, then the requirements for the rehabilitation program is relaxed to create more novel ecosystems that would be designed to meet the safe, stable and non-polluting policy requirements."

Table 1. Synthesis of 60 stakeholder views on the benefits and risks regarding novel and hybrid (i.e., *no-analogue*) rehabilitated ecosystems

Benefits of no-analogue rehabilitated ecosystems	***Risks associated with no-analogue rehabilitated ecosystems***
Achievable and Quantifiable • "*The benefit is that the rehabilitation is possible, proceeds and can be quantified (i.e. realise and measure progress against achievable targets)."*	**Loss of cultural heritage integrity** • "*Novel and hybrid ecosystems ignore the intangible cultural heritage integrity that places importance on all parts of the environment".*
Provides a greater range of species options • *"Native species from other regions may be more representative of the new environmental conditions and therefore maybe be more suited".*	**"Lowering the bar"** • "*Could be used as an excuse to reduce upfront costs and efforts like seed saving and may foster an "anything goes approach". They are an amazing opportunity for mining companies to reduce their*

Benefits of no-analogue rehabilitated ecosystems	***Risks associated with no-analogue rehabilitated ecosystems***
• *"More flexible in terms of species choices for rehab—You just have to look at what species do well on overburden that has not been rehabilitated, it is often only a few species that are able to recolonise these areas."* • *"Takes into account the hysteresis involved in moving from a pre-clearing ecosystem to a cleared landscape and back again to a revegetated state. Hybrid, designer or novel ecosystems provide the opportunity to select species for rehabilitation based on their functional attributes necessary to support revegetation first, and their endemism to a region second."* • *"Can be tailored to specifically account for the particular characteristics of the soil/growth medium, new landform shape, different aspect (e.g. slopes facing different directions which impact on vegetation establishment) that are unique to the disturbed landscape."*	*rehabilitation standards while presenting this as a benefit*." • "*A focus on achieving 'hybrid' systems is accepting a lower level of ambition and suggesting that the current levels of success reflects what is possible is not accurate. We need to see examples of where appropriate efforts have been made and failed rather than draw conclusions about the possibility of success based on the huge number of poorly rehabilitated and abandoned sites."* • "*In most rehabilitation programs I have seen, the use of native species to achieve the environmental outcomes is feasible, there would have to be very compelling circumstances as to why introduced species non-native to Australia would be needed and appropriate risk assessment undertaken as part of the justification. The risks would include long term suitability and survival rates of non-native species, their ability to support native fauna etc. with regard to physical components."* • "*Risks potentially lower ecosystem function, biodiversity values and carbon storage capacity."* • "*The major risk is that a mine obtains approval for destruction of an ecosystem on the basis of commitments that it will develop a rehabilitation plan at a later date".* • "*Reduces the focus on saving topsoil and viable seed bank*".
Potential Habitat Benefits • "*A benefit of a hybrid system is that it could be worth restoring the area to a state which, although might be markedly different to the pre-clearing state, does provide some form of refugia/habitat for species from other sites where their habitat is declining or under challenge from climate change etc."* • "*Novel ecosystems have been shown in literature to provide home for some animal species that were present pre-mining. It opens up possibilities to manipulate vegetation to support threatened species that may occur in the local area. 'Novel' is a good term and aligns with concepts in Planetary Boundaries theory.*"	**Loss of ecological value** • "*Overall, there seems to be little benefit in creating an ecosystem that doesn't exist naturally in the landscape already*." • "*Permanently losing biodiversity and ecosystem functions, which further contributes to the ecosystem degradation and biodiversity crises plus damages our society via reduced ecosystem services including to human health".* • "*Risks are that not all animal species might find the novel ecosystems a suitable habitat, due to structural differences compared to the pre-mining vegetation."*
Long-term Management • "*May be more likely to be managed by a post mining land manager than a native ecosystem, presuming it has been designed with economic benefits"*	**Long-term management** • "*Risks are to long-term sustainability of ecosystems not being actively managed and reduction in ecological and environmental outcomes."* • *"Novel ecosystems might limit further options for improvement/enhanced restoration of the land."*
Potential Functional Benefits • "*May result in functional, productive and/or economic outcomes such as storm water and hydrology control, habitat, carbon sequestration, visual and recreational amenity, economic value (grazing, high value horticulture etc.)" [*note grazing and horticulture are not native ecosystem rehabilitation objectives]	**Less integration with landscape** • "*Sure, the system might be safe, stable and non-polluting, however if it's unable to function/integrate with the wider landscape, and support the species that inhabit that wider landscape, what 'use' does it provide?"*

Benefits of no-analogue rehabilitated ecosystems	***Risks associated with no-analogue rehabilitated ecosystems***
Reduced Recovery Time • "*May provide faster and more stable slope surfaces - for some areas of rehab priority is the development of a stable final slope surface that does not deteriorate with extreme weather patterns that are experienced in Central Queensland.*" • *"Faster groundcover and stabilisation"*	**Possible weed introduction** • "*Could introduce exotic weeds into the surrounding landscape".* • *"Exotic grass species detrimental to natural regeneration of canopy species."*
Ease • "*Easier for rehabilitation to become safe, stable and sustainable as a novel ecosystem*."	**Resilience may be reduced** • "*Greater risk of rehab failure in the future if the vegetation component is subject to disease, or disturbances such as fire."*
Pragmatic • "*It is impossible to keep non-native species out as many of them are now endemic and early colonisers."* • *"In reality, it is not feasible to exclude naturalised exotic species from post-mining landscapes. Where those species do not threaten the primary rehabilitation goal there is no point in expending the human and financial resources in trying to eliminate them."*	**Potential non-beneficial outcomes** • "*May encourage mines to create PMLUs that do not benefit the region or its wildlife."*
Reduced Cost • "*The benefit is to the mining company, and 'possibly' a post mining land user."* • *"Lower cost"*	**Loss of previous ecosystem** • "*Mining destroys species habitat. Rehabilitation should be undertaken with a view to returning species habitat through native species to that area, to enable the return of the species displaced. Allowing novel/hybrid ecosystems risks removing this benefit, so the habitat is lost forever. This increases risks to threatened species in Queensland not recovering from habitat destruction."*
	Lack of understanding, more research needed • "*How to classify them. What are the completion/achievement criteria? Should these be given the same weighting as naturally occurring regional ecosystems that have not been disturbed? Do they even offer the same environmental values/microhabitat features that make native ecosystems valuable?"* • "*Unpredictable - require a lot of research to determine feasibility and risk*". • *"Unknown and unpredictable. Concerns around lack of knowledge. If they are hybrid or novel, how do we know the ecosystems are going to function at a local scale but also with the surrounding landscape*".
	"***Introduction of diseases***"

3.5 Measures of native ecosystem rehabilitation success

Native ecosystems provide a myriad of services, goods and functions supporting life within and beyond their spatial range. A focus on particular value outcomes can help direct rehabilitation planning and decisions. Stakeholders were asked: **In your understanding, which of the following indicators are the most important measures of native ecosystem rehabilitation success?** Up to five multi-choice options could be selected, comprising:

- Native biodiversity
- Presence/habitat for species of concern/iconic species/keystone species etc.
- Plant species composition in the rehabilitated ecosystem reflects plant species composition in the area pre-mining
- Plant species composition in the rehabilitated ecosystem reflects plant species composition in the surrounding area today
- The rehabilitated ecosystem is resilient (e.g. able to recover after disturbances such as drought, fire or flood)
- The rehabilitated ecosystem directly adjoins/provides for connectivity with other areas of native ecosystems in the region
- The rehabilitated ecosystem contains culturally important species and cultural values (e.g., spiritual, aesthetic, artistic, educational or scientific uses of an ecosystem)
- The rehabilitated ecosystem supports recreational/tourism opportunities and values
- The rehabilitated ecosystem moderates pollution and/or takes up heavy metals
- The rehabilitated ecosystem is self-sustaining, with ongoing management inputs not exceeding those of surrounding landscape
- The rehabilitated ecosystem has economic value e.g., through a carbon credit system or offset scheme.

From the selection provided above, stakeholders most commonly identified the importance of ecosystem resilience and ecosystem self-sustainability (Figure 6). Ecosystem resilience can be defined as the capacity for an ecosystem to respond to a perturbation or disturbance by resisting damage and recovering quickly (Gunderson, 2000). Following these, the next most common selection by stakeholders was ‘Plant species composition in the rehabilitated ecosystem reflects plant species composition in the surrounding area today’, and ‘The rehabilitated ecosystem directly adjoins/provides for connectivity with other areas of native ecosystems in the region’. The latter selections highlight the importance of connectivity of the rehabilitated ecosystem to the surrounding landscape to stakeholders, which is a concept that was explored directly in a later question.

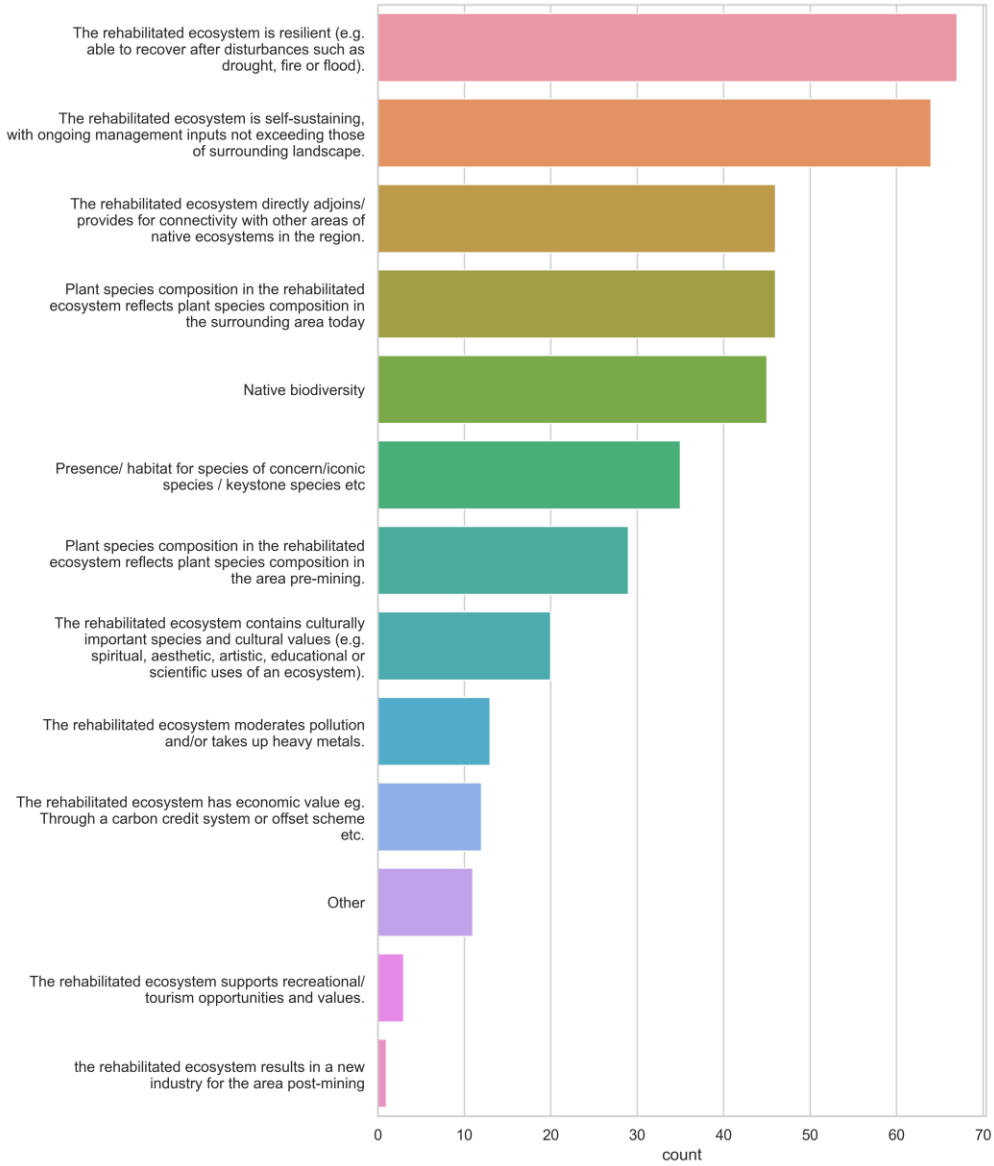

Figure 6. Stakeholder views on the most important measures of native ecosystem rehabilitation success. Count is the number of responses (n=362) from the 82 respondents. Major stakeholder groups that formed the 82 survey respondents were mining professionals (30.5%), consultants (24.4%), academics (14.6%), state government (12.2%); multiple responses were allowed.

3.6 Ecosystem connectivity

Ecosystem connectivity is the degree of connection the rehabilitation shares with the various natural environments present within a landscape, in terms of their components, spatial distribution and ecological functions. Ecosystem connectivity can refer to biological fluxes such as pollen and seed dispersal, migration, movement of animals between habitats, access to water and feeding grounds, and connection between populations for breeding and nutrient exchange through the landscape, to name a few. Connectivity can also occur through hydrological connections and air flow, these being contiguous aspects that play a vital role in ecosystem health, biodiversity and support biological connection. From a rehabilitation perspective, connectivity between the rehabilitated site and surrounding ecosystems encourages reintroduction of mobile or dispersive species into the site from surrounding ecosystems. When asked "**Is connecting native ecosystem mine rehabilitation sites with other native ecosystems in the region an important consideration for you?"**, 46% of stakeholder respondents rated connectivity as important and a further 35% rated it as very important (Figure 7).

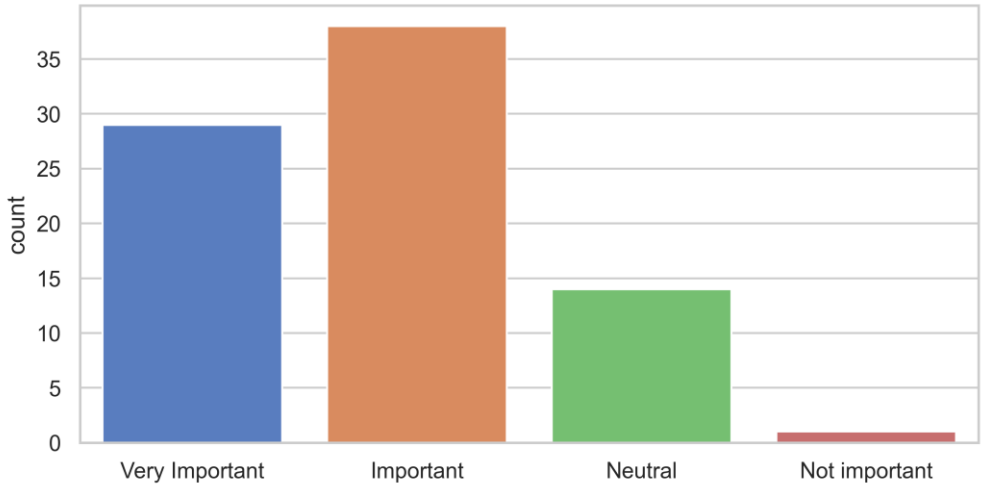

Figure 7. Stakeholder ranked importance of native ecosystem rehabilitation connectivity to existing ecosystems. Count is the number of responses (n=82). Major stakeholder groups that formed the 82 responses were mining professionals (30.5%), consultants (24.4%), academics (14.6%), state government (12.2%).

3.7 Native ecosystem rehabilitation assessment methodologies

Monitoring of rehabilitation provides the basis for assessing performance and generates information for stakeholders (Wortley et al., 2013; Iftekhar et al., 2017). Monitoring also helps inform future rehabilitation activities (Nilsson et al., 2016), and characterises the type of rehabilitation that has been established. Stakeholder respondents reported that benchmarking against a reference site was by far the most selected methodology for assessing native ecosystem rehabilitation (Figure 8). Mine-specific custom method score ranked second in terms of respondent's first choice selection while BioCondition score followed in terms of first and second choice selection combined, followed by Landscape Function Analysis, Ecosystem Function Analysis and then ecosystem services measure, soil quality index and finally Accounting for Nature®. While overall, stakeholders place the most value on obtaining data directly from reference sites in unmined native vegetation, it can be inferred that measures that include data on a range of ecosystem parameters e.g., ecosystem and/or landscape level measures, are also considered important.

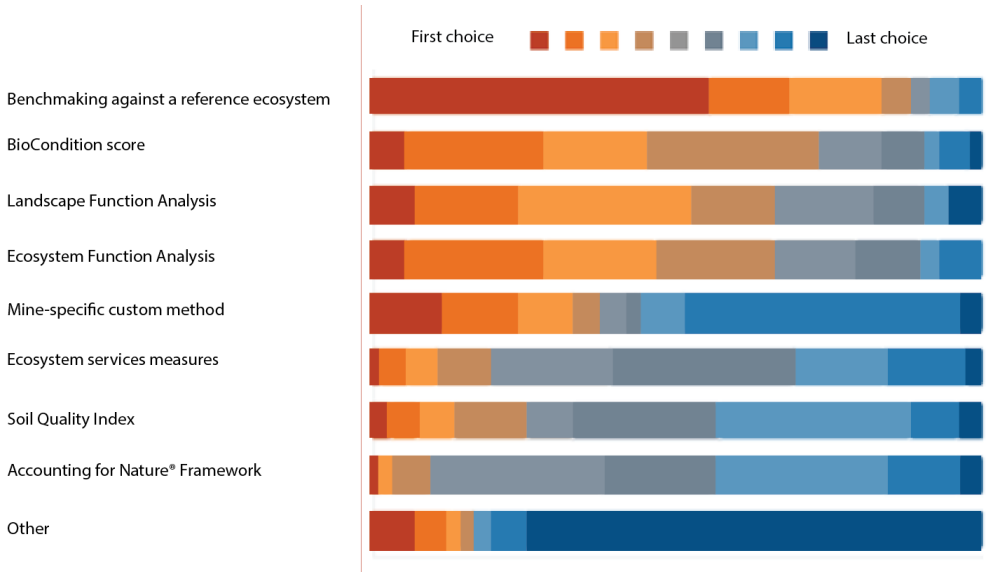

Figure 8. Stakeholder ranked native ecosystem rehabilitation assessment methodologies.

3.8 Key considerations in reference site selection

Following on from the previous question, which confirmed the importance of reference sites for benchmarking, stakeholders were asked what their key considerations were for the selection of reference sites for planning or assessment. Stakeholders were able to select their top three considerations from the list outlined in Figure 9. The most selected consideration was that “Reference community matches the anticipated land use”, closely followed by “Reference community occurs on a landform that is analogous to post mining landform”. Some stakeholders took the opportunity to share further insights in the “Other” box, which allowed for open-ended responses. These stakeholder insights included the following statements:

“Reference sites vary so much, so many are required to estimate the recovery trajectory.”

“Critical that evidence is used to demonstrate that the native reference is NOT able to be restored - must be scientifically robust"

“This is site specific and must include community consultation. We have been working with traditional owners around these questions and aspects of proximity and correct 'ecozones' are frequently mentioned.”

“I don't feel our standards are high enough in this area, the standard my clients are asking me to create would be completely unacceptable on a high visibility project, we're just not aiming high enough.”

“Need to consider landscape ecology. Does it fit and is it resilient to the prevailing natural disturbance regime? Species should reflect REs in the surrounding landscape for similar PMLU landforms."

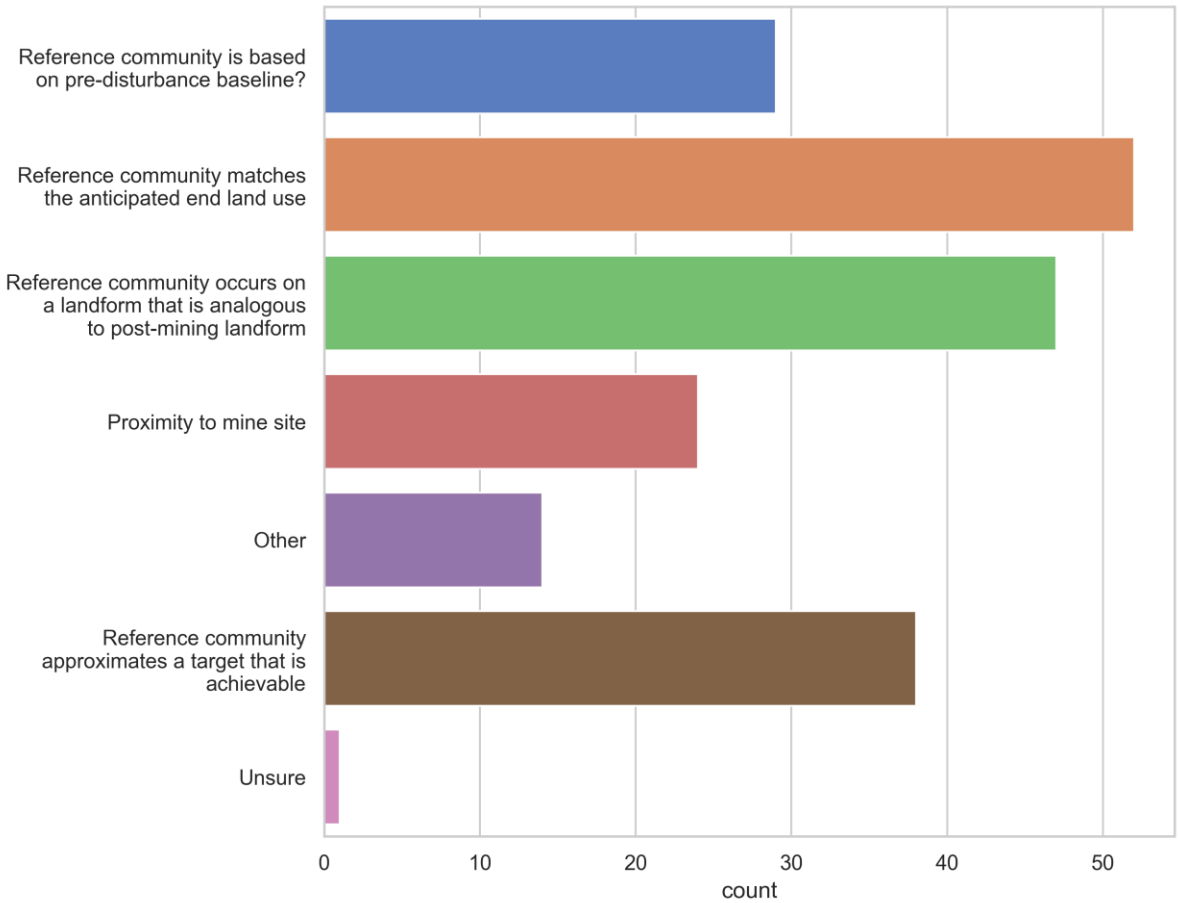

Figure 9. Stakeholder perspectives on key considerations in reference site selection. Count is the number of responses (n=205) from the 82 respondents. Major stakeholder groups that formed the 82 survey respondents were mining professionals (30.5%), consultants (24.4%), academics (14.6%), state government (12.2%). Multiple selections were allowed.

3.9 Use of exotic species in mine rehabilitation

In the literature on the topic, 'novel ecosystems' are primarily considered in relation to exotic species (Hobbs et al., 2013). Exotic species may threaten rehabilitation goals, especially in the context of native ecosystems recovery. However, under certain circumstances specific species may be useful due to their ability to perform a certain ecosystem function. This role, however, must be exercised with caution as non-intended outcomes may result. Exotic and invasive weedy species can threaten targets by preventing the establishment of native species through competition. For example, buffel grass (*Cenchrus ciliaris*) is a common invasive pasture species in the many grazing areas of Queensland and readily and rapidly grows on mine rehabilitation sites (Morrison et al., 2005). Whilst providing quick cover and some initial stabilising function, it can inhibit native ecosystem development, carry fire at much higher temperatures and truncate biodiversity (Jackson, 2005; McKenna et al., 2017; Emmerton et al., 2018; Wright et al., 2021).

