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RE-NEW (OPINION) ARTICLE

A life-of-mine approach to fauna monitoring is critical for recovering functional ecosystems to restored landscapes

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Mineral extraction activities are intensely disruptive to ecosystems and their associated fauna. Few countries globally have comprehensive legislation surrounding mine site restoration, but within Australia, restoration of discontinued mine sites is a legislative requirement. However, substantial ambiguity regarding the optimal techniques for restoring biodiverse and functional fauna assemblages remains, and monitoring activities typically focus on vegetation communities despite functioning ecosystems being reliant on key trophic interactions involving fauna. When fauna are considered, monitoring efforts typically yield baseline surveys of species richness and the presence or absence of conservation-significant taxa. Even where complete ecosystem recovery is not the goal of post-mining ecological recovery, we argue that there is a critical need for a life-of-mine approach to fauna monitoring underpinned by greater dialog between researchers, environmental regulators, and the mining industry. Environmental Impact Assessments should include requirements for the consideration of all potential impacts of mining on the structure, behavior, and ecological roles of fauna communities, restoration practices must facilitate the return of functional, resilient, and biodiverse fauna communities to restored post-mining landscapes, and the scope of monitoring practices should be broadened to a holistic examination of fauna communities. Recognizing, quantifying, and monitoring the impacts of mining activities and subsequent rehabilitation or restoration on fauna is vital to understanding how anthropogenic disturbances affect natural ecosystems, and in assisting in the successful recovery of ecosystem functionality to areas that have been damaged, degraded, or destroyed.

Key words: impact assessment, management, mine, monitoring, restoration

Implications for Practice

- Complete ecosystem recovery relies on key trophic interactions involving fauna.
- The assumption of fauna return to restored landscapes may be inadequate for returning fully functional ecosystems.
- Restoration must consider the requirements of fauna groups that promote long-term, functional, biodiverse fauna assemblages.
- Researchers, environmental regulators, and the mining industry must take a life-of-mine approach to fauna monitoring to assist in the successful recovery of ecosystem functionality to landscapes that have been degraded or destroyed.

Background

Australia is one of a handful of countries with comprehensive legislation outlining expectations of mine site rehabilitation and restoration following the discontinuation of mining activities (Clark & Clark 2005). However, there are still few examples of landscapes being successfully returned to functional native ecosystems following mining (Carlucci et al. 2020; Cross et al. 2020*a*). Notably, despite ecosystem recovery being reliant upon the reassembly of trophic interactions between animals and other components of the ecosystem (Ruiz-Jaen & Mitchell

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Aide 2005; Fraser et al. 2015; McAlpine et al. 2016), fauna remain broadly overlooked in restoration planning and monitoring (Cross et al. 2019). Our understanding of how fauna communities reassemble and behave in rehabilitated or restored areas in comparison with reference ecosystems remains limited for many taxonomic groups (Cross et al. 2019, 2020*a*). We argue that there is a critical need for collaboration and discussion between scientists, environmental regulators, industry, and associated restoration practitioners, toward a life-of-mine (i.e. before, during, and after active operations) approach to considering fauna. This approach should be three-pronged; aiming to (1) appropriately assess and quantify all potential impacts of mining on fauna during Environmental Impact Assessments (EIAs), (2) mitigate these impacts, where possible, and improve restoration practices to facilitate the return of functional, resilient, and biodiverse fauna communities to restored post-mining landscapes, and (3) improve and broaden the scope of monitoring practices to provide more holistic information about community assembly and the behavior of fauna communities along restoration trajectories. Although we present an Australian focus, we stress that these concepts are globally portable (e.g. Gann et al. 2019).

Improving Environmental Impact Assessments

Although the importance of EIAs in conservation and management planning is well recognized, concerns have arisen regarding their effectiveness in guiding environmental management best practice (Morgan 2012; Bigard et al. 2017). Current guidelines focus upon baseline surveys of fauna population assemblages, with an emphasis on the presence and abundance of conservation significant taxa (e.g. DMIRS 2020). However, EIAs should also provide baseline reference for structure and ecological function of fauna communities within proposed impact zones; assessments currently rarely acknowledge ecological processes and the roles of functional groups in providing critical ecological services (Slootweg & Kolhoff 2003; Frick et al. 2014). Given the critical role of fauna in ecosystems (e.g. Majer 1989; Godínez-Álvarez 2004; Jouquet et al. 2011), a lack of specific consideration of the diverse impacts of mining activities on fauna represents a major weakness in the foundations of mine site restoration right from the planning stage. Regulatory agencies should also include requirements for the assessment of structure and functioning (e.g. degree to which fauna perform integral ecosystem roles; Akçakaya et al. 2020) in fauna assemblages, determination of the requirements of species critical to ecosystem functioning, and identification of the ecological processes sustaining viable fauna populations (Slootweg & Kolhoff 2003; Wale & Yalew 2010). Knowledge of the requirements for population support (e.g. baseline resources, key habitats), particularly for specialist species whose ecological requirements may not be met in the restored environment, is crucial to ensuring targeted and adaptive management strategies can be developed and implemented from the outset of mining operations. Pre-approval surveys provide a critical opportunity to lay solid foundations for effective and successful mine site rehabilitation and restoration.

