Ecological Engineering 85 (2015) 1–12

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Reconciling waste rock rehabilitation goals and practice for a phosphate mine in a semi-arid environment

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ARTICLE INFO

Article history:
Received 10 July 2015
Received in revised form
14 September 2015
Accepted 19 September 2015
Available online 18 October 2015

Keywords:
Analogue ecosystems
Novel ecosystems
Landform design
Mine planning
Closure criteria
Rehabilitation success

ABSTRACT

True restoration of highly disrupted native ecosystems is universally difficult, and has not been achieved on waste rock dumps at a rock phosphate mine in the resource-limited rangeland environment of semi-arid Queensland, Australia. Thirteen years after rehabilitation, there is general correspondence, but some temporal variation, in tree and shrub species richness between rehabilitated and analogue native vegetation sites. Large differences in the composition and extent of ground cover vegetation were associated with dominance of most sites by an introduced perennial pasture grass species and by periodic drought. Complete reinstatement of native ecosystems is shown to be inconsistent with the physical constraints of waste rock dumps, the erratic climate, the previous history of extensive grazing and a lack of effective rehabilitation planning. Revised goals of strict landscape stability and broad biodiversity attributes, based on those of relevant native ecosystem analogues, are proposed to enable the identification of appropriate native and novel ecosystem targets for the modified landscapes. Novel ecosystems combining tree and shrub components of the native vegetation, and ground cover (including introduced grasses) could provide the most effective targets for mined land rehabilitation in a semi-arid environment. Principles are suggested for the selection of vegetation targets for the rehabilitation of mine waste rock dumps, considering the new lithologies and landforms and the occurrence of a dominant introduced grass species. These principles should be applicable widely, but especially in resource-limited environments.

1. Introduction

Mining is a transient activity in relation to natural landscape-forming processes, so the identification of post-mining land use objectives has long been an integral part of mine planning and approval processes (UK Government, 1958; USA Congress, 1977). The objectives of ecologically sustainable development (UNEP et al., 2005) require that rehabilitated mined land should above all be safe, stable and non-polluting. This principle is embodied in many national and international guidelines (e.g., DITR, 2006; European Parliament, 2014), local regulations (e.g., DEHP, 2014a) and practical handbooks (e.g., MCA, 1998; ICMM, 2008; Tongway and Ludwig, 2011). Recent attention to the importance of biodiversity targets for land restoration and management activities (e.g., Convention of Biological Diversity, 2012) has added urgency to the identification and attainment of the highest practicable post-mining land use objectives.

Ecological restoration has been defined very broadly (Hobbs and Norton, 1996; Wiens and Hobbs, 2015), but practitioners in the mining environment have often preferred to describe their activities as rehabilitation, or the reinstatement of an acceptable degree of species diversity or ecosystem function (Bell, 1996; Ehrenfeld, 2000). Complete ecological restoration is an entirely justifiable goal (Murcia et al., 2014) and is attainable in some circumstances for mined land (Koch and Hobbs, 2007; Humphries, 2013), but its full costs should be incorporated in the planning and financing of any disturbance (Koch and Hobbs, 2007; Blignaut et al., 2014). Where complete restoration is not possible, different objectives for the form and function of the final landscape may be unavoidable (Holl and Howarth, 2000; Ellis et al., 2013; Audet et al., 2015). Because rehabilitation objectives are critical to the design and execution of mine operations as well as to rehabilitation activities themselves, it is necessary to ensure that they are conceptually sound, acceptable to society and practically attainable (Cairns, 2000; Tongway and Ludwig, 2011; Burton et al., 2012; Perring et al., 2013; Balaguer et al., 2014; Blignaut et al., 2014; Glenn et al., 2014; Murcia et al., 2014; Burger, 2015; Koch, 2015; Wiens and Hobbs, 2015).

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http://dx.doi.org/10.1016/j.ecoleng.2015.09.063
0925-8574/

In Australia, the reinstatement of natural or native ecosystems has become a common goal for mined land rehabilitation (e.g., ANZMEC/MCA, 2000; Bell, 2001; DITR, 2006), based on the premise that natural ecosystems represent the highest ecological value of a site. Less desirable rehabilitation goals include, in decreasing order of preference, the development of a higher value commercial land use, reinstatement of the previous use, or the development of a lower value use (DