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Identifying industry practice, barriers, and opportunities for mine rehabilitation completion criteria in western Australia

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ABSTRACT

Around the world, the development of acceptable and achievable completion criteria is a necessary part of mine closure planning and fundamental to the successful transition of mined land to a post-mining use. Without adequate completion criteria, a mining company cannot proceed to the process of relinquishment, which is the ultimate goal of most mine closure processes. Despite the central role of completion criteria, there is still a need to build capacity and understanding of how to set targets and develop measurable completion criteria that are accepted by all stakeholders involved.

We investigate how completion criteria are currently developed in one of Australia's major mining jurisdictions: Western Australia. Through an industry consultation process that involved interviews and a survey with a total of 102 participants from mining companies, consulting businesses, and relevant regulators, we highlight key challenges and opportunities that the sector faces to successfully define clear, achievable, and agreed completion criteria.

This is one of the few industry-wide investigations to capture and analyze the perspectives of stakeholders involved in writing and assessing mine closure completion criteria. Results show that some major challenges included inconsistent coordination within and between stakeholder groups, a lack of knowledge or data about restoration, and an overreliance on *status quo* practices and post-mining land uses. Our work shows that ongoing research on ecological restoration and technological innovations is necessary, but that additional organizational and regulatory barriers need to be addressed to achieve a consistent, coordinated, multi-stakeholder approach to define completion criteria and to advance successful mine rehabilitation and relinquishment.

1. Introduction

The mining industry plays a crucial role in supporting human society and its development, as it provides the materials required to produce fertilizer, generate energy, and build infrastructure and every-day products (Basu and van Zyl, 2006; Carvalho, 2017). In 2016, the total value of global mine production was estimated at 1,000 billion USD, to which coal, iron ore, and gold contributed 50%, 13%, and 11% respectively (Ericsson and Löf, 2019). At the same time, mining can cause negative environmental and social impacts, such as loss of biodiversity (Murguía et al., 2016) and heritage (Lewis and Scambary, 2016), or soil and water contamination (Monteiro et al., 2019). Australia—where mining accounts for 7.4% of GDP and the largest share of gross value added (10.2%) (ABS, 2019)—is among the world's top five producers of gold, iron ore, lead, zinc, mineral sands, coal, and nickel (Britt et al., 2017). Although the mining footprint only covers 0.02% of Australia's land (ABARES, 2019), its environmental and social impacts are increasingly perceived as critical by practitioners, regulators, academics and general public. This is due to the high prevalence of negative legacies such as the 50,000+ abandoned or orphaned mine features across Australia (Unger et al., 2015) and marginalization of Aboriginal perspectives on whose lands mines often operate (Bond and Kelly, 2020; Lewis and Scambary, 2016; Solomon et al., 2008). Mines that are not successfully closed and rehabilitated often enter so-called 'care-and-maintenance' mode (Ashby et al., 2016; Pepper, 2020) or become abandoned, both of which may entail serious risks to humans and the environment, as well as negative economic and reputational impacts for operators and regulators (Unger, 2017; Unger et al., 2020).

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While regulations vary across international jurisdictions (Cowan et al., 2010; DMP & EPA, 2015; Government of Chile, 2012; Heikkinen et al., 2008; Kabir et al., 2015; Sánchez et al., 2014; South African Government, 2015; Young et al., 2019), a common overarching objective of mine rehabilitation is to return the site to a state that is safe, stable, non-polluting, with a self-sustaining ecosystem, and capable of supporting an 'agreed' post-mining land use (DMP & EPA, 2015; Watson and Olalde, 2019). Measuring progress towards this objective requires the definition of mine completion (or closure) criteria, i.e. quantifiable targets that show whether a site is on the trajectory to eventually reach its agreed closure state (LPSDP, 2016b). Typically, mining companies must demonstrate that such completion criteria are met before land tenure and financial liabilities can be relinquished (Tiemann et al., 2019), and the site can progress towards its intended post-mining land use (Gardner and Bell, 2007).

A large body of research is dedicated to advancing the scientificunderstanding of ecological restoration, as one of the critical components to meeting completion criteria (e.g. Brearley, 2003; Burke, 2018; Gardner and Bell, 2007; Grant, 2003, 2006; Miller et al., 2016; Muñoz-Rojas et al., 2016; Neldner and Ngugi, 2014). Further research has been dedicated at investigating technical, geochemical, and geomorphic factors, such as landforms stability (Emmerton et al., 2018) and acid mine drainage (Jouini et al., 2020). In addition to ecological and environmental research, rehabilitation guidance is available from numerous national and international frameworks (ANZMEC & MCA, 2000; APEC, 2018; ICMM, 2019; LPSDP, 2016a, 2016b; Standards Reference Group SERA, 2017). Despite this ongoing research and available guidance, mine closure and rehabilitation remain a critical challenge around the world (Holmes et al., 2015; Manero et al., 2021). This is evidenced by the fact that, in major mining jurisdictions like Australia, Brazil, Canada, and South Africa, mines may close prematurely (without being rehabilitated; Laurence, 2011) and very few mine sites have been succssfully relinquished to the competent authority or post-mining land user (Blommerde et al., 2015; de Jesus and Sánchez, 2013; Holmes et al., 2015).

