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Applying ecosystem services assessment in closure planning to enhance post-mining land-use outcomes: learning from bauxite mining in Brazil and Australia

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Abstract

Ecosystem services assessments help us understand the benefits that society obtains from ecosystems, and they are increasingly being used to understand the human–nature relationship in many applications. This paper presents the results of two ecosystem services assessments applied as part of mine closure planning and rehabilitation activities for two bauxite mining operations operated by the same company, one located in Brazil, the other in Australia. The focus was on the value of the post-mining land use that was being realised for local community users. For the Juruti mine site, located in Amazon rainforest, the research examined the return of culturally and economically important forest products—such as Brazil nuts, natural fruits and timber—to local communities living in the vicinity of the mining operations. For the Australian operation, located in the jarrah forest of Western Australia, the research focused on recreationists' perceptions of the value of rehabilitated bauxite mine areas for bushwalking and mountain biking. Interviews were the principal method employed to understand community stakeholder interactions with pre-mining and post-rehabilitation areas. Workshops were conducted with regulators responsible for mine closure planning and rehabilitation activity. In the Brazil case, taking an ecosystem services approach to explain and explore the mine closure planning process with both the community and the mining company alike provided a pathway for getting to an agreed post-mining land use as the approach's inherent anthropic focus provides a way to include community perspectives. In the Australian case, the recreation values sought by forest users had not been returned in rehabilitated mined areas, although it was clear that forest users' perspectives were strongly influenced by historical rehabilitation efforts, which have been transcended by recent practices. Regulators saw value in using ecosystem services assessment methods to both plan the mine closure and monitor the progress of rehabilitation as a way to demonstrate social benefits rather than solely ecological results. In both countries, regulators agreed that results analysis of rehabilitation practices was poorly done. While Brazilian regulators saw ecosystem services as an opportunity to fill some current gaps in rehabilitation practices, such as stakeholder engagement, the Australian regulators believed that the planning process already made implicit use of ecosystem services. In both cases, the actual biophysical basis of rehabilitation practices was found to be robust, but taking an ecosystem services approach to mine closure planning enhanced the process and generated valuable insights for guiding post-mining land-use determinations. Overall, the study demonstrates that meeting regulatory requirements for rehabilitation, as measured by ecological indicators, does not automatically correlate with acceptable social outcomes.

Keywords: *ecosystem service assessment, rehabilitation, stakeholder engagement, mine closure planning*

1 Introduction

The ecosystem services concept has been promoted internationally as a way to communicate and understand the relationship between people and nature (Fish et al. 2016; International Panel on Biodiversity and Ecosystem Services 2019). It is an opportunity to translate biophysical issues into socially relevant terms, facilitate communication with decision-makers (Rosa & Sánchez 2016; Scholte et al. 2016; Slootweg et al. 2010) and enhance public engagement within different planning processes (Preston & Raudsepp-Hearne 2017), including environmental impact assessment and mine closure planning (Rosa & Sánchez 2015; Rosa et al. 2018a, 2018b). Ecosystem services assessment is promoted as a multidisciplinary approach that integrates socio-ecological systems (Baker et al. 2013). It offers a useful way to address a whole range of planning and management functions (Baral et al. 2016) and is credited with providing a common language that can improve communication and stakeholder engagement and enable comparisons of different land-use scenarios (Mascarenhas et al. 2016; Paudyal et al. 2015). Given that mining is a temporary land use, areas rehabilitated post-mining should be able to provide services to society.

Mine closure planning is well established internationally by regulators, industry and financiers of mining proposals alike as an intrinsic part of the entire lifecycle of mining—from initial design through to operation, rehabilitation and closure (e.g. International Council on Mining and Metals [ICMM] 2008; Mining Minerals and Sustainable Development 2002; Morrison-Saunders et al. 2016; Sánchez et al. 2014; Sweeting & Clark 2000). The mine closure planning process includes stakeholder engagement as an important component in reaching agreed and acceptable post-mining land uses that the local community will inherit at relinquishment (ICMM 2019).

Our purpose with this research was to apply an ecosystem services assessment approach to mine closure planning, including site rehabilitation. To this end the Ecosystem Services Assessment for Rehabilitation (ESAR) approach was developed and tested in two bauxite mines (Rosa et al. 2018a, 2018b). This approach provides a means to include social indicators in rehabilitation planning and evaluation, in particular the expectations of local communities for post-mine land use, which is an accepted principle for mine site closure planning (e.g. Morrison-Saunders et al. 2016; Sánchez et al. 2014). Use of the ecosystem services concept when applying ESAR can improve engagement with stakeholders because the concepts are more accessible to community participants (Rosa et al. 2018a). Before presenting our methodology for the study, we will first briefly explain the ESAR framework.

