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Restoration and Rehabilitation of Degraded Land in Arid and Semi-Arid Environments: Editorial

Miriam Muñoz-Rojas[1,2,3] Paloma Hueso-Gonzalez[4], Cristina Branquinho[5] and Thomas Baumgartl[6]

[1]Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, UNSW Sydney, 2052 Sydney, NSW, Australia

[2]School of Biological Sciences, The University of Western Australia, 6009, Crawley, WA, Australia

[3]Kings Park Science, Department of Biodiversity, Conservation and Attractions, Kings Park, 6005, WA, Australia

[4]Instituto de Geomorfología y Suelos (IGSUMA), Departamento de Geografía, Universidad de Málaga, Málaga, Spain

[5]Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências, Universidade de Lisboa (cE3c-FC-ULisboa), Edifício C2, 5° piso, Campo Grande, 1749016 Lisbon, Portugal

[6]Geotechnical and Hydrogeological Engineering Research Group, Federation University Australia, Churchill, VIC 3842, Australia

Correspondence to: M. Muñoz-Rojas, Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, UNSW Sydney, 2052 Sydney, NSW, Australia. E-mail: m.munoz-rojas@unsw.edu.au, miriam.munoz-rojas@gmail.com

Widespread degradation is impacting land at the global scale as a consequence of intense anthropogenic pressures and accelerated changes in climate. The expansion of land degradation may cause the destabilization of ecosystems' structure and functioning and may be somewhat comparable to a global health crisis such as the corvid19 pandemic (Di Marco et al., 2020). Although areas of high biodiversity can host high numbers of pathogens, biodiversity may serve as a protective factor for preventing transmission and maintaining ecosystems helping to reduce exposure to infectious agents (Romanelli et al, 2015). Recently it has been suggested that degraded habitats may encourage more rapid evolutionary processes and diversification of diseases allowing pathogens to spread easily to livestock and humans (Zohdy et al., 2019). Thus, conserving, or in the case of irreversible degradation, restoring, are the goals that society has to enforce to maintain or rebuild an equilibrium with nature. Particularly susceptible regions are drylands, which include arid and semi-arid environments. These areas are largely affected by climate change and land degradation impacts (Berdugo et al., 2020) with ecosystems facing serious threats such as long periods of drought, unpredictability of rainfall, and intense use of the land.

The capacity of ecosystems to regenerate is limited, and therefore restoring degraded land is becoming essential to repair the integrity of impacted forests, rangelands, mine-affected areas) and numerous habitats around the globe (Ockendon et al., 2018). Land restoration and rehabilitation can enhance the natural capital of land and the provision of soil ecosystem services play a key role for climate change mitigation as well as adaptation (Hobley et al., 2018; Nunes et al., 2016). This special issue of *Land Degradation & Development* compiles 23 articles reporting research conducted across all global geographic regions except Antarctica, i.e. Africa, Asia, Australia/Oceania, Europe, North America and South America. These papers address current and upcoming challenges and opportunities for the *Restoration and Rehabilitation of Degraded Land in Arid and Semi-Arid Environments.*

The United Nations (UN) General Assembly adopted a resolution in March 2019 declaring 2021-2030 the UN Decade on Ecosystem Restoration (Willemen et al., 2020). This global call for action is expected to bring together scientific research and political and administrative efforts to scale up restoration in the upcoming years. This resolution has been preceded by several initiatives to reverse land degradation such as the Convention on Biological Diversity's Aichi Targets, the Bonn Challenge and its regional initiatives to restore more than 150 million hectares of land; and most recently the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs) (Bateman and Muñoz-Rojas, 2019). One of the challenges identified by the SDGs is the need to define appropriate indicators for measuring the progress towards achieving the goals proposed, and to understand which areas to prioritise and allocate resources to (Ockendon et al., 2018; Nunes et al., 2016).

Defining suitable indicators for monitoring and assessing the success of restoration should be a priority within restoration programs as highlighted in this issue (Bateman et al., 2018; Shackelford et al. 2018). However, monitoring restoration success is often challenged by the complexity and scales of studies over time. (Costantini et al, 2016). Some countries like China are currently tackling extensive land degradation caused by agricultural pollution and rely on indicators to assess the sustainability of agricultural remediation. In their paper, Hou et al. (2018) review the state of these assessments and discuss the social, economic, environmental, and agricultural implications within the complex human-environmental system. Their study remarks that the implementation of action plans for land remediation needs to consider social aspects and the implications for long-term sustainability. An increasing number of studies are showing the importance of long-term monitoring in restoration (Shackelford et al. 2018), as vegetation establishment and soil properties can go through transient states over time and may evolve over decades (Yu and Wang, 2018). At landscape scales, geomorphic analysis and remote sensing techniques provide sensitive satellite-derived indices that can offer multiple possibilities for monitoring studies at such large ranges. This is well exemplified in Xu et al. and Murthy and Bagchi (2018).