The widespread lack of success could, at least partially, be attributed to the definition of unrealistic targets (completion criteria), which often aim to return mine sites to pre-disturbance conditions (Blanchette et al., 2016; Manero et al., 2020). Such 'full' ecosystem restoration in heavily disturbed landscapes is extremely difficult, if not impossible (Gardner and Bell, 2007; Gillespie et al., 2015). In this paper, we argue that successful mine closure and rehabilitation requires not only biophysical research on how to achieve completion criteria, but the *definition* of feasible and specific completion criteria that are agreed between proponents and regulators. Few studies have looked at how mine completion criteria are defined by industry, and—in particular—what regulatory or organizational challenges exist. Blommerde et al. (2015) highlighted that current guidance for mine closure and rehabilitation in Australia is inadequate, and that unclear guidance and regulatory requirements pose a challenge to developing suitable completion criteria and performance indicators. Unger et al. (2020: 104) also pointed at "*ineffective regulations*" as a cause for limited mine closure success in Australia. The authors noted that leading practice in mine rehabilitation are not yet widely adopted and that regulatory guidance is lacking. Studies in Canada and Australia have pointed at inadequate management and inconsistent regulations across jurisdictions resulting in unclear expectations, and therefore a widening gap between potential rehabilitation outcomes and what is being achieved in practice (Holmes et al., 2015; Lamb et al., 2015; Unger et al., 2020). A South African case study highlighted a lack of trust among stakeholders, and government incapacity to enact new legislation, as two of the main reasons for failing to meet post-closure outcomes (Marais, 2013). In fact, a comprehensive review of South Africa's legal framework for mine closure and rehabilitation concluded that, despite recent reforms, the vast amount of guidance provided by the multiple ministries and agencies resulted in legislation being excessively complex and even hard to understand (Alberts et al., 2017).

Recognizing the current knowledge gap around organizational and regulatory barriers in the definition of completion criteria, this study investigates how completion criteria are currently developed in Western Australia (WA) and what challenges are encountered by industry practitioners and regulators in the process of defining clear, achievable, and agreed completion criteria. A focus on WA is warranted given the significant contribution of the resources sector to Australia's economy. WA's mining sector is home to almost half of Australia's 421 operating mines, and contributes to over half of the national mining gross value added (ABS, 2019; DJTSI, 2020; Geoscience Australia, 2015). In 2018–19, WA's mining accounted for 112,000 jobs and 103.1 billion AUD, equivalent to 36% of the gross state product (DJTSI, 2020). In this study, we engaged industry and government stakeholders to highlight differences in the challenges faced by regulators and industry practitioners, whilst drawing attention to their points of commonality. Our results suggest that, unless institutional and organizational barriers are addressed, scientific and technological advances alone will not be able to ensure successful definition and fulfilment of mine completion criteria.

2. Methods

We used a mixed-methods approach in a two-phase exploratory research design (Creswell and Poth, 2017) that consisted of (1) semi-structured qualitative interviews, which informed the development of (2) an online survey.

Data was collected between January 2018 and October 2018 (see also Kragt and Manero, 2021). The target sample consisted of WA mining industry professionals who are directly involved in the writing or assessing mine completion criteria—or related planning and closure processes. Three groups of stakeholders were targeted: i) environmental managers or compliance officers within mining companies, ii) consultants engaged with developing mine closure plans and completion criteria; and iii) State Government regulators with experience in assessing mine closure plans or mine completion processes. Our work does not engage with community stakeholders, local and Federal government, or researchers who potentially provide input into mine closure planning as well (Unger et al., 2020). We recognize the importance of social closure objectives and the critical role played by community stakeholders, as thoroughly examined in the existing literature (Botham et al., 2011; Collard et al., 2020; Edwards and Maritz, 2019; Everingham et al., 2018; Solomon et al., 2008). However, in this study, we focus on an industry perspective and government stakeholders who are directly responsible for approving completion criteria. In the following sections, we describe the interview and survey method.

2.1. Stakeholder interviews

Semi-structured, in-depth interviews were conducted to gain an understanding of why, from the perspectives of industry and regulatory stakeholders, mine completion criteria are often not met and very few mines in Western Australia have been successfully closed and rehabilitated. The open-ended nature of the questions enabled participants to provide narrative, descriptive answer. This more qualitative line of investigation allows interviewees to provide new insights that may not have been previously mapped (Ayres, 2008).

In particular, we aimed to identify any strengths, weaknesses, opportunities, and threats associated with the development of completion criteria and mine closure planning processes in WA. Qualitative answers were systematically analyzed employing the SWOT method (Houben et al., 1999), which serves to assess positive and negative impact factors in an organization's internal (Strengths and Weaknesses) and external (Opportunities and Threats) environments. The qualitative responses were synthesized into common ideas through a thematic analysis (Thornberg and Charmaz, 2014). Following recommendations in the literature (Creswell and Poth, 2017; Lichtman, 2012), the synthesis

aimed to identify between five and seven main themes.

Potential interviewees were identified through purposive sampling (Rapley, 2014), targeting managers in the rehabilitation and closure teams of mining companies, closure specialists at consulting businesses, and environmental officers or managers at State Government agencies involved in mine closure planning and approval (henceforth 'regulators'). Potential participants were invited via email and, if agreeing to an interview, a suitable date and time was identified. Prior to each interview, written consent was provided, in compliance with the University of Western Australia ethics protocol RA/4/20/4241. To reduce any potential interviewer bias that may arise in in-person qualitative data gathering (Lavrakas, 2008), interviews were conducted by experienced researchers who were not previously known to participants.