To record more information around current mine site rehabilitation practices related to the use of exotic species in Queensland and the temporary or long-term generation of *no-analogue* ecosystems in this regard, the stakeholder respondents were given a list of vegetation types and asked: **Are any of the following types of exotic species intentionally introduced into your native ecosystem rehabilitation? (Select all that apply.)** This was an optional question, as it was not applicable to all stakeholder groups. The question garnered responses from 52 participants (Figure 10). Pasture grasses were clearly the most selected, followed by sterile grasses and then trees and shrubs.

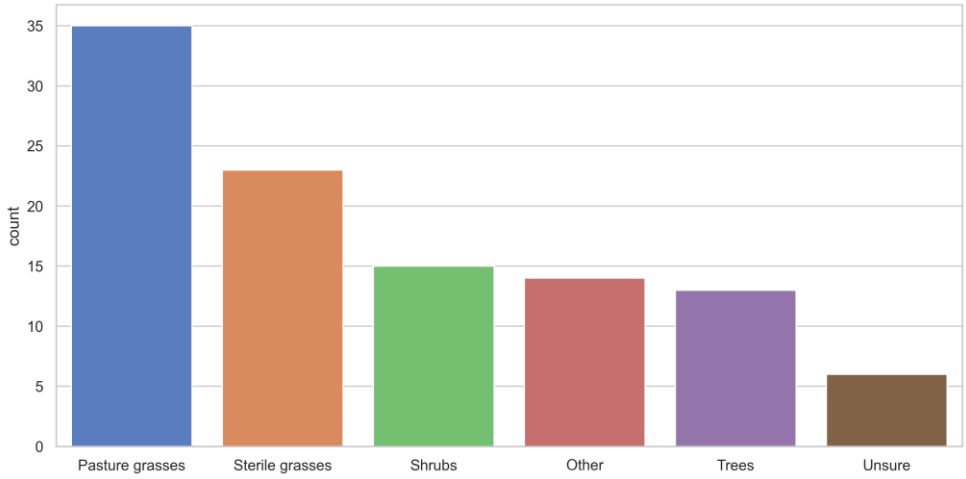

Figure 10. Stakeholder experience with use of exotic species in mine rehabilitation to native ecosystem. Count is the number of responses (n=106); this was an optional question with multiple selections allowed.

Some respondents added comments as follows:

"There should not be exotic species intentionally introduced into native rehabilitation."

"In all my sites I have worked, exotic species have been introduced for various reasons including, erosion protection or just to meet a stem/ha criteria in an EA [Environmental Authority]…."

"Vegetation in restoration comes from an approved species list based on provincial species where possible."

"Only when desperate to stabilise the land."

"All of the above when considered in a whole of landscape approach."

3.10 Determination of seeding/planting list

Initial plant community assemblages of rehabilitation are a primary determinant of later rehabilitation success (Jefferson, 2004; Grant, 2006). Therefore, careful selection of species and seeding rate within the seed mix or plantings is important in terms of achieving specific native ecosystem rehabilitation objectives. There are a range of theories and methodologies for how seeding/planting lists for mine rehabilitation could be determined. However, to gain insight into how seeding/planting lists are currently created in practice, and a sense for what stakeholder respondents see as preferential, it is of value to understand current practices and future possibilities. Stakeholders were asked "**How was your seeding/planting list determined? For those who aren't working on a specific rehab site how should the seeding/planting list be determined?"** This was an optional, open-ended question in the survey and resulted in 62 responses. Many respondents mentioned multiple considerations in their answers, and these have been separated into their relevant categories in Appendix 3: Determination of seed and planting lists for native ecosystem rehabilitation . When determining seed and planting lists for native ecosystem rehabilitation, the key considerations for stakeholder respondents were: ecological and geographic (i.e. functional traits and species guilds), geographic regions of origin, use of reference sites and outcome orientation (i.e. tailored from PMLU and similarity to surrounding area), and human and knowledge factors (i.e. use of expert opinion, issues with legacy rehabilitation and species list, lack of within-operation specialist capability), and accessibility of seed/tubestock.

3.11 Seed/tubestock access

The best rehabilitation plans mean little unless they can be executed through timely, on-ground access to the planting material required in sufficient quantities and quality. For example, there are often practical issues for seed collection due to spatial and temporal variability in seeding of target species (Vickers et al., 2012; Broadhurst et al., 2015). To gain an understanding of how significant this is as a barrier for rehabilitation in Queensland, the following question was asked to stakeholders in the survey: **"Are your seed/tubestock suppliers typically able to provide the species required?"**

There were 59 responses to this optional question, with 47% reporting "Usually", 39% "Sometimes", 10% "Almost always" and 3.5% "Almost never" (Figure 11). This result indicates that there is some difficulty in obtaining seed for the required species, which may in some cases be severe. The finding echoes other stakeholder studies that have asked similar questions (Hancock et al., 2020).

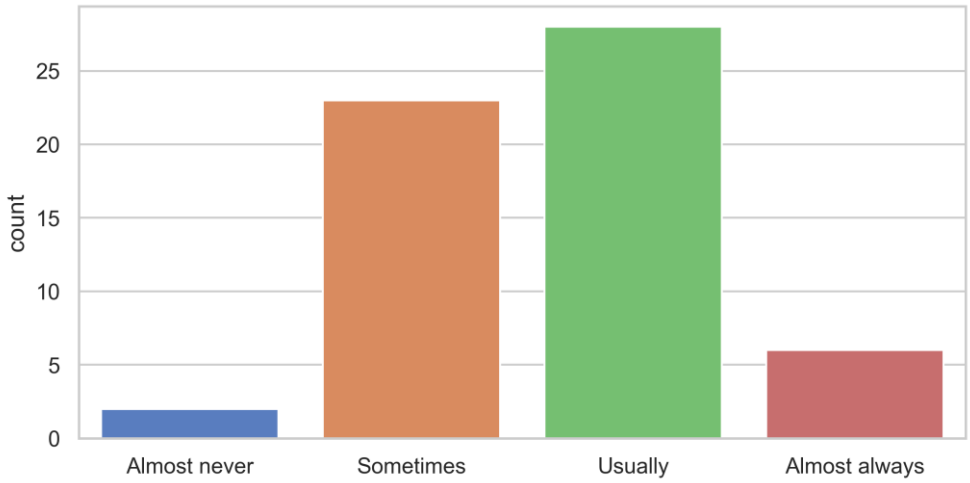

Figure 11. Stakeholder experience with availability of seed/tubestock required for native ecosystem rehabilitation in Queensland. Count is the number of responses (n=59); this was an optional question.

3.12 Exotic species use in functional roles in mine rehabilitation

As noted above, specific exotic species may play a functional role in rehabilitation in certain circumstances and with certain stakeholder perspectives. Gaining further insight into on-ground stakeholder experience with the use of exotic species is useful in revealing the extent and nature of *no-analogue* ecosystem creation in mine rehabilitation, the circumstances where it occurs and the reasoning behind this course of action. Forty-seven respondents commented in the optional open-ended question: "**Do you have examples of exotic species that play a functional role in your rehabilitation? If yes, please specify."** For results, see Table 2.

The only non-pasture grass or forage legume mentioned was the shrub/tree genus *Cassia* spp.

Key reasons mentioned for the use of exotic species were to stabilize the soil, fix nitrogen and provide value as pasture grass. Statements from stakeholders in this regard included: "*Rarely [use exotic species]… when desperate to stabilise the site*."; "[exotic] g*rasses acting as pioneer species*."; "*Use of Jap*[anese] *millet as a cover crop whilst native trees/shrubs/grasses establish, provides initial erosion protection, rots down to provide organic matter*."; "[exotic species] *help establish stability/mitigate erosion control and establish microclimates for other species to establish)*."; "*Invasive exotics can provide good cover and complement native spp. Seen good work on this in a restoration environment in WA*."

Some stakeholders took this opportunity to explain their resistance to the introduction of exotic species in mine rehabilitation, for example: "*… introduce exotics at the peril of your native ecosystem*."; "*Possibly some of the more recent ground stabilising hybrids but there are numerous examples of land stabilising exotics that have become problematic weeds on Australian mine sites*"; "*No, native species are always best utilised. Species provenance needs to be more considered along with species selection whilst keeping in mind post mine soil conditions, hydrology and climate change impacts."*

Table 2. Examples of exotic species potentially playing a functional role in native ecosystem rehabilitation.