The ESAR framework was designed to include community members in mining rehabilitation processes and to translate biophysical outcomes into social benefits. The sequential approach comprises an ecosystem services review, rehabilitation plan development, the monitoring of ecosystem services, and an outcome analysis. Details of the four steps follow. Results from practical applications are discussed later in the paper.

1.1 ESAR Step 1: ecosystem services review

To apply ecosystem services to mine rehabilitation and closure, it is necessary to identify the ecosystems affected by mining, the ecosystems' services and their respective beneficiaries. This is done through an ecosystem services review (Landsberg et al. 2013; Rosenthal et al. 2015), by identifying, measuring and mapping the services provided by affected ecosystems and characterising their beneficiaries. Using this baseline data, the next task is to establish a decision tree (de Groot et al. 2010; Landsberg et al. 2013) tailored to the specific circumstances in order to select the most important ecosystem services relevant to the mine site rehabilitation.

1.2 ESAR Step 2: input to rehabilitation planning

Getting an agreed post-mining land use requires engagement in order to define goals for mine site rehabilitation and to select appropriate targets against which performance will be monitored (ICMM 2019). It is important to identify and address the potential trade-offs between restoring two or more selected

ecosystem services (Geneletti 2016; Rosenthal et al. 2015). Different time scales should be considered for defining targets—that is, a target may change according to the progress of rehabilitation.

1.3 ESAR Step 3: monitoring ecosystem services

As rehabilitation work progresses, ecosystem services would be monitored—normally by the mining company responsible—with regular disclosure of findings to the regulators and the community in keeping with mine closure planning expectations (ICMM 2019; Sánchez et al. 2014). The methods that are applied to measure and map services in Step 1 should also be used here to enable comparison with goals, especially if the rehabilitation goal is to restore ecosystem services that existed prior to mining. Analysis of monitoring results will be in relation to the targets established in Step 2, enabling a recovery trajectory to be determined (Harris & Diggelen 2006.

1.4 ESAR Step 4: outcome analysis

A continuous improvement and adaptive management approach is consistent with international expectations for mine site rehabilitation and closure planning (Morrison-Saunders et al. 2016). The ESAR approach focuses on demonstrating that ecosystem services are being restored and that the expectations of communities are being met (Rosa et al. 2018a, 2018b). It is important to understand and explicitly demonstrate which kind of beneficiaries (communities, interest groups, families, individuals) are being considered and how they will benefit from mining rehabilitation. Therefore, it is not simply a matter of presenting technical results to local communities or other stakeholders but rather an interactive and ongoing engagement process.

2 Methodology

To apply ecosystem services assessment to mine rehabilitation and closure planning, we used two bauxite mine sites, one in the Amazon (Brazil) and the other in Western Australia. The two bauxite mines are located in forest environments: Amazon rain forest in Brazil (Figure 1) and Jarrah forest in Australia (Figure 2).