A total of 17 interviews were conducted with a total of 27 participants[1]: eight interviews with mining companies (IDs MC1–MC8; 14 participants), five consulting firms (IDs C1–C5; 7 participants), and four State Government departments (IDs R1–R4; 6 participants) (Supplementary Materials A). All interviews were recorded and transcribed by the researchers after completion. Each of the semi-structured interviews followed a general interview guide (Ayres, 2008) that consisted of four parts (Supplementary Materials B):

1. Decisions about post-mining land use;
2. Definition of completion criteria (including attributes and references used);
3. Risk assessment and monitoring practices;
4. Comments on the process of mine closure planning in Western Australia (including coordination with regulators and resource availability).

2.2. Industry survey

The interview results provided input for development of an online survey[2] that targeted mining companies, consultants, and regulators. The survey aimed to quantify the issues revealed during the interviews. Respondents were sampled through non-probability techniques, including convenience sampling, expert sampling, and chain-referrals (Daniel, 2012). Potential participants were identified through professional networks of the project staff, word-of-mouth, and from publicly available information such as company websites (e.g. authors of company mine closure plans), government websites (e.g. Department of Mines[3]), and published literature (e.g. Mine Closure Conference proceedings). Potential respondents were invited via email to an anonymous survey link. The initial survey invitation was sent to 100 valid email addresses.[4] Respondents were asked to distribute the link to other members of their team(s) involved in mine closure or in developing mine completion criteria. The industry survey was completed by 75 respondents: 41 mining companies' employees (IDs MC9-MC49), 18 consultants (IDs C6–C23), and 16 government employees (IDs R7-R22). Because the software system does not keep count of forwarded surveys (only those completed), we cannot identify the precise survey response or refusal rate.

Because some questions were phrased differently for different stakeholders, and depending on a respondent's answers to previous questions, the number of questions shown to respondents varied (see Kragt and Manero, 2021). The survey was administered and coded in Qualtrics online survey software (Qualtrics, 2005) and included questions about the respondent's organization, development of completion criteria and associated challenges, monitoring and evaluating progress towards closure, coordination within the organization and engagement with other organizations, and resources needed to define completion criteria. The survey data was analyzed using a mixed methods approach (Tashakkori and Teddlie, 2003): quantitative thematic assessment of the open-ended text responses and qualitative statistical analysis of multiple choice, ranking, and Likert-scale questions.

3. Results

In this section, we first describe the results of the interviews, followed by an analysis of the survey data.

3.1. Interview results

A thematic analysis of the 17 interviews yielded six key themes: post-mining land use, coordination, completion criteria, monitoring, capacity, and processes (Table 1). For each of the 17 organizations interviewed, key strengths, weaknesses, opportunities, and threats (SWOT) were identified (Table 1 and Supplementary Materials C). Negative aspects hindering the definition of mine completion criteria were often pinpointed as being the result of other organizations' practices (*threats*, n = 87), whilst admission of internal limitations was much less frequent (*weaknesses*, n = 35). Similarly, participants tended to praise their own efforts for positive outcomes (*strengths*, n = 24), but recognized less beneficial contributions from others (*opportunities*, n = 15). This finding reflect a well-known phenomenon observed in applied psychology and business studies, referred to as 'actor-observer' asymmetry (Gioia and Sims Jr., 1985; Malle et al., 2007). This explains how, when people are questioned about their own behavior, they tend to attribute negative outcomes to external causes, while internalizing positive influences (Malle et al., 2007). Yet, the opposite is true when judging another person's behaviors, i.e. others are to blame for their own failures.

For example, when discussing post-mining land uses (PMLUs), one employee of a mining company explained that: "*We have internal guidelines and examples to inform the establishment multiple end-land uses*", whilst also adding that "*Regulators (…) are not willing to accept alternative land-uses, as they typically push their preferred option: ecological restoration*" (ID MC1). This contrasts with a government employee who argued that "*Mining companies don't want to commit to PMLU, but rather keep their options open*" and *"There is a risk that third parties won't want to take on alternative land uses after relinquishment"* (ID R1). Further, internal knowledge was often highly regarded by mining companies' employees and consultants, e.g. "*We have enough internal resources, as well as an education program about the importance of rehabilitation*" (ID MC2), and *"We have a system that identifies knowledge gaps and whether such gaps will lead to completion criteria not being met"* (ID C5), contrasting with regulators who argued that "*Companies proposing to do the 'best that can be achieved' is tricky as some companies do not really try as hard as they could"* (ID R1) and *"Mining companies have no driver to work towards what will be left after closure"* (ID R4).

Mining employees tended to dismiss government guidelines as "*changing over time*" (ID MC3 and MC7), which hindered their ability to develop adequate completion criteria. On the other hand, regulators noted that, despite guidelines being regularly updated to reflect the best available practices, companies responsible for closure did not follow them as they lack financial incentives to pursue high rehabilitation outcomes (ID R1). The lack of adequate incentives was also mentioned by consultants (IDs C3, C11 and C12) and even some mining companies' employees, e.g. *"Mining companies have very little incentive to relinquish, as they don't make any money once operations have ceased" (ID MC8)* and *"Small companies plan to divest, so there's no incentive to carry out proper, cost-effective closure planning" (ID MC6)*.

The most commonly mentioned challenge was the perceived disconnect, and even disagreement, among different government departments (IDs MC1–2, MC4–8; C1; R1–3). This is clearly illustrated by the experience shared by one mining company employee:

[1] Some interviews involved multiple participants from the same organization, hence the number of interviews < the number of participants.