Do you have examples of exotic species that play a functional role in your rehab? If yes please specify.	
Pasture grasses and forage legumes	• "*Currently pasture grasses are good at stabilising and a lot of weeds that grow quick help to stabilise soil. Over time these annual species get outcompeted by natives and through weed control."* • "*Sorghum grass is generally applied as a fast growing species to establish organic matter but other means of organic matter are recommended - i.e. mulch of some description."* • "*Exotic species have been used to assist in erosion (i.e. millet). In a previous role, I have used 'exotic species' in developing green manure crops to improve soil quality in the rehabilitation program."* • "*Stylos, legumes, annual grasses, single generation sorghums, creeping bluegrass (Bothriochloa insculpta)."* • *"Red Natal Grass, Sterile Sorghum and Millets, Rhodes Grass at times, Couch for stabilisation of drainage lines in wetter areas. Definitely not buffel as this is a competitive weed from the topsoil that outcompetes other species and leads to a mono culture."* • "*Sterile millet etc to provide initial soil stabilisation and nitrogen."* • "*Wintaroo Oats; Creeping bluegrass; Indian bluegrass; Rhodes grass (Reclaimer); Green couch; Sabi grass; Butterfly pea; Progardes; Verano; Seca Stylo"* • "*Exotics can generate high veg cover at a rapid pace so can reduce erosion."* • "*Nitrogen fixers can assist the soil development eg. Stylo species, Butterfly pea etc."* • "*Only pasture grasses, there are a limited number that are salt tolerant to generate rapid grass coverage and protection from erosion within 4 to 6 weeks of rehabilitation."* • "*The site topsoil contains a substantial seed bank dominated by Johnson Grass [an exotic pasture grass]. This species germinates to form a dense, tall cover. This precludes the requirement to plant a cover crop to stabilize the surface and provides a carbon/mulch source for the rehab landform. This species naturally declines in*

Do you have examples of exotic species that play a functional role in your rehab? If yes please specify.	
	dominance over about 5 years allowing other species to grow through. It is also shade intolerant and so does not create a threat to the rehab goals."
Shrub/Tree species	• *"Cassia spp."*

3.13 Field trials

Fifty-two stakeholders responded to the optional, open-ended question:

"Does your organisation undertake field trials prior to or during the rehabilitation program? Please elaborate if possible" (see Table 3).

Topsoil testing and seed/planting trials were the most common answers. From the seed mix and planting method perspective, tests like seed viability and functionality, tree and shrub establishment and dispersal methods were noted. Soil trials included soil testing and improvement with amendments, green manure trials, being the most common answers. It is noted that some responses appeared to conflate field trails with monitoring of general rehabilitation. Also, grazing trials were raised, however they are only applicable to grazing PMLU, not native ecosystem PMLU. As resilience was listed highly in the previous question about values it was interesting to see there was only two responses that listed trials that relate to resilience – "*grazing trials with kangaroos*" and "*impacts of fire*".

One stakeholder expressed frustration at a perceived trend away from field trials "*In the past without a doubt; since the EMOS* [Environmental Management Overview Strategy] *era it [field trials] has become the exception sector wide in QLD (arguably Aust); the sector has been focused on generating regulatory documents since circa 1991. We are now enduring yet another regulatory inspired approach to rehabilitation in QLD. Based on experience this is guaranteed to divert priorities and resources from doing to talking about it and not doing*." In the same vein "*I give advice. Not always followed*." Yet another added "*yes, this is critical and in many situations is poorly implemented and sometimes not at all*". Two more mentioned the timing of trails in the mining cycle "*Yes, but generally very late in the mining cycle*."; "*Not enough, mining companies leave it till the last minute to start rehab, and then there is no time for trials. They need to be much better planned and start a trial much earlier on in the process*."

Another stakeholder explained their conceptual view of the relationship between field trials and rehabilitation "*Rarely [undertake field trials]. Arguably all rehabilitation constitutes a trial, and all trials constitute rehabilitation*."

One idea put forward by a stakeholder linked field trials to wider possibilities: "*Field trials are essential and should begin and run concurrently with mine operations. On traditional lands development of nurseries and field trials is an area where involvement of traditional owners supported by flexible management structures could have positive benefits for communities, restoration and maintenance of cultural connections."*

Table 3. Native ecosystem rehabilitation field trials undertaken by stakeholder organisations

• **Does your organisation undertake field trials prior to or during the rehabilitation program? Please elaborate if possible.**	
Theme	**Responses**
Growth medium	• Topsoil depths and appropriateness for different species • Green manure trials to improve quality of topsoil • Soil testing and different ameliorates (lime, gypsum, cow manure, fertiliser and organic growth medium) • Trial of different application rates of compost/humisoil and spreading of straw/hay mulches to determine application rates to enhance fast cover crop and grass establishment for erosion control • Different types of topsoil and fertilisers (phosphorous in seeding area and phosphorous + biochar in a tubestock planting area) • Surface prep techniques in harsh environments
Seed mixes and planting methods	• Annual monitoring to understand seed viability data and determine good pioneering specie. • Different seed application rates • Seed treatment to make grass seed heavier • Species establishment and survival trials • Rely on the seed supplier to provide their own field-testing results/lab germination test results but have undertaken field trials to measure species growth with/without fertilizer and in absence/presence of topsoil • Hydroseeding techniques • Using seeds of different provenance (but the known characteristics/traits) that likely match changed conditions • Seeding vs. tubestock planting • Plan to trial direct seeding of tree and shrub species 2–3 years post rehab to improve tree and shrub establishment • Plot trials if aiming for a novel ecosystem • Species trials to determine species that establish in the rehab from direct seeding or from replaced topsoil
Response to stress	• Resilience to fire • Impact of grazing by kangaroos etc. • If capping or other cover required, trial tends to occur more for the integrity of the cap, rather than the vegetation

3.14 Multi-use post mining land use (PMLU)

In order to explore which PMLUs are combined with native ecosystem rehabilitation, the following optional multiple-choice question was put to the stakeholders: "**Do you combine native rehabilitation objectives with other rehabilitation objectives within your organisation's rehabilitation program/s? If so, what? (Select all that apply.)"**

Pasture grazing was the most selected, with cultural heritage a distant second (Figure 12). One stakeholder cautioned about cultural heritage in a multi-use PMLU situation stating "*Cultural Heritage: Try not to combine 2 outcomes for same area - cultural spp* [species] *is only one*". In the 'Other' category a stakeholder respondent listed *"Establishment of SEVT [semi-evergreen vine thicket] nodes where possible and practical."* While another stakeholder listed *"Biodiversity and carbon sequestration."*