A group of articles in this issue, is focused on revegation techniques. Revegetation has been for many years a conventional strategy for rehabilitation of degrading landscapes (Hobley et al., 2018) and using native plants adapted to drought can facilitate plant establishment in degraded soils under water stress conditions (Bateman et al., 2018). Revegetation efforts generally result in improvement of soil fertility and enhancement of ecosystem services and functions such as carbon sequestration (Gao et al., 2018), nutrient cycling (Barliza et al., 2018 Hu et al., 2018) and soil microbial diversity and activity (García et al., 2018; Liu et al., 2019); nevertheless, it can also lead to adverse effects such as salinity which may affect the success of restoration efforts in the long term (Yu and Wang, 2018). Some native plants such as halophytes, may on the other hand assist in the remediation of salt-affected soils (Shaygan et al., 2018) (Figure 1). Applying vegetation buffer strips can be an effective measure for reducing erosion and soil nutrient movement in degraded hillslopes (Kavian et al., 2018). However, the establishment of vegetation in large-scale rehabilitation operations may not be sufficient to support new and economically driven developments in the construction of landforms with increased spoil elevation, and detailed geological information is essential in these instances (Emmerton et al., 2018).

A large share of articles in this issue evaluates the use of amendments in restoration. The use of amendments in restoration programs is being increasingly encouraged because of their positive effects on soil physical, chemical and biological characteristics (Hueso et al., 2018). Organic amendments such as biosolids, composted material and mulches may increase soil microbial activity, which favor organic matter decomposition and mineralization, and generally increases plant productivity and carbon sequestration in the medium or long-term, as highlighted in this issue by Valdecantos and Fuentes (2018). Also in this issue, Luna et al. (2018), show that woodchip mulch can be effective for trapping runoff and sediment in mine rehabilitation sites whereas organic amendments formed by composted waste can improve infiltration and reduce water erosion (Figure 2). There are, however, risks associated with the use of these techniques and the source of these amendments, which may incorporate potential contaminants such as heavy metals or polycyclic aromatic hydrocarbons that are often overlooked (Carabassa et al. 2018). Importantly, the practice of using locally sourced amendments can also contribute to the circular economy reducing the amount of exogenous fertilizers and contributing to climate change mitigation (Hueso Gonzalez et al., 2018). In socio-economically developing regions, organic amendments such as native mulches can be in fact one of the few available options for improving soil fertility as dicssued in this issue by Félix et al. (2018) and Ndegwa et al. (2018). Félix et al. (2018) show that adding a native shrub, e.g. ramial wood, in high volumes could sustain crop yields in Burkina Faso. Yet, the amount of biomass needed exceeds the available capacity in the landscape and afforestation would be needed to support food production. Similarly, charcoal demand is growing in developing countries because of the lack of alternative energies which exerts a high pressure on available forest resources. To address this issue, Ndegwa et al. (2018) propose a sustainable plan for wood harvesting considering the annual biomass increment of woodlands.

A final group of articles documents examples of innovative approaches and technologies used in restoration. Thesen novel methods include the use of polymers (Liao et al., 2108) and bio-inoculants such cyanobacteria that form biocrust (Roman et al., 2018) and endophytic bacteria (Galaviz et al., 2018). As an alternative to compost application, Galaviz et al. (2018) inoculated degraded desert soils with the endophytic bacteria *Bacillus pumilus*, which resulted in an increase of the *Rhizobium* population in the soil. Roman et al. (2018) highlight in their study the potential of inoculated N-fixing cyanobacteria from soil biocrust to increase soil C and N in semi-arid degraded soils (Figure 3). With advanced tools such as highly specified molecular technologies, these approaches have expanded from the agricultural and biotechnological sectors to the fields of ecosystem restoration and land rehabilitation opening new possibilities in these research areas (Muñoz-Rojas, 2018).

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Conflict of interest

The authors declare no conflict of interest

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Figure captions

Figure 1. Halophytes tolerating and self-remediating saline soil conditions in Eramonga, Australia (May, 2012). Photo: Thomas Baumgartl.

Figure 2. Quarry mine restoration using woodchip mulch and compost as soil amendments (green square-shaped patch in the lower side of the photo) in South Spain (Jun 2016). Photo: Albert Sole.

Figure 3. Soil substrates from degraded arid soils with loamy sand texture inoculated with cyanobacteria isolated from soil biocrust. Microcoms next to the flasks with cyanobacteria cultures contain inoculated soils (three replicates). The other microcosms contain non-inoculated soils (Sep 2018). Photo: Jose Raul Roman.