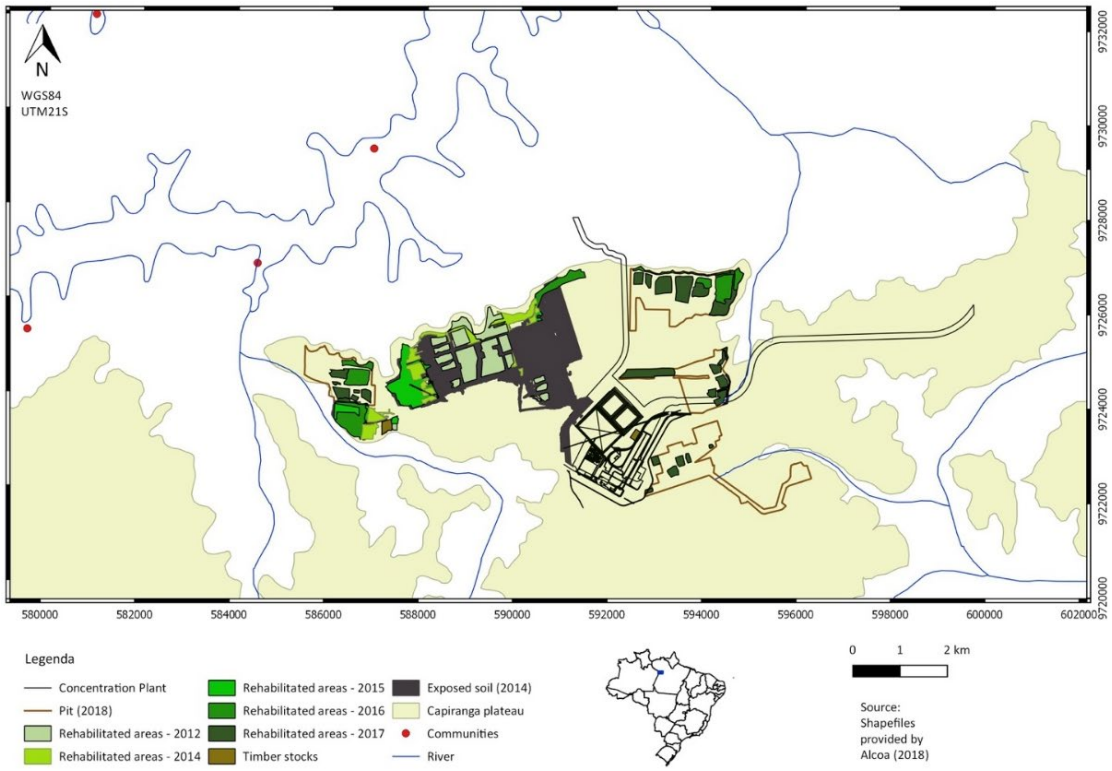

Figure 1 The Brazilian bauxite mine site: characteristics

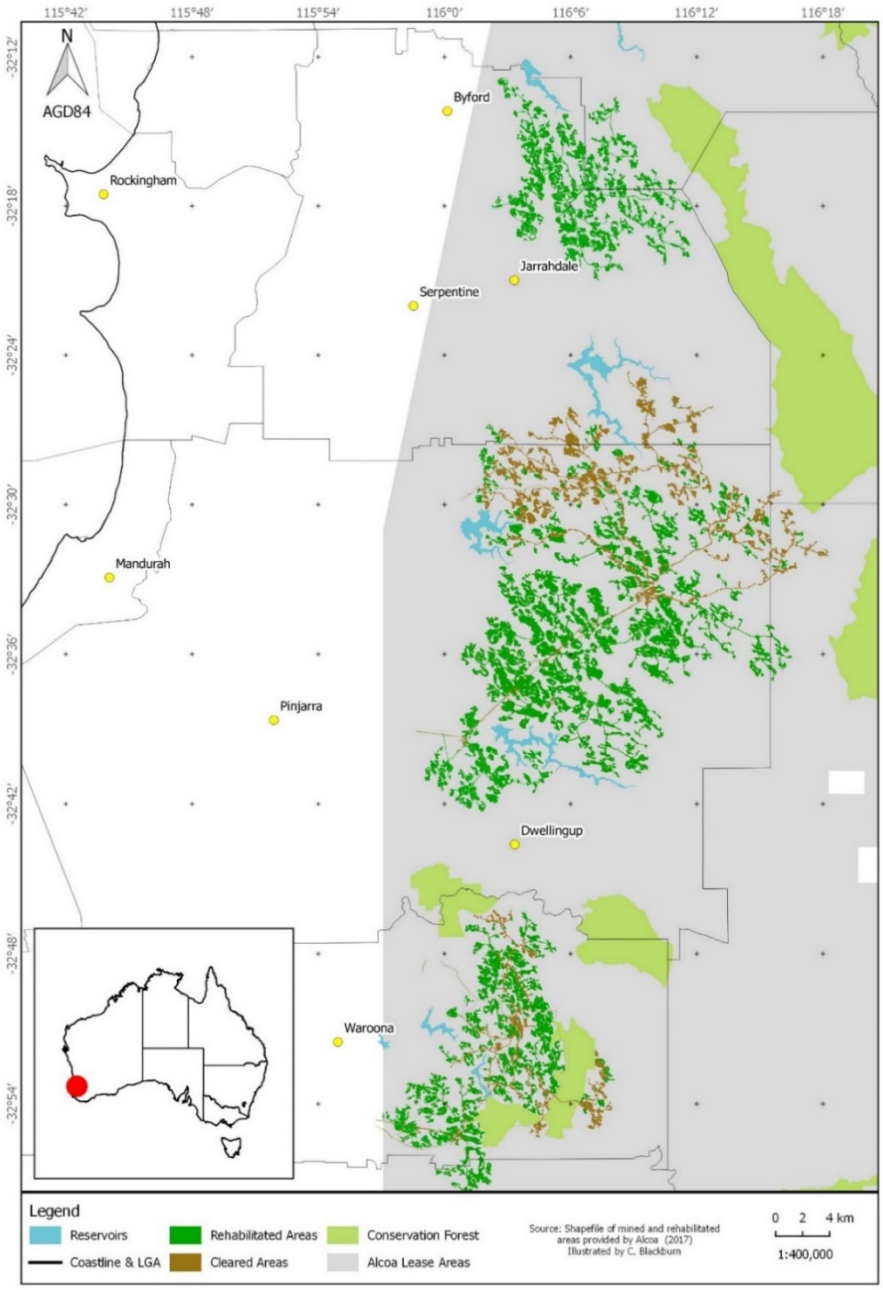

Figure 2 The Western Australian bauxite mine site: setting and characteristics

In both cases, topsoil, overburden and bauxite are sequentially excavated, with overburden and topsoil returned to restoration plots for revegetation. The mines are operated by Alcoa, a global company operating in the aluminium business—from mining to smelting and specialty applications. When both operations were developed and initial rehabilitation plans were established by the company, neither the Brazilian government nor the Australian government had detailed guidance in place for monitoring or conducting rehabilitation programmes; rather, these have evolved along with the active mining activity.

For the Australian case study, which draws on some 50 years of continuous operations, the current rehabilitation goal is focused on four land uses: timber production, recreation, water harvesting (reservoirs) and biodiversity conservation, which are represented by 30 completion criteria (Alcoa of Australia 2015; Grant et al. 2007). In contrast, the current rehabilitation goal for the Brazilian operation, a new mine with seven years of operation, is simply related to ‘improving land rehabilitation’, a broad and ambiguous goal

that lacks the inclusion of focused and achievable monitoring targets (Rosa et al. 2018a). Further contextual information on each of the two case study operations are incorporated into our account of data collection methods that follows.

The application of ESAR was conducted using a similar approach with both mines, firstly by reviewing rehabilitation monitoring data collected by the company for regulatory purposes. Interviews were then the principal method employed to understand community stakeholder interactions with pre-mining and post-rehabilitation areas. The final stage in the research was to conduct a review of our approach by consulting with professionals who work at the mining and environmental regulatory agencies. Workshops were conducted with regulators responsible for mine closure planning and rehabilitation activity at both operations. This component of the research complements an earlier suite of workshops conducted with mining company representatives in Brazil and Australia, previously reported in Rosa et al (2018b), which is not replicated here. Further detail on each of these methods follows.

2.1 Interviews with beneficiaries

Interviews were conducted with beneficiaries in Brazil and Western Australia. Beneficiaries in Brazil are local traditional communities for whom the forest (and its ecosystem services) is an important source of income, food and cultural values (Rosa et al. 2018a). Here the community have land rights that were collectively assigned to traditional communities in an arrangement established by the government in 2005 known as the Juruti Velho Agroextractivist Settlement (Rosa et al. 2018a), meaning that at mine site closure and relinquishment, rehabilitated forest areas will be returned to the community. Beneficiaries in Western Australia are recreationists who live in Perth or its surrounds in proximity to the jarrah forest region where bauxite mining takes place. In