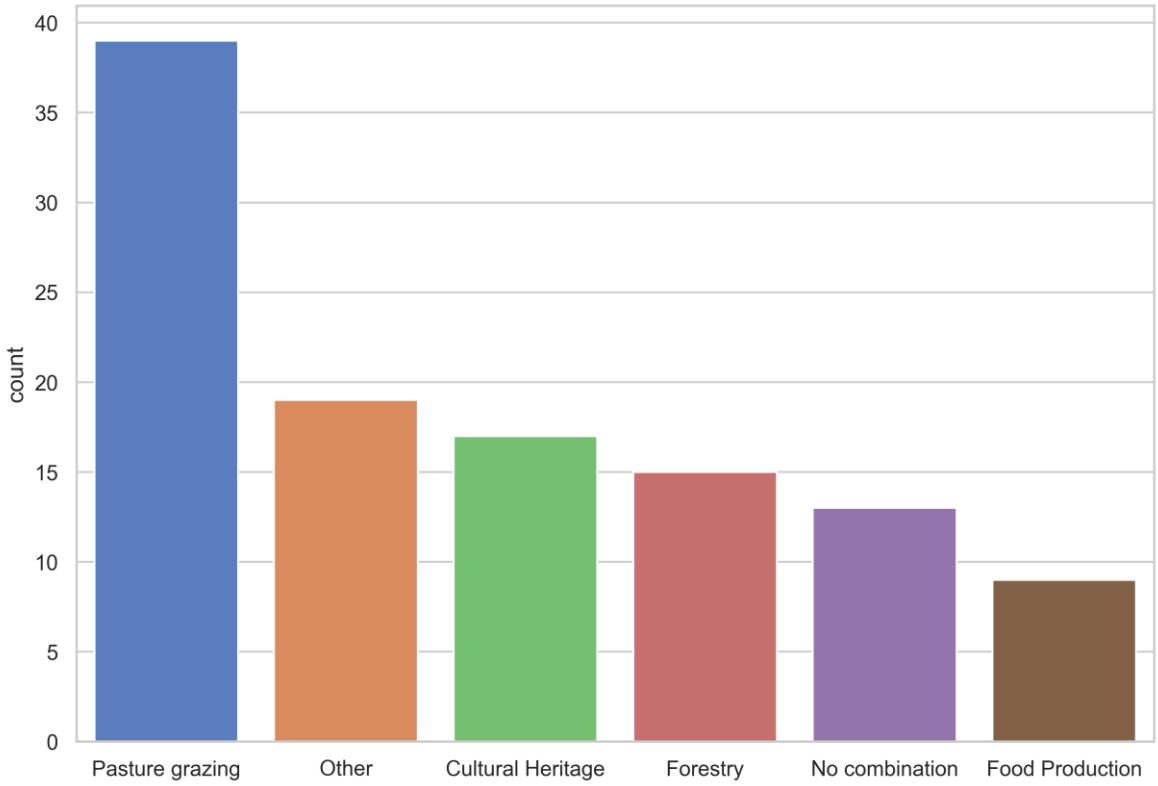

Figure 12. Stakeholder experiences combining native ecosystem rehabilitation with other Post Mining Land Uses (PMLUs). Count is the number of responses (n=112); this was an optional question with multiple selections allowed.

3.15 Prevalence of legacy native rehabilitation

The presence of legacy rehabilitation plantings and trajectories can be a significant challenge in achieving PMLU objectives (Annandale et al., 2021). To better understand how much of a challenge this is for mine sites in Queensland, the final question of the survey asked: "**Does your operation have "legacy" native rehabilitation, established in an earlier period when methods or objectives were different to the present? If yes, what is the current status of these areas? (Select all that apply.)"** Many stakeholders who responded to this question answered that they do not have legacy native rehabilitation. Of the stakeholders who do have legacy established rehabilitation, a different set of approval criteria applies in recognition of its legacy status; see Figure 13. A comment made by a stakeholder respondent in regard to the management of legacy native rehabilitation explained the "*Need to weigh up merit of redisturbance if functioning, conduct research to demonstrate—not just superficial monitoring. Need to gather evidence to decide best next steps*

rather than a company imperative of do nothing to save money and time." Another respondent felt "*legacy often an excuse to do nothing and define as novel".*

Many stakeholders included comments associated with a grazing PMLU. It is noted that native ecosystems may be grazed but also that grazing and pasture can constitute a PMLU independent of native ecosystem outcomes. This reflects a genuine ambiguity about how grazing intersects with native ecosystem rehabilitation targets and is more reflective of an agro-ecosystem landscape, rather than the native ecosystem rehabilitation by definition. These comments emphasise a need for better distinction criteria between native ecosystem PMLUs that have a grazing element (i.e., an agriculture ecosystem specifically for grazing into the future) and legacy established rehabilitation from a period when rehabilitation objectives were different.

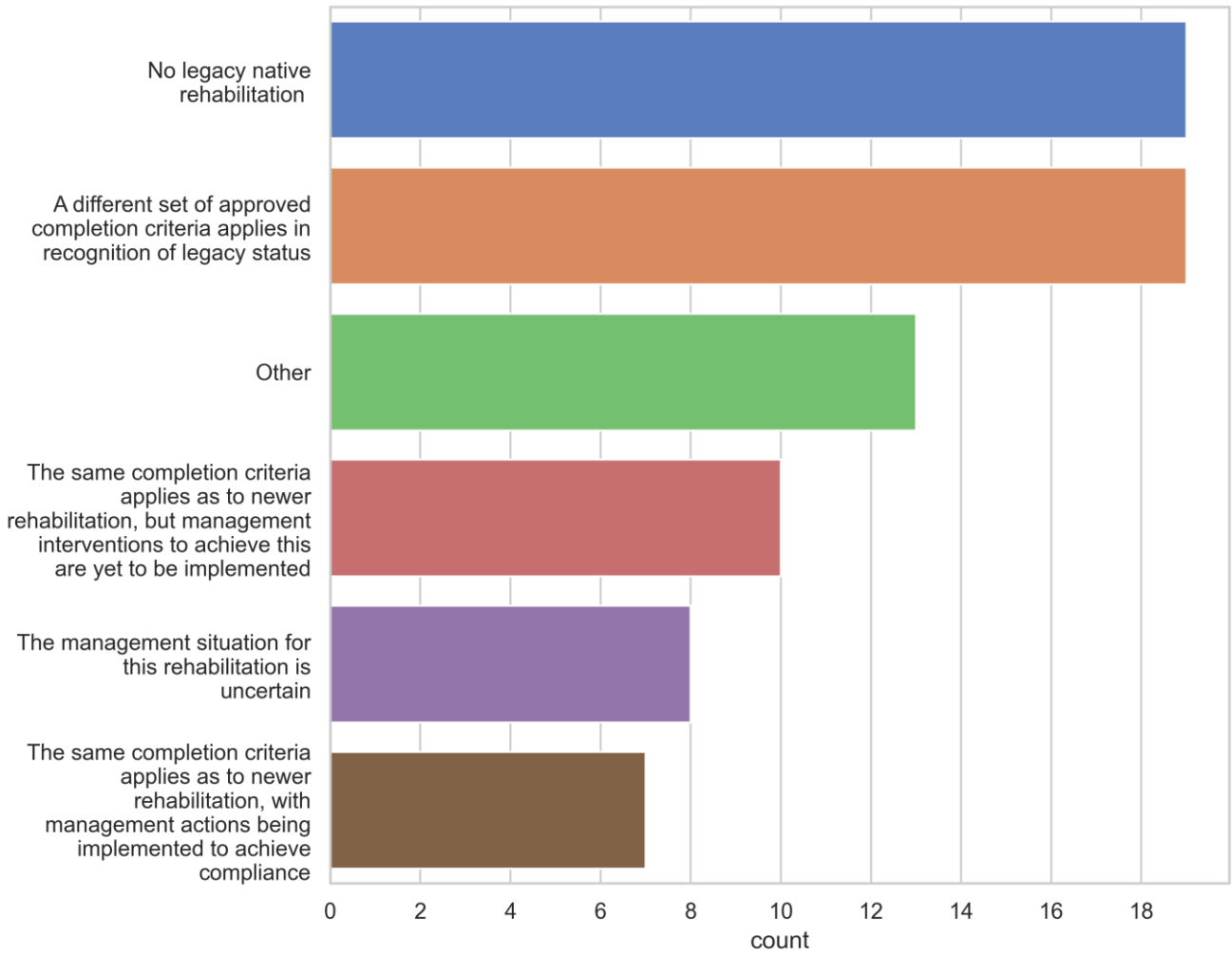

Figure 13. Stakeholder experiences of how legacy native ecosystem rehabilitation is currently treated on sites. Count is the number of responses (n=76); this was an optional question with multiple selections allowed.