[2] The full questionnaire is available at DOI: 10.26182/x2fw-s027.

[3] https://minedex.dmirs.wa.gov.au/Web/home.

[4] Email addresses that did not 'bounce'.

Table 1
SWOT thematic analysis of qualitative data from 17 semi-structured interviews.

Themes	+ Strengths or Opportunities; - Weaknesses or Threats	Times mentioned
Coordination	- Disconnection and disagreements among various government departments	11
	- Disconnection between teams within mining companies	7
	- Inconsistent guidance given by regulators over time and staff	6
	- Limited knowledge sharing among mining companies	2
	+ Knowledge sharing among mining companies	2
Capacity and Processes	+ Good internal knowledge and practices	10
	- Competency gap within the government to assess the many aspects of closure (engineering, safety, pollution, biodiversity, community, long-term planning etc.)	8
	- Lack of incentives for companies to invest in closure planning and achieve high rehabilitation outcomes	8
	- Residual risk (liability) linked to alternative land uses as a main impediment to relinquishment/alternative land uses	8
	- Perceived differences in regulation of older (previously mined) vs new sites; shallow vs hard-rock mining; big vs small companies; sites under *Mining Act* vs under State/Ministerial Agreements	5
	+ The regulator's level of knowledge and guidance provided are adequate	2
Completion criteria	- Too narrow focus on numerical targets and ecological aspects, with little consideration for overall rehabilitation success or safe, stable, non-polluting aspects	8
	- Rehabilitating to 'what was there before' is ecologically impossible and financially infeasible	4
	- Lack of guidance to define SMART[a] criteria and criteria for 'self-sustaining ecosystem'	4
	- Benchmarking against analogue sites is unrealistic, particularly for hard-rock mining	4
	- No policy on rehabilitation	4
	- Narrow focus on ecological targets	3
	- Risk should be incorporated in development of completion criteria (and monitoring)	3
Post-mining land use (PMLU)	- Contradiction of preferred PMLU between regulators and stakeholders	6
	+ Regulators are becoming more open to new ideas, e.g. alternative PMLU	5
	- Limited consideration of PMLU, other than reverting to pre-mining land use	4
	- High risk and liabilities associated with 'alternative' PMLU	4
	- Lack of consultation with land planning	2
	- Lack of guidelines on how to select PMLU	1
Monitoring	- Lack in monitoring guidelines (particularly on new technologies) and limited monitoring consistency	5
	- Monitoring is currently not time-bund but it should be	3
	- Monitoring is often untargeted and not matched against completion criteria	2
	+ Advances in technology help monitoring	2

[a] Specific, Measurable, Achievable, Relevant and Time-bound.

> "Sometimes there are contradicting demands from different departments. Once, this resulted in a Mexican standoff between Local Government Authorities, Dept. of Planning,[5] and Dept. of Biodiversity.[6] There are too many agencies we have to interact with, they all have their own ideas and agenda." (ID MC1)

Another coordination issue noted in seven interviews (IDs MC4, MC7–8; C1, C3; R3) was the inconsistency between teams within mining companies. For example, the immediate goal of the approvals teams is to obtain legal authorization to start mining operations, which requires the formulation of a mine closure plan to reach high-quality rehabilitation standards. While this occurs at early stages of the life-of-mine, a serious problem rises decades later, at the end-of-mine phase. Typically, closure/rehabilitation teams find themselves with unrealistic targets promised by approvals teams, while faced with a different set of circumstances that may render those previously agreed targets unattainable. As explained by one consultant:

> "Integrated management of mine closure is not done well: closure planning is focused on obtaining approvals, while relinquishment requires agreement from multiple stakeholders. (…) Focusing on pre-mining environmental conditions makes it easy for companies to obtain approvals. However, conditions in the approval documents do not often take into account post-mining conditions, leading to unrealistic goals." (ID C1)

Although participants' narratives were dominated by shortcomings of 'external' agents, a few organizations also admitted their own weaknesses which, in some cases, coincided with threats identified by others. For instance, senior managers within regulatory agencies echoed practitioners' concerns by acknowledging that lack of government staff was a major problem, resulting in delays in the approvals process:

> "Even though we are on the working group looking at closure guidelines, there is no responsible person [in our department]. At the government level, there are not enough resources to manage the [mine closure] process" (IDR2)

> "Government departments provide contradictory guidance to industry by swinging from too detailed advice to too vague, and also, guidelines that are not well matched across departments. (…) We lack resources and thus, we don't collaborate much with other government departments, as we are already too busy with day-to-day tasks." (ID R3)

Positive attention was drawn to regulators' recent and gradual shift in mindset, chiefly regarding the acceptance of alternative post-mining land uses and references (IDs MC1, MC3; C3; R1–2). For example, *"Aiming for previous land use does not limit any future changes to other potential land uses"* (ID MC3). While return to pre-mining conditions remains the default rehabilitation objective, regulators are becoming more open to considering alternatives, and there appears to be some recognition that returning the land to pre-mining use is unrealistic.

3.2. Survey results

Survey respondents were asked about the ways in which they defined completion criteria within their organization, and any barriers or challenges they encountered when defining completion criteria. Because mine closure professionals typically work across multiple sites, survey respondents were asked to think about a specific mine site that would be representative of their broader experience when answering the questions about post-mining land uses and example completion criteria. Questions about coordination within the organization, stakeholder

[5] Department of Planning, Lands and Heritage (DPLH).
[6] Department of Biodiversity, Conservation and Attraction (DBCA).