this instance, the forest is an important cultural service, especially for recreation purposes such as bushwalking and mountain biking. The jarrah forests are managed by the Western Australian government to meet multiple uses, including water production, timber harvesting, and conservation, among other uses (Conservation Commission of Western Australia 2013). Both sets of interview responses were analysed in order to code and categorise them according to similarity of meanings. The aim of the interviews was to gather qualitative data about people's views and experiences regarding their use of the forest—that is, ecosystem services—and hence it was not intended to achieve representative sampling.

In Brazil, living close to the mining operations are five communities whose members told us they had made use of pre-mined areas to extract a variety of forest resources, and information regarding this had also featured in the environmental impact study for the project (Consórcio Nacional de Engenheiros Construtores 2005). In the past, these communities accessed forest areas in close proximity to their dwellings. In light of the communal nature of these settlements, we conducted joint interviews with 19 families in November 2016. The lead researcher resided in the area for several weeks, with repeated interactions and engagement with the community. This meant that multiple conversations tended to take place rather than a single interview being conducted in one sitting. Interviews were based on five questions that sought to capture the pre-mining land uses of the area and the potential post-mining land uses, as follows:

- What were your previous uses (i.e. ecosystem services) of the current mining area?
- Which of these uses do you consider most important or miss the most?
- Have you stopped performing or producing something as a consequence of mining impacts? If yes, why?
- How would you like the company to return the land for post-mining use?
- To what extent do you anticipate that the next generation of your family/community will use the rehabilitated lands?

In Western Australia, 15 recreationist clubs were contacted by email and phone; as a result, interviews were conducted with representatives of six bushwalking clubs and four mountain biking clubs to determine recreationists' perceptions of pre-mining forest and post-mining rehabilitated forest. These face-to-face interviews, conducted between October 2017 and February 2018, were based on the following five questions:

- Thinking about the last time you went (bushwalking/mountain biking) and the place(s) you visited, what do you consider to be the most desirable characteristics of an area for (bushwalking/ mountain biking)?
- Thinking about a time you went (bushwalking/mountain biking) and did not enjoy the place, what are the characteristics of an area that you would avoid when (bushwalking/mountain biking)?
- Have you accessed some mining rehabilitated area for recreation in the last 12 months? Did you see some differences between a natural and rehabilitated area?
- Do you have some suggestions to improve rehabilitated mining areas for recreation purposes?
- Do you think that the next generation (e.g. your children and grandchildren) will access mining rehabilitated area for recreation?