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5. Appendices

5.1 Appendix 1: Survey questions

Native Rehabilitation Stakeholder Survey

* Required

1. In the context of mine rehabilitation, which of the following best describes you? *
   - Environmental practitioner or manager within mining company
   - Other employee of mining company
   - Consultant advising to the mining industry
   - Academic researcher
   - Employee - Local Government
   - Employee - State Government
   - Traditional Owner
   - Local Community (e.g. neighbouring resident, landholder, business operator)
   - Member of an environmental conservation group
   - Other special interest group or business operator
   - Other

2. What mining process/es is your work/organisation or community associated with? (Select all that apply.) *
   - Coal mining (open cut and underground)
   - Bauxite, vanadium, sand mining (i.e. commodities mined by strip mining method)
   - Base & precious metal mining (excluding vanadium, bauxite, mineral sands)
   - Other mining (e.g. phosphate, clay, limestone)

3. Native ecosystem rehabilitation can mean different things to different people. In the context of mine rehabilitation, which of the following most closely aligns with your understanding of, or aspirations for, 'native ecosystem rehabilitation' for your organisation or current site/s? For more information on what Regional Ecosystems are please see https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/about *
   - Establishment of an ecosystem using plants from a specific Regional Ecosystem
   - Establishment of an ecosystem using local or bioregional plant species, but not necessarily targeting a specific naturally occurring Regional Ecosystem
   - Establishment of an ecosystem with Australian plants
   - Establishment of an ecosystem using native and exotic plants, but dominated by native plants
   - Establishment of an ecosystem using native and exotic plants, but dominated by exotic plants (e.g., exotic pasture grasses)
   - Other

4. Thinking about open cut mining, how achievable do you think it is that rehabilitation will restore an ecosystem similar to a pre-disturbance ecosystem? *

Unachievable	Somewhat difficult to achieve	Neutral	Somewhat achievable	Highly achievable
○	○	○	○	○

5. Can you list examples of where this has been achieved in your view

Novel and Hybrid ecosystems

The nature and extent of environmental disturbance associated with mining commonly can result in completely new and challenging combinations of hydrology, lithology and landform. Consequently, the outcomes of ecological processes associated with the recovery or restoration of ecosystems can vary from previously known associations between their physical and biological components. For radically disturbed sites, it is not always feasible to aim for the restoration of historical ecosystems. However, there is debate that hybrid (reversibly different) or novel (irreversibly different) ecosystems comprising new combinations of physical and biological components, including both native and non-native species, might theoretically provide levels of stability and functionality acceptable to some stakeholders and within feasible management regimes (adapted from Doley and Audent 2013).

6. We are interested in your thoughts about "novel and hybrid ecosystems". Do you think novel and hybrid ecosystems are acceptable rehabilitation objectives in Queensland? *
   - ○ Yes
   - ○ No
7. What are the benefits/risks you see in regard to these options?
8. In your experience can you list any examples of novel/ hybrid ecosystems in the mine rehabilitation context?
9. In your understanding which of the following indicators are the most important measures of native ecosystem rehabilitation success? (Select up to 5 options.) *
   - Native biodiversity
   - Presence/ habitat for species of concern/iconic species / keystone species etc
   - Plant species composition in the rehabilitated ecosystem reflects plant species composition in the area pre-mining.
   - Plant species composition in the rehabilitated ecosystem reflects plant species composition in the surrounding area today

- The rehabilitated ecosystem is resilient (e.g. able to recover after disturbances such as drought, fire or flood).
- The rehabilitated ecosystem directly adjoins/ provides for connectivity with other areas of native ecosystems in the region.
- The rehabilitated ecosystem contains culturally important species and cultural values (e.g. spiritual, aesthetic, artistic, educational or scientific uses of an ecosystem).
- The rehabilitated ecosystem supports recreational/ tourism opportunities and values.
- The rehabilitated ecosystem moderates pollution and/or takes up heavy metals.
- The rehabilitated ecosystem has economic value eg. Through a carbon credit system or offset scheme etc.
- The rehabilitated ecosystem is self-sustaining, with ongoing management inputs not exceeding those of surrounding landscape.
- Other

10. Is connecting native ecosystem mine rehabilitation sites with other native ecosystems in the region an important consideration for you? *

Not at all important	Not important	Neutral	Important	Very important
○	○	○	○	○

Current Practices

The following questions are directed at those currently involved in site rehabilitation planning/ works/ monitoring/ assessment, please answer where possible.

11. We are keen to understand your perspective on native ecosystem rehabilitation assessment methodologies. What mine rehabilitation monitoring methods do you find most useful in general? Please rank by dragging and dropping your selections with the most useful at the top.
    - Benchmarking against a reference ecosystem
    - Landscape Function Analysis https://link.springer.com/chapter/10.5822/978-1-61091-007-1_13
    - Ecosystem Function Analysis https://papers.acg.uwa.edu.au/p/852_30_Lacy/
    - BioCondition score (Ngugi, M.R., Neldner, V.J., 2015 Two-tiered methodology for the assessment and projection of mine vegetation rehabilitation against mine closure restoration goal, ECOLOGICAL MANAGEMENT & RESTORATION, Vol 16 No 3.)
    - Accounting for Nature® Framework (https://www.accountingfornature.org/)
    - Ecosystem services measures
    - Soil Quality Index
    - Mine-specific custom method
    - Other

12. What are the key considerations you believe are most important when choosing a reference site for planning or assessment? (Select up to 3 options.)
    - Reference community is based on pre-disturbance baseline?
    - Reference community approximates a target that is achievable
    - Reference community matches the anticipated end land use

- Reference community occurs on a landform that is analogous to post-mining landform
- Proximity to mine site
- Unsure
- Other

13. Are any of the following types of exotic species intentionally introduced into your native rehabilitation? (Select all that apply.)
    - Sterile grasses
    - Pasture grasses
    - Shrubs
    - Trees
    - Unsure
    - Other

14. How was your seeding/planting list determined? For those who aren't working on a specific rehab site how should the seeding/planting list be determined?

15. Are your seed/ tubestock suppliers typically able to provide the species required?

Almost never	Sometimes	Usually	Almost always
○	○	○	○

16. Do you have examples of exotic species that play a functional role in your rehab? If yes please specify.

17. Does your organisation undertake field trials prior to or during the rehabilitation program? Please elaborate if possible.

18. Do you combine native rehabilitation objectives with other rehabilitation objectives within your organisation's rehabilitation program/s? If so what? (Select all that apply.)
    - Pasture grazing
    - Forestry
    - Food Production

- Cultural Heritage
- No combination
- Other

19. Does your operation have "legacy" native rehabilitation, established in an earlier period when methods or objectives were different to the present? If yes, what is the current status of these areas? (Select all that apply.)
    - No legacy native rehabilitation
    - The same completion criteria applies as to newer rehabilitation, with management actions being implemented to achieve compliance
    - The same completion criteria applies as to newer rehabilitation, but management interventions to achieve this are yet to be implemented
    - A different set of approved completion criteria applies in recognition of legacy status
    - The management situation for this rehabilitation is uncertain
    - This rehabilitation is planned to be removed
    - Other

5.2 Appendix 2: Responses to understanding of 'native ecosystem rehabilitation' open-ended question

Native ecosystem rehabilitation can mean different things to different people. In the context of mine rehabilitation, which of the following most closely aligns with your understanding of, or aspirations for, 'native ecosystem rehabilitation' for your organisation or current site/s?

For more information on what Regional Ecosystems are please see https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/about

For those that selected "Other" as their response and provided detail:

"*I believe you have captured most descriptions of 'native ecosystems'. I have worked at different sites where different interpretations have been applied. The only other ones would be 'vegetation cover similar to surrounding area', 'fits in with surrounding vegetation', 'self-sustaining vegetation communities'. Other descriptions are captured in Fogarty et al. 2019 https://papers.acg.uwa.edu.au/p/1915_74_Fogarty/ "*

"*Restoring an ecological community with as many as possible of the various ecosystems that were naturally occurring prior to the area being cleared for mining or cleared initially for grazing and subsequently for mining is an aspirational ambitious goal but should be the objective where feasible. The restoration should comprise of species sourced from provincial seed or cuttings that are as provincial as possible rather than from other sites in the bioregion. The site's soil will also determine what species should be restored. However, if the area has its geology and hydrology significantly modified or is subject to a change climate, then restoration back to the pre-clearing state may not be possible. Any restoration will take decades if not centuries for a site to restore to being even close to its pre-clearing state. Exotic plants, particularly non-native pasture grasses should not be used. Hydromulch should not be used. Stabilisation using polyacrylamide must not be used."*

"Definitions are defined in various EA conditions - often require pre-disturbance value could be specific RE or other."

"*Establishment of an Ecosystem which includes both floral and faunal species, landform, and ecosystem function and services relative to a predefined analogue (preferably an RE replicate of that which was destroyed by the mining activity)."*

"*Establishment of functioning ecosystem framework using predominately plants from a specific RET, to provide the conditions to allow natural recruitment and succession over time, recognising that conditions at the time of rehabilitation are different to the conditions pre-clearing."*

"Historically this may reflect any of the first four options depending on the site-specific context and rehabilitation commitments. However, for contemporary approvals, this is most likely to reflect the first two options."