Table 2
Pre- and post-mining land use at sites selected by survey respondents.[a].

	Pre-mining land use (# of sites)	Post-mining land use (# of sites)	Pre-mining LU same as Post-mining LU (# of sites)
Pastoral	25	25	24
Natural ecosystem	17	19	14
Forestry	6	4	4
Agriculture	5	6	5
Recreation	1	6	1
Other (e.g. industrial or commercial, residential, or energy generation)	3	12	–
Total	57	72	48

[a] The number of pre- and post-mining land uses is larger than the 39 total received responses because all but three sites had multiple pre-mining land uses and/or multiple post-mining land uses.

Table 3
Survey responses to "What information source(s) do you use to guide the development of completion criteria?" (Respondents could tick multiple answers).

Type of source	Information source	% of received responses	
		Mining companies	Consultants
Companies' internal sources	Our rehabilitation team's knowledge base	16%	14%
	Our previous closure plans	15%	12%
	Our approvals team's knowledge base	7%	9%
	Internal guidelines to the company	11%	5%
	Closure plan examples from other companies	9%	5%
State guidelines	Guidelines for Preparing Mine Closure Plans (DMP & EPA, 2015)	19%	16%
	EPA Environmental Factor Guidelines (EPA, 2016)	4%	8%
	EPA Guidance *Rehabilitation of Terrestrial Ecosystems* (EPA, 2006)	4%	7%
National guidelines	Mine Closure Leading Practice Handbook (LPSDP, 2016a)	5%	8%
	Mine Rehabilitation Leading Practice Handbook (LPSDP, 2016b)	4%	7%
	National Standards for Ecological Restoration (Standards Reference Group SERA, 2017)	1%	5%
Other	Other sources	4%	3%
	Don't know	1%	0%

engagement, and challenges were set in a general mine rehabilitation context. Detailed survey descriptive statistics can be found in the accompanying Data in Brief article (Kragt and Manero, 2021).

3.3. Post-mining land use

An overarching objective of rehabilitation is to return the site to agreed post-mining land use(s). This puts the selection of the post-mining land use front and center to the development of mine completion criteria and closure planning. We asked mining company employees about the pre- and post-mining land uses at their representative mine site (see above). Pastoral land uses and natural ecosystems were the predominant pre- and post-mining land uses in our sample (Table 2). In the vast majority of responses (36 out of 39 received responses), the site would revert back to its pre-mine land use(s) upon closure (in 11 cases with an additional land use, such as recreation, energy generation, or commercial land use).

Of the 67 responses from mining company employees, 25 (37%) said that post-mining land use decisions are typically based on 'what was there before'. In Western Australia, land use is largely determined by the tenement holder. Most pre-mining tenement holders were pastoral leases (36%) or Unallocated Crown Lands (26%—Data in Brief), which partly explains the predominance of, respectively, grazing and natural ecosystems as post-mining land uses.

3.4. Developing completion criteria

Respondents were asked about the process used to develop completion criteria in Section 3 of the survey (Data in Brief). All but four of the surveyed mining companies' employees and consultants indicated they engaged with the main regulators involved in the development of mine closure plans, including the Dept. of Mines; the Dept. of Biodiversity, Conservation and Attractions; and the Dept. of Environment and its incorporated Environmental Protection Agency (EPA). By contrast, only 14 respondents (23%) indicated they engaged with the Pastoral Lands Board and the Dept. of Planning, Lands and Heritage. This is surprising given that this Department is the ultimate custodian of all pastoral and Unallocated Crown Lands, and that pastoral use is the most prevalent pre- and post-mining land use (Table 2). Mining companies and consultants were asked whether they have one or multiple points of contact with the regulator. The vast majority (72% of mining industry and 100% of consultants) stated that they liaise with different individuals within one agency. This means that advice provided by a regulator could vary depending on the contact person involved, which reflects interviews' observations on reported inconsistences in government advice (Table 1).

We were interested in knowing what guidance documents are used to aid the development of mine completion criteria. Mining companies and consultants primarily used sources of information internal to the company, e.g. their own knowledge (58% and 45% of received responses; Table 3). The second most commonly used type of information is State guidelines, with the official Guidelines for Preparing Mine Closure Plans (DMP & EPA, 2015) only being mentioned by 19% of mining employees and 16% of consultants. Such a low uptake was unexpected since these guidelines lay out the standards that Mine Closure Plans need to meet to satisfy WA regulatory requirements. Additional guiding documents at the national level from government bodies (LPSDP, 2016a; 2016b) and independent expert organizations (Standards Reference Group SERA, 2017) were mentioned only by a few practitioners.

Because successful mine rehabilitation and closure relies on the definition of realistic targets (completion criteria), we asked whether developed mine rehabilitation completion criteria currently meet the SMART[7] principle. Most industry respondents said that they aim to base completion criteria on measurable targets and a specific reference. For

[7] Specific, Measurable, Achievable, Relevant and Time-bound.