2.2 Workshops

Two workshops were held with regulators in Western Australia, one with four professionals of the Department of Biodiversity, Conservation and Attractions and another with five professionals of the Department of Mines, Industry Regulation and Safety. Both workshops were carried out in February 2018. The workshop with regulators in Brazil was conducted with seven professionals of the Pará State Sustainability and Environment Secretariat (*SEMAS* in Portuguese) in November 2018.

All workshops commenced with a presentation about the ESAR framework and the application of ecosystem services assessments in mine rehabilitation and closure, using the initial research with the community in Brazil (Rosa et al. 2018a) by way of example. Subsequently, participants were invited to discuss the following three questions:

- Could the ecosystem services concept be useful for mine rehabilitation (planning and monitoring)? Useful for what? How?
- Do you see value in using ESAR in current monitoring carried out by Alcoa?
- Of the proposed tasks within ESAR, what would be difficult to apply in practice? What do you suggest to remedy this?

3 Results

Results for the two phases of the research are presented in turn.

3.1 Interview findings

The main findings from interviews with the Brazilian beneficiaries (Table 1) show that the forest was recognised as providing the following ecosystem services: natural medicines; fibres; food (fruits, seeds and nuts); and timber to construct boats, houses and community buildings. All services mentioned by interviewees were provision services, but it was apparent that for these communities, provision and cultural services are intertwined, as noted by Gavidia & Kemp (2017). The majority of respondents affirmed that food is the most important service and that collecting Brazil nuts is what they miss the most when areas of forest become unavailable to them during mining (Rosa et al. 2018a). Activities such as collecting nuts, producing sweets and holding harvest celebrations are no longer carried out. To recover this service, 20 seedlings/ha were planted in the rehabilitated post-mined areas, with early monitoring reports (i.e. most rehabilitation areas have been established for fewer than five years) showing a survival rate of eight individuals/ha. Trees of this species are naturally quite dispersed in the landscape (Scoles et al. 2011), and flora inventories of pre-mining sites found five trees/ha on average (Marca Consultant 2015). In other

words, the rehabilitation strategy has been to deliberately increase the density of Brazil nut trees. However, trees do not start producing until they are 20–25 years old, meaning that the current generation will not benefit from the expected recovery of this service.

According to the respondents, mining only affects extractive activities in the forest, such as timber harvesting; hence, they did not cease producing goods or carrying out other activities. At the time of the field survey, the impacts of mining affected about 5% of the total forest within the collectively tenured land (Figure 1).

Results from interviews showed that the local communities living near the Brazil mining operations know that the rehabilitated areas will be returned to them, and similarly the Australian recreationists know that rehabilitated areas will be returned to the government and once again become publicly available. When asked directly about the post-mining land use, both Australian and Brazilian respondents emphatically stated that they want 'the forest to be returned in the same conditions as it was before mining'. However, all respondents in both countries also affirmed that they do not believe it is possible to accomplish this.

The final interview question concerned longer-term use of the forest and post-mining areas. On the one hand, about 50% of Brazilian families indicated that they expect the next generation will undertake the same activities as they do. On the other hand, some families wish for a better quality of life for the next generation (e.g. having access to better jobs and infrastructure), and on this basis, they do not want them to maintain a similar lifestyle. In addition, some respondents noted that as children do not see their parents using the forest, it is not likely that, when grown-up, they would choose to use the forest in the traditional manner of the communities anyway.

Table 1 Summary responses from community interviewees in Brazil

Interview questions	Key responses
1. What were your previous uses (i.e. ecosystem services) of the current mining area?	Traditional uses focused on provisioning services, such as natural medicines; fibres; food (fruits, seeds and nuts); and timber to construct boats, houses and community buildings.
2. Which of these uses do you consider most important or miss the most?	Collecting Brazil nuts was consistently the most commonly identified forest use here.
3. Have you stopped performing or producing something as a consequence of mining impacts? If yes, why?	Most said 'no', because the area affected by mining is a small part of the forest.
4. How would you like the company to return the land for post-mining use?	Forest, as it was before mining.
5. To what extent do you anticipate that the next generation of your family/community will use the rehabilitated lands?	Around half of interviewees believe that the next generation will undertake the same traditional activities as they do, but they expect better life conditions for them. A similar number noted that as children do not see their parents using the forest currently, it is unlikely that they would seek to use the forest in the traditional ways.