5.3 Appendix 3: Determination of seed and planting lists for native ecosystem rehabilitation

How was your seeding/planting list determined? For those who aren't working on a specific rehab site how should the seeding/planting list be determined?	
Ecological and geographic	
Functional traits, species guilds	• *"Representation of lifeforms and functional characteristics. e.g., cover crops for rapid establishment that will be replaced by pasture grasses and legumes suited to the specific soil texture and chemistry, plus native shrubs and trees that are known to establish readily, will create an ecosystem structure that will support further recruitment. Function and capacity to establish are prioritized over pre-clearing occurrence. Planting to provide the required functionality"* • *"Fire-resistant"* • *"Shallow rooting"* • *"Seeding/planting should be determined after you determine what the necessary plant growth medium and landform is to be created to support the seeding and planting."* • *"Also the inclusion of intermediate successful pasture species. These are often introduced species but are a successful pasture species as they are quick to germinate, productive, provide good biomass and cover and are resilient."* • *"When aiming for novel systems, compatibility between species (e.g. recovery traits) should be accommodated for. For example buffel grass is highly competitive and will outcompete most native forbs/grasses. It also generates fire conditions (severity/intensity) that will impact on native shrubs and trees)."* • *"Mix of long-lived Acacia/Eucalypt species with supporting mid storey shrub species from the bioregion."* • *"Because we're creating manufactured soils made from waste and using mine affected water to generate short-term rehabilitation outcome, we do benchtop germination trials using water from the site to assess and determine seed mixes."* • *"Target for endangered native animals"* • *"Species suitability to local climate and conditions, availability, purpose"* • *"Cross checking the area to be seeded with pre-clearing layers in ArcGIS to understand what types of species were there historically. Using these ecological conditions then looking up vegetation species, specifically ones that are endangered, have additional benefits (indigenous aspects, medicinal) along with if they are primary foods for endangered animals to the area (koalas)."* • *"Grasses that are hardy, establishes quickly and controls erosion. Trees that are native and hardy species (i.e. eucalypts)"*
Geographic region of origin (local, bioregional etc)	• *"Native to region"* • *"Endemic local species, species suited to stabilisation or other rehabilitation objective, species commercially available."* • *"Mixture of local species tolerant of predicted physical and biological components of the final landform"* • *"Based on technical description of the Regional Ecosystem in conjunction with field surveys to confirm species actually growing in the area, and then determine what is commercially available."* • *"List of species occurring in regional ecosystems in vicinity plus species found to be suitable to the site conditions elsewhere. Remove species unsuited to specific site e.g., remove riparian species from use on elevated slopes."* • *"Should be based on RE's that occur in the area and native pasture grasses for grazing"* • *"Locally occurring species, results from rehab monitoring, species occurring at reference sites"* • *"Based on the RE characteristics of the pre-mining ecosystem"* • *"Based on target RE, excluding that which is present in the topsoil (provided topsoil is viable)"*
Use of references	• *"Using reference community data"*

How was your seeding/planting list determined? For those who aren't working on a specific rehab site how should the seeding/planting list be determined?	
sites	• *"Native ecosystem seed lists should reflect closely the species mix found in the reference ecosystem."* • *"Informed by a number of appropriate reference sites"* • *"The native reference ecosystem and agreed land use that was agreed at the time of mine commencement."* • *"It should be based on a reference MODEL (see SER standards), which may draw on a combination of reference sites, historical conditions, scientific research and other additional information.* *Research propagation methods if any."* • *"Based on what occurs in reference sites. Also a large research program to understand what seeds occur in soil seedbank and what can be collected and germinated"*
Outcome oriented	
Tailored from PMLU	• *"Sourced to match the pre-existing ecological biodiversity"* • *"Should be determined as a ratio necessary to establish the desired species composition at the end and with the consideration that it may take over 30 years to establish a successful ecosystem i.e., enough organic matter in soil to support successful plant establishment."* • *"Seeding/Planting should be based on the proposed PMLU and the species endemic/native to the region and its wildlife"* • *"Two considerations - End land use (which is a function of technical, regulatory and social factors), Availability of seed/tubestock"* • *"Applied ecology methods - post mining land use, soils, climate, aspect. Select species for success in achieving a sustainable outcome with a post mining land use and user."* • *"Based on the intended post-mining land use."* • *"We rely on the seed bank in the stripped topsoil for our ongoing rehabilitation works; however, if seeding were to be undertaken, the seeding/planting list would be determined by what is best suited for the rehabilitated landform and the proposed post-mining land use, acknowledging the potential limitations of the rehabilitated landform in sustaining certain species."* • *"By land use, surface stability, recruitment capability and contribution to overall ecosystem services and function of the final sustainable ecosystem to be achieved"* • *"Target end land use (if grazing target pasture grasses)"* • *"Based on approximation to target ecological system that is to be established, considers likely success of establishment."*
Similarity to surrounding area	• *"Ecological surveys in relatively undisturbed, nearby sites with similar REs."* • *"A diverse and broad mix of species from surrounding REs. The species that are most suitable for that soil, aspect, micro relief will establish over time (long term)."* • *"Local native species from locally sourced seed."* • *"Based on species present in pre-mining and/or adjacent ecosystems that are similar to the desired end land use ecosystem, including grasses, trees and shrubs from certain Regional Ecosystems."* • *"The better examples have been based on survey of adjacent reference sites with mixes chosen to match desired end states which reflect both surrounds and the likely end landform".* • *"Depends on what is being aimed for - such as similar to surrounding native ecosystems/reference sites"* • *"Similar species to surrounding area/analogue site"* • *"Reflecting typical plants found in vicinity of local conditions"* • *"Based in the surrounding species mix but with due consideration to any altered conditions and to ease of propagation/availability of planting material. Provenance is less of an issue when conditions are substantially altered."*

How was your seeding/planting list determined? For those who aren't working on a specific rehab site how should the seeding/planting list be determined?	
Human and knowledge factors	
Use of expert opinion	• *"Review Herbarium and ALA [Atlas of Living Australia] records. Consult with local SGAP group and botanists."* • *"Full review of historic and current regional ecosystems. Engaging ecologists to design send mix and plantings. Start with trial areas on different landform units and improved adjust seed mix over time before arriving at accepted strategy."* • *"The species list should be determined by agreed mine closure planning commitments supported by independent research that confirms best methodologies to achieve agreed mine closure commitments"* • *"Local agronomist Ecologist"* • *"External consultants and trial/error"* • *"Landholder discussions"* • *"Recommendation report from specialist consultant considering PMLU and species endemic to the area."* • *"Should be based on trials, and experimentation of using natives from different rainfall regions."* • *"Unsure - contractor provided."* • *"Using site specific determined by specialists who know the type of final land use expected from the rehabilitated area."* • *"Also species type recommended by consultant based on RE veg types"* • *"Using expert advice plus agronomy to guide. Using species identified during the baseline rehabilitation survey and species known to germinate/thrive at sister mine operations in the area."*
Issues with legacy species lists	• *"In all my operational roles, rehabilitation seed/species lists have been inherited either from legacy approvals or provided by consultants (typically over the top ecologists) without consideration of PMLU."*
Lack of within-operation specialist capability	• *"I have found numerous times when undertaking a review of rehabilitation programs that results of analogue sites are then not reviewed and provided as a feedback mechanism in continual review of the rehab programs i.e., it becomes a tick and flick exercise. Rehabilitation programs for mines, tend to be a static program that has the 'set and forget' mentality. Rehabilitation is a specialised practice yet there are no rehabilitation specialists employed at mine sites who are typically an environmental 'generalist'. Mining companies, especially in QLD where a cultural change is needed which highlights the significant resources requirements needed if mine rehabilitation success is to be achieved."*
Availability	
Accessibility of seed/tubestock	• *"The list was derived from the species occurring in analogous local sites. The final selection was based on what species could be economically obtained from commercial suppliers."* • *"Also requires canvassing a number of seed collecting companies and seedling providers to ensure local provenance and quality seed and seedlings. Together with this understand soil materials and variability not just surface but also subsurface soils physical and chemical properties...all integral to planning and design"*