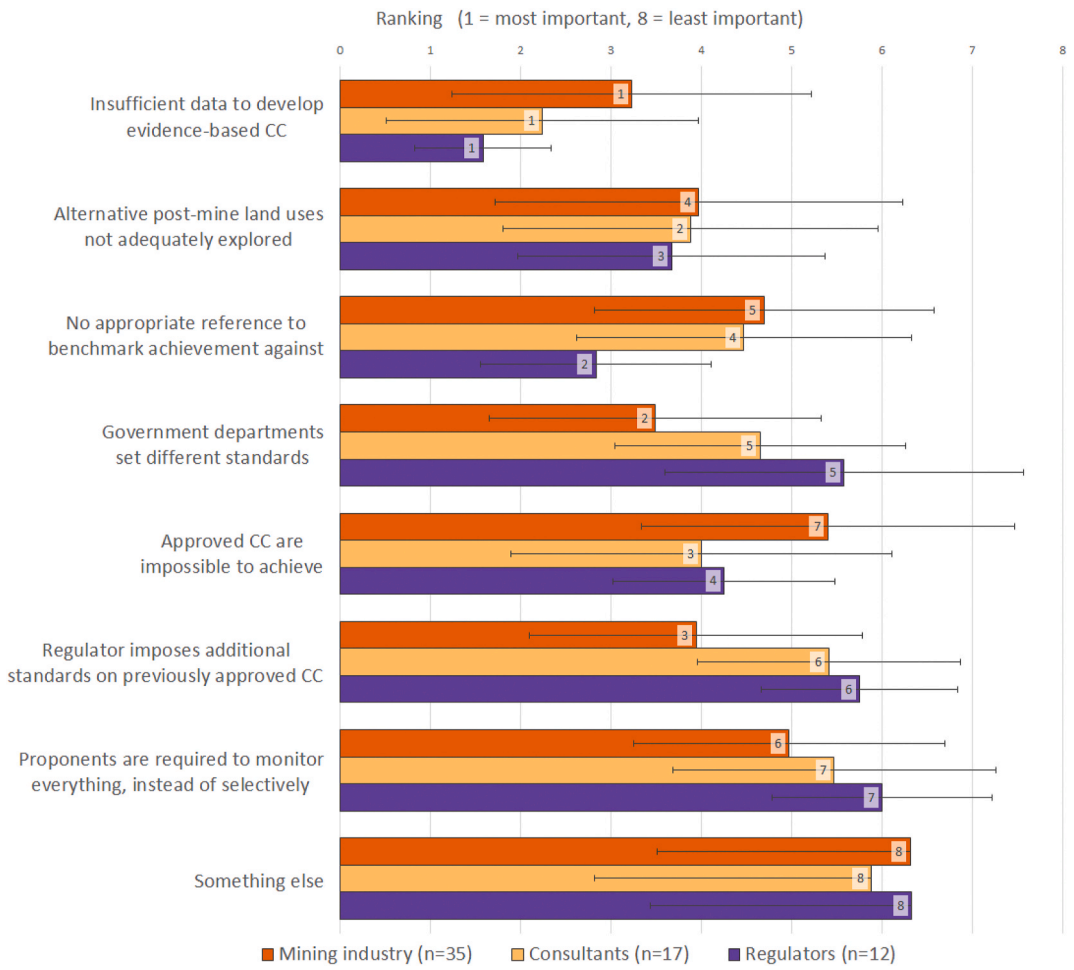

Fig. 1. Challenges when developing completion criteria (CC; Mean estimate for each stakeholder group; Ranked from 1 = most important, 8 = least important; Error bars show standard deviations).

example, one respondent from a large consulting firm illustrated that they developed completion criteria around a "*monitoring program to ensure all aspects can be measured and have a defined end point*" (ID C10), while another respondent aimed to base completion criteria "*around factors that can be measured*" (ID MC38). However, when asked to provide examples of indicators used to define completion criteria (see Supplementary Materials D), many indicators were expressed in a more qualitative manner (e.g. "*vegetation is sustainable*"—ID MC30), which is typically difficult to measure. Indeed, more than half of regulators (8 of 14 responses) said that most plans do not contain measurable indicators. One regulator commented that "*The most important is a lack of understanding of an appropriate approach to working out what are the SMART criteria for all the relevant aspects for their site*" (ID R7). Government respondents stressed that the level of detail in completion criteria and target indicators varies greatly between sites and companies (10 of 15 responses). This sentiment is well captured by the following answer: "*The big corporates generally have well documented plans which are frequently reviewed and updated. (..) Small companies generally have no idea! Mid-tier companies are very much at the bequest of their consultants and often have products that are not fit for purpose*" (ID R13).

3.5. Challenges around defining or assessing completion criteria

All respondents were asked what major challenges they encountered when defining or assessing completion criteria. Respondents were shown eight potential challenges (sourced from the interviews), which they ranked from most important (1) to least important (8).

The challenge ranked most highly by all stakeholder groups was a lack in data to develop evidence-based completion criteria (Fig. 1). This is consistent with other comments in the survey, where respondents noted that there is still insufficient knowledge about rehabilitation and ecological restoration in Western Australia such as "*We are lacking in site specific data for complex rehabilitation activities*" (ID MC11), "*I'd argue that all companies do not have sufficient data*" (MC9), "*Lack of baseline scientific data*" (R18), and "*[Insufficient] Science-based understanding of long-term impacts on disturbed ecosystems*" (ID C20).

The second highest ranked challenge overall (averaged for all stakeholders) was that 'Alternative post-mine land uses are not adequately explored'. This sentiment was expressed during the interviews and came back in many of the open survey questions. In many cases, there may be an expectation that the previous land use will be reinstated at a site, which may be impossible given the vast impacts of mining projects on the land. There was no clear evidence as to who drives this expectation to return to the previous land use. One regulator acknowledged that "*Returning a mine impacted area to pastoral land end use is not achievable and not economic. Alternative end land uses need to be considered*" (ID R16). However, mining companies felt that regulators don't allow alternative post-mine land uses for fear of lowering environmental standards: "*[There is a] lack of ability for the regulator to think outside the box as to what the best end use for that particular parcel of land is post operations"* (ID MC23).