Restoring Biodiverse and Functional Fauna Communities

Current regulatory guidance requires the monitoring of specific environmental outcomes and "performance criteria" relating to fauna throughout active mining operations, e.g. "no death of conservation significant native fauna through entrapment in mine facilities" (DMIRS 2020). However, guidance and policy apposite to returning abundant, diverse, and functional fauna communities to mined lands other than these monitoring requirements are lacking (Thompson & Thompson 2020). A significant body of literature exists which could inform the development of guidance and policy in this area, and such guidance would greatly assist industry in setting appropriate goals for post-mining restoration and establishing completion criteria (Block et al. 2001; Lindell 2008; Majer 2009; McAlpine et al. 2016). For example, movement ecology of many species is predicated upon landscape-level changes in habitat (e.g. Allen & Singh 2016; Tarszisz et al. 2018; Cross et al. 2020*b*, 2020*c*), yet movement ecology and other knowledge of fauna behavior are rarely considered in restoration planning despite their vital role in facilitating the functional place of animals in ecosystems (Lindell 2008; Cross et al. 2020*a*). Although behavioral studies are sometimes overlooked due to being perceived as an ineffective financial investment (Blumstein & Berger-Tal 2015; Berger-Tal et al. 2016), such studies are increasingly becoming more financially viable both for monitoring individuals (e.g. Fischer et al. 2018) and population trends (e.g. Wildermuth et al. 2013).

Even where mining industry is under legislative obligation to monitor fauna populations (e.g. conservation significant species), impacts other than habitat loss, such as the effectiveness of prescribed exclusion zones in adequately protecting fauna from the deleterious effects of disturbances (e.g. dust, noise, vibration, and light), are rarely addressed (Raiter et al. 2014; Cross et al. 2021). These factors can create significant ecological, behavioral, and physiological barriers to community reassembly and ecosystem functioning (e.g. Baker & Richardson 2006; Kight & Swaddle 2011), potentially constraining the success of rehabilitation and restoration efforts. While studies have demonstrated the value of incorporating high-resolution spatial data to guide the habitat requirements of key fauna groups in their restoration and translocation (Tomlinson et al. 2018; Saleeba et al. 2020; Tomlinson et al. 2020), this approach is also yet to be widely incorporated into EIA processes, restoration and closure planning, or other mitigation measures (Bradley et al. 2021). We encourage more dialog between academics, policy makers and industry to facilitate three-way knowledge sharing in this space—about current scientific theory and best practice relating to fauna ecology, how this can inform policy development that simultaneously provides improved guidance for industry and ensures adequate environmental protection, and how practical, effective, and cost-efficient restoration solutions can be developed to assist industry in meeting and exceeding these requirements.

Broadening the Scope of Fauna Monitoring

Assessments of fauna in post-mining restoration typically still favor presence–absence surveys of select taxonomic groups (Cross et al. 2019, 2020*a*), which provide limited insight into ecosystem functionality, resource availability, and whether restored landscapes might support functional and self-sustaining fauna populations (Aldridge & Boyce 2007; Lindell 2008; Cross et al. 2020*a*). More holistic assessments of community composition, coupled with study of the physiological and behavioral responses of fauna to changing environmental conditions, provide greater insight into the integrity and resilience of fauna assemblages than presence–absence data alone (Sutherland 1998; Jones & Davidson 2016; Hale & Swearer 2017; Hale et al. 2020). For example, while restored landscapes may be inhabited by fauna, they often lack key resources necessary for population support (e.g. refuges such as coarse woody debris: Craig et al. 2014; Cross et al. 2020*b*), which can constrain the self-sustainability of fauna communities by increasing the energetic costs or predation risks associated with the restored landscape (Tomlinson et al. 2014; Cross et al. 2020*c*). Understanding how animals interact with their environment and respond to environmental change is vital to ensuring the effective return of functional ecosystems representative of pre-disturbance landscapes (Tomlinson et al. 2014). Better understanding these requirements will also assist in reintegrating restored areas into the surrounding landscape, rather than leaving a legacy of discrete, isolated patches of incompletely restored habitat.

Conclusions

Even where complete ecosystem recovery is not the ultimate goal of post-mining ecological recovery initiatives (Gann et al. 2019), efforts to collect, interpret, and synthesize ecological data to better inform how fauna are considered in restoration are crucial. A life-of-mine approach to returning fauna to mined landscapes is urgently required, underpinned by a much stronger focus on the composition, structure, and behavior of fauna assemblages and how these factors are impacted by potential mining disturbances. It is crucial that restoration activities are planned and executed with this information in mind to ensure developing ecosystems support the requirements of all fauna groups, with monitoring assessing whether habitats undergoing restoration are promoting the long-term return of functional, biodiverse fauna assemblages (Lindell 2008; Majer 2009; Cross et al. 2020*a*). Achieving this aspirational goal will require meaningful engagement and long-term partnership between academia, industry, and regulators, but will yield generational dividends by avoiding a legacy of revegetated landscapes devoid of animal life and supporting the social license of industry to mine.

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