During interviews with recreationists in Western Australia (Table 2) regarding the main characteristics of a desirable area to recreate in, or what they enjoy about the places in the jarrah forest that they currently visit, the bushwalkers and mountain bikers alike gave subjective answers such as 'natural bush', 'quiet and peaceful place' or 'exercise, fitness, the healthy benefits of going to the bush'. From these responses, we identified two different groups regarding the level of development of recreation sites and infrastructure.

The first group comprised bushwalkers and mountain bikers who would like to see the provision of infrastructure such as more trails and facilities (along with suitable roads and car parking for access purposes), and they see the rehabilitation process as an opportunity to achieve that. The second group, comprising only bushwalkers, prefer a completely wild environment to recreate in (i.e. with no development of facilities), and they have a strong sense about what is a native and natural forest versus rehabilitation areas. For this latter group of people, it is very difficult to restore the benefits lost—at least, not in the timeframes that have lapsed since mining ceased (i.e. it might take hundreds of years for rehabilitated sites to return to a form comparable to native forest).

Regarding the undesirable characteristics or areas that the Western Australian recreationists avoid, interviewees mentioned 'not nice bush', referring to forest areas that have been cleared or mined in the past or forest areas that are noisy due to the proximity of currently active mining areas. Both groups of recreationists have this perception, although the bushwalker perception appears stronger than the mountain biker perception, as perhaps might be expected.

Table 2 Summary responses from recreationist interviewees in Australia

Interview questions	Key responses
1. Thinking about the last time you went (bushwalking/mountain biking) and the place(s) you visited, what do you consider to be the most desirable characteristics of an area for (bushwalking/mountain biking)?	Natural bush, quiet and peaceful places, exercise, fitness and other health/wellbeing benefits of being in the bush.
2. Thinking about a time you went (bushwalking/mountain biking) and did not enjoy the place, what are the characteristics of an area that you would avoid when (bushwalking/mountain biking)?	Forest areas that have been cleared in recent logging operations or have been mined in the past and areas that are noisy due to the proximity of currently active mining areas.
3. Have you accessed some mining rehabilitated area for recreation in the last 12 months? Did you see some differences between a natural and rehabilitated area?	Most said 'yes'. The rehabilitated areas consisted of pine plantations or non-endemic eucalyptus trees with a lack of diversity in understory vegetation.
4. Do you have some suggestions to improve rehabilitated mining areas for recreation purposes?	Using native species; providing interpretive signs regarding historical land use.
5. Do you think that the next generation (e.g. your children and grandchildren) will access mining rehabilitated area for recreation?	Most respondents want forest as it was before mining and agreed that the rehabilitated mining areas will be more acceptable for the next generation.

The interviewees also provided some perceptions of the forest with regard to the current rehabilitation practices. For example, establishment of pine plantations or non-endemic eucalypt trees with a lack of diversity in understorey vegetation are characteristics related to old rehabilitation practices (in the early years of bauxite mining in the 1970s) and were unacceptable for the majority of interviewees, but universally so for bushwalkers. The current rehabilitation efforts that seek to return only native plant species endemic to the local jarrah forest ecosystem (Gardner & Bell 2007), which is promoted by the mining company and government (e.g. on information signboards in some recreational areas in the forest), were assessed as good practice by recreationists. From the specific remarks provided by interviewees, we determined that societal acceptance of the mine rehabilitation in the Western Australia case depends in part on the communication of changes in rehabilitation practices. This finding underscores the importance of ongoing engagement, disclosure and accountability for mine closure undertakings as advocated in local

and international guidance alike (Department of Mines and Petroleum & Environmental Protection Authority [DMP & EPA] 2015; ICMM 2019).

In response to the final interview question regarding whether the next generation will use the rehabilitated areas of the jarrah forest, most respondents agreed that the rehabilitated mining areas will be more acceptable for the next generation and will continue to be an important area for recreation in the future. Here, though, they also highlighted the importance of the company returning a forest ecosystem to what it was before mining (or as close as possible).

3.2 Workshop findings

Brazilian environmental regulators affirmed that applying ecosystem service assessment into mine rehabilitation and closure would help to improve stakeholder engagement, especially when mining affects traditional communities; integrate biophysical and social data, enhancing outcome analysis that is poorly practised currently; and enhance community participation in decision-making about post-mining land use (Rosa et al. 2018a).