'We have no appropriate reference to benchmark achievement against' was the second highest ranked barrier amongst regulators, while 'Government departments all set different standards' and 'The

regulator imposes additional standards on previously approved criteria' were ranked a second and third most important barrier by mining companies (Fig. 1). Indeed, survey respondents commented that the "*Acceptable completion criteria vary between assessing regulatory officers*" (ID C8), and that "*Regulators have changed the goal posts on completion criteria that have been agreed in the past*" (ID MC38).

In both the interviews and in survey responses, stakeholders raised the issue that 'Approved completion criteria are impossible to achieve' (Fig. 1). Some respondents blame this on "*Unrealistic expectations from regulators*" (ID MC14), but achievability also ranked highly for consultants and regulators (third and fourth respectively—Fig. 1). In an open question, eight industry and consulting respondents emphasized the difficulty in defining 'achievable' criteria, because of knowledge gaps around what levels of ecological restoration are feasibly achievable in Western Australia (echoing the 'insufficient data' sentiment). One mineral sands miner stated that "*Current criteria were written during approval phase [of our project], and are, in their current form, unachievable*" (ID MC22). This comment points not only at the issue of achievability of existing completion criteria, but also at inadequate coordination between team objectives within a company. Out of 15 regulator respondents, 14 agreed that, in general, completion criteria defined in mine closure plans are not achievable. This was mostly because closure plans are still under development, but also because rehabilitation targets objectives are generally not defined specifically enough to provide auditable detail. Consistent with the interview results, and echoing answers from mining companies, one regulator commented that:

> "Completion criteria are usually written to make sure they can be complied with but are too ambiguous for accountability. They are designed to get approval for the development of the closure plan from regulators rather than to satisfy the land manager." (ID R14)

Many answers to open-ended questions mentioned a lack in regulatory guidance as a major impediment to rehabilitation and closure. All stakeholder groups commented on the need for regulatory alignment around mine closure and relinquishment. For example, "*Government have no functioning lease relinquishment process - mining proponents therefore have no real incentive to effectively track closure performance*" (ID C21) and "*[We are lacking] A clearly defined and tested process for achieving sign-off/endorsement of mine closure*" (ID MC12). One of the government employees also mentioned "*Gaps in regulation around mine closure plans*" (ID R8).

As the final issue, we mention the risk of deferring rehabilitation and closure planning when a company divests its assets, i.e. selling or transferring mine ownership and liabilities to another (typically smaller) company. This leads to the perception by some stakeholders that companies agree to completion criteria that "*They have no intention of achieving, as divestment of the project at the end of the life of the resource is usually a more common option taken than fully rehabilitating and closing a mine*" (ID R7). When companies change ownership, there may be "*Poor record keeping, so loss of historic information*" (ID C10) to continue rehabilitation. This is consistent with Unger's (2017) international observations in the context of abandoned mines: "*When smaller, less well-resourced companies with limited capacity to deal with the scale of closure risks take over the site, the mining operation rapidly can transition to insolvency*". In WA, companies will need to build assurances around the issue of liability transfer (and thus improve their social license to operate), and regulatory innovations are needed to reduce this risk (White et al., 2012).

4. Discussion

The development of measurable, achievable, and acceptable completion criteria plays a key role in guiding mine rehabilitation and closure. Despite their importance, limited research has gone into how mining companies come up with completion criteria, and what challenges are encountered in the process. This research aimed to fill this knowledge gap by assessing the multiple perspectives of industry stakeholders (mining companies, consultants, and regulators) on the development of mine closure completion criteria. We conducted semi-structured, qualitative interviews with 26 participants followed by a survey of 75 respondents, both of which involved mining industry employees, consultants involved with developing mine closure plans or completion criteria, and government regulators who assess or provide input into mine closure plans and completion criteria. The wider industry survey corroborated results obtained from the in-depth interviews.

We identified several organizational and regulatory roadblocks hindering successful definition of accepted completion criteria in WA. The first major roadblock to achieve rehabilitation standards is a (perceived) lack in capacity—in particular data and knowledge about what successful ecological restoration looks like (Fig. 1). As one mining company employee stated: "*[There is a] lack of advanced rehabilitation in the region from which learnings can be taken*" (ID MC30). Despite ongoing research, there thus appears to be insufficient knowledge about how restoration of Western Australia's unique ecosystems can be achieved, which also hinders the definition of SMART completion criteria. Improving our science-based knowledge about rehabilitation can aid the design of more specific and realistic completion criteria, which addresses expressed concerns that current standards are not achievable based on the current state of knowledge. To improve the dissemination of the knowledge that is being collected, and our understanding of successful rehabilitation, it will be important that baseline field trials and monitoring data are shared across the industry: "*[We need] Sharing of detailed rehabilitation data, seed mixes, treatments, outcomes. Regulators should facilitate public availability and collaboration to share knowledge*" (ID C7). This is currently difficult because disclosure of data and innovative corporate practices is often discouraged or banned by companies themselves, meaning that much of the knowledge is locked in inaccessible corporate or compliance reports (Hernandez-Santin et al., 2020).