Participants mentioned that one important challenge of mine rehabilitation is defining indicators to monitor the rehabilitation efforts and outcomes. They consider that monitoring reports are excessively descriptive and provide insufficient analysis and interpretation. In addition, being presented on an annual basis, monitoring reports do not provide time-series results. Although participants believe that the ecosystem services concept could help to overcome these challenges, they indicated that practical results are needed.

In the opinion of the Brazilian environmental regulators, the intrinsic characteristic of engagement required by ecosystem services assessments is the most difficult task to lead in terms of practical application (Table 3). In particular, they indicated that achieving an agreement among the different stakeholders about post-mining land use could be very challenging, especially in the case of the Amazon, where there is a forest with high biodiversity and cultural values.

Table 3 Summary results from the workshop with regulators in Brazil and Australia

Workshop discussion questions	Key responses of Brazilian professionals	Key responses of Australian professionals
1. Could the ecosystem services concept be useful for mine rehabilitation (planning and monitoring)? Useful for what? How?	Yes, to improve stakeholder engagement, integrate biophysical and social data, and enhance community participation in decision-making about post-mining land uses.	Yes, to integrate data and in case mining affects traditional communities. Stakeholder engagement is already included in mine closure process.
2. Do you see value in using ESAR in current monitoring carried out by Alcoa?	Yes, but to be sure practical applications and results are needed.	No, as the current process includes the ecosystem service concept implicitly.
3. What would be difficult to apply in practice? What do you suggest to remedy this?	The intrinsic characteristic of engagement required by the framework and the outcome analysis. It is hard to achieve an agreement between the stakeholders.	Outcome analysis and truly adaptive management. It is already required and currently poorly performed.

Australian regulators affirmed that promoting stakeholder engagement in mine rehabilitation and closure is not new for them, and there is well-established mine closure guidance (which is periodically reviewed and updated) that lays out clear expectations for this process (DMP & EPA 2015). Regulators also emphasised

that engagement must be ongoing during the entire life of the mine because society expectations do change over time as has happened with the Alcoa operation in Western Australia (e.g. regarding changes in rehabilitation practices over time). One perspective that did emerge in both workshops was recognition of the potential for the integrated ecosystem services assessment to be helpful in engaging and identifying the needs and expectations of Aboriginal community stakeholders because of their close cultural relationship with nature.

One important challenge identified in Western Australia regarding rehabilitation and closure of mined areas is related to climate change. It is necessary to understand how climate change is affecting or will affect the rehabilitation outcomes that have been obtained so far and what this might mean for rehabilitation strategies in the future. This pertains to decreasing rainfall and a consequent need to consider revising tree and other vegetation density in rehabilitation areas. In addition, restoring multiple-use forest and meeting the needs and expectations of different stakeholders continues to be a challenge. Participants essentially agreed that they do not see how the ecosystem services concept could be helpful to overcome these challenges, which speaks to a more fundamental discussion that would need to take place about acceptable uses of public forest areas (to balance mining with other uses of the forest).

Finally, the Australian regulators shared a common view with those in Brazil—that is, the most difficult task of applying ecosystem services assessments to mine rehabilitation and closure lies in analysing outcomes. To implement a truly adaptive management cycle in mining rehabilitation, closure planning and relinquishment appears to be a challenge confronted in both countries.

4 Discussion

Our research findings demonstrate that applying an ecosystem services assessment approach to mine closure planning can enhance understanding and realisation of post-mining land-use outcomes. This is because of its intrinsic characteristic of translating biodiversity into social benefits. This finding is consistent with published perspectives on other applications of the concept (Geneletti 2016; Rosa & Sánchez 2016; Slootweg et al. 2010). In particular, the concept has been found by us to improve stakeholder engagement, especially local communities who may otherwise struggle to comprehend some of the terminology around biodiversity rehabilitation targets (Rosa et al. 2018a, 2018b). Although stakeholder engagement is recommended as good practice in mining closure and rehabilitation, it has not been advancing in Brazil in particular (Sánchez et al. 2014). However, Western Australia has been producing guidelines about how to engage stakeholders in order to make decisions about post-mining land use (DMP & EPA 2015) without making use of ecosystem services explicitly. However, we note that the Western Australian *Environmental Protection Act 1986* (Government of Western Australia 1986) does use the concept of 'environmental values', which means '(a) a beneficial use; or (b) an ecosystem health condition'. Environmental values can be associated with or aligned to ecosystem services, which is conceptualised as 'benefits that nature provides to people' (Neugarten et al. 2018). In essence then, ecosystem services have been used implicitly in Western Australian decision-making processes surrounding mining. As noted by Geneletti (2016), it is not a completely new concept but it is a new way to understand the relationship between nature and society.

Restoring biodiversity, which is the current focus of mine closure criteria in both countries, does not mean restoring ecosystem services, at least not within near-term time periods. In Brazil, it will be at least one generation before the recovery of Brazil nut trees will be at an age for harvesting. In Western Australia, some recreationists do not believe in the success of mine site rehabilitation, although the company reports that it does restore 100% of species diversity (Alcoa of Australia 2017). As with the findings of van der Plank et al. (2016), there is scepticism about mine rehabilitation in general expressed by stakeholders in Western Australia, which underscores the importance of effective stakeholder engagement, especially with local communities. The negative perception is especially associated with the mine rehabilitation practices implemented until 1987, when exotic species were planted and the rehabilitation goal was simply to establish a functioning and self-sustaining eucalypt forest rather than returning the endemic forest species. In this case, the success of restoring social benefits (i.e. ecosystems services) is tied to communication regarding current mine rehabilitation outcomes. This communication works in both directions. On the one

hand, mining companies and regulators may need to educate or inform the community about mine site rehabilitation and closure practices and outcomes. On the other hand, if the recreationists are not using rehabilitated areas and have no opportunity to express their views on the quality and nature of the environment being returned to them, then the recreation services would not be restored because they do not form part of the specific closure criteria in use. The expectation in mine closure planning guidance to achieve post-mining land uses in agreement with the community (e.g. DMP & EPA 2015; ICMM 2019) in the Western Australian instance could lead to different rehabilitation practices being realised, such as provision of recreational facilities and infrastructure.

The notion that restoring biodiversity does not mean restoring ecosystem services also holds true for the Brazil case. Here, the communities expected restoration of the full forest ecosystem that existed in pre-mined areas, and some key important species, such as the Brazil nut trees, they especially care about. Planting and growing this species could represent the restoration of biodiversity, but it would not mean that the social benefit itself would be restored, because of the time lag before the trees are mature enough to produce nuts that can be harvested. In other words, even if the Brazil nut trees never produce a nut, the species diversity could be considered to have been restored but the ecosystem service and its social benefits could not. This highlights the benefit of adopting an ecosystems services approach to mine closure planning.

This process of discussing the mine rehabilitation results with communities to verify the extent to which the expected post-mining land uses will be delivered is part of the outcome analysis when applying the ESAR framework. Participative outcome analysis is a fundamental part of the ecosystem service assessment approach, and it is a good way to communicate the mine rehabilitation outcomes and maintain ongoing stakeholder engagement. In both sets of workshops with the mining and environmental regulators in Brazil and Western Australia, opportunities to enhance the outcome analysis process through an ecosystem services approach were identified. The government regulators see benefits in ecosystem services assessments in terms of providing a slightly different way of monitoring and reporting on mine closure performance. Furthermore, an ecosystem services assessment does allow mine rehabilitation to be critically reviewed in the process. It may be possible to identify better land-use outcomes this way, which is consistent with best practice principles in mine closure planning (ICMM 2019; Sánchez, et al. 2014).

Beyond the outcomes analysis process, discussions with stakeholders in both countries revealed a lack of good databases and associated information storage and retrieval systems regarding rehabilitation practices and performance outcomes. Best practices advocated by ICMM (2019 p. 53) include ensuring that closure costs are ‘documented fully in a way that can be audited by a third party’. and that accountability for closure governance is available to relevant stakeholders. The first step of the ESAR framework leads to the establishment of a database based on ecological and social data that allows for integrated analysis. This, combined with adequate stakeholder engagement, is essential to demonstrate the success of mine rehabilitation (Harris & Diggelen 2006) and ultimately to relinquish a mine site.

5 Conclusion

This paper has discussed how an application of the ecosystem service assessment for mine site rehabilitation and closure was explored by involving community representatives and regulators in Brazil and Western Australia. It has become clear that an ecosystem service assessment helps to define post-mining land use, especially when mining affects local communities’ use of culturally and economically important products of natural ecosystems. Current rehabilitation processes emphasise restoration of biodiversity, but compliance with this goal does not guarantee that the benefits the community derived from the ecosystems affected by the mining operations are themselves restored. The application of an ecosystem service assessment in mine closure planning was shown to be particularly helpful in highlighting this issue as well as for enhancing the post-mining land-use outcomes being sought from both operations. The research also demonstrates that the ecosystem services concept usefully integrates ecological and social considerations during mining closure planning and enhances stakeholder engagement. Regulators and mining companies alike could benefit from using this approach when engaging with the beneficiaries to

facilitate participative decision-making processes consistent with expectations for best practices in mine closure planning advocated by the ICMM. Ongoing stakeholder engagement—provided by a focused monitoring program on social benefits—promotes mining rehabilitation and closure activities that enhance post-mining land-use outcomes, thereby ensuring a positive legacy for all stakeholders.

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