Associated with a lack in data, is a lack in human and financial capacity for regulators to successfully assess and administer mine closure and rehabilitation plans in WA. Regulators as well as industry participants in our study agreed they do not have access to adequate resources (knowledgeable staff and time), leading to inconsistent advice provided to industry over time, and a limited capacity to accurately examine closure planning details at the level of each individual mine site ("*DMIRS, DWER and DBCA are all understaffed and time poor*"—ID MC36). Pointedly, regulators also mentioned that highly trained departmental staff may move to work for mining companies after some time, enticed by higher salaries, which State Government agencies cannot offer. Thus, in the absence of data, and with limited human and financial resources available, regulators may not know what is achievable and therefore set high closure standards as an assurance mechanism. However, such high standards can be difficult to achieve with the current levels of knowledge and experience, which may hinder rehabilitation progress altogether.

A second barrier to mine closure planning is inadequate coordination within organizations and between stakeholder groups. Within mining companies, there appears to be a perceived mismatch between high levels of rehabilitation committed to by project-proposal teams (who seek fast regulatory approvals), and what is considered achievable and feasible by rehabilitation teams at later stages of the life-of-mine. There is also a perceived lack in coordination between different government departments. For example, research participants stated inconsistencies in (regulatory) requirements by the Dept. of Mines—who approves project applications, and the Dept. of Planning—who (in the case of public lands) take over land tenure upon mine relinquishment. It is essential that the regulator who signs off on the ultimate liability for mines being relinquished to government (the 'custodial authority') is involved in the mine closure planning process. Work in other countries also found that corporate and regulatory barriers can impede effective

mine rehabilitation and closure (Unger, 2017). There is, therefore, a need for more consistent coordination across government departments on what defines 'acceptable' completion criteria.

A third main barrier that we discuss here is the perpetuation of an (ineffective) *status quo*. There is an (almost) unquestioned return to 'what was there before' as the preferred post-mining land use, and the use of (unrealistic) pre-disturbance conditions as the default reference for setting completion criteria. Critically, reverting back to pre-disturbance conditions is not always feasible in highly modified mining landscapes, which often renders baseline and analogue conditions impossible to reinstate (Gillespie et al., 2015; Hernandez-Santin et al., 2020). A challenge to exploring alternative post-mining land uses and indeed alternative rehabilitation practices could arise from companies' strong reliance on their internal knowledge as the main information sources for the development of completion criteria (Table 3). Favoring pre-existing, familiar knowledge rather than novel information can severely impact companies' performance and capacity to innovate (Park et al., 2010). While we acknowledge that environmental, social, and economic constrains vary greatly across geographies, the industry could draw from international examples of 'alternative' post-mining land uses and practices, such as recreation, energy generation, industry, or public infrastructure (Kivinen, 2017). Encouragingly, our results show a cautious willingness amongst all stakeholder groups to consider 'alternative' post-mining land uses, as long as risks and liabilities are thoroughly mitigated.

The fourth and final barrier we discuss is the absence of regulatory guidelines for long-term land management and liability transfer of closed mines after rehabilitation. At the time of our research, there appeared to be a lack of clear policy and legislative guidance for mine relinquishment in Australia (Tiemann et al., 2019), which was aptly identified as the "B*iggest gap preventing effective relinquishment and development and achievement of closure criteria"* (ID C21).

The research described in this paper focusses on an industry perspective. We aimed to understand how completion criteria/closure standards are currently developed, and what additional advice would be helpful to improve practices. To this effect, we engaged with mining company employees, consultants, and State Government agencies who write or approve mine rehabilitation completion criteria in WA. It is important to acknowledge that we did not consult with community stakeholders, local governments, or indigenous peoples about their experiences with mine rehabilitation processes. The results from this study should thus be interpreted as an industry perspective rather than a wider stakeholder consultation process. Furthermore, because participation in the research was entirely voluntary, we cannot entirely discard the risk of self-selection bias (Lavrakas, 2008). It is possible that those who perceive no issues with mine rehabilitation in WA saw no point in participating in a study that aimed to improve the process, while at the same time, those who are seriously discontent with the current situation may also refuse to participate. Nevertheless, with over 100 participants and the wide range of perspectives provided, we are confident that this research captures the most important challenges around the development of completion criteria currently faced by industry.

5. Conclusion

Through qualitative interviews and a survey with mining companies, consultants, and regulators, we identified strengths, weakness, opportunities and threats (SWOTs) to successful development of mine completion criteria. Our analysis highlights commonalities across multiple viewpoints, as well as key issues and pathways for improvements. These include the need for greater knowledge sharing of rehabilitation data and practices; improved internal communication and coordination between government and corporate departments; increased consideration of 'alternative' post-mining land uses; and investments in increasing regulators' capacity to guide the development of mine closure planning. Our findings were shared with project participants during consultation workshops. This helped, regulators and employees of mining companies to develop a renewed sense of mutual understanding over challenges affecting them all.

Our results will be relevant to mining jurisdictions worldwide, given common challenges across many jurisdictions (Holmes et al., 2015). Thus, we strongly support the development of similar studies to ours, as a means of comparison and cross-learning. We hope that ongoing collaborative and transdisciplinary work on mine rehabilitation and closure planning will improve knowledge and communication among industry stakeholders and regulators, whose actions and behaviors are at the core of the critical rehabilitation and closure challenges the industry faces.

Author contribution

Marit Kragt: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft, Supervision, Project administration. Ana Manero: Methodology, Formal analysis, Investigation, Data curation, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.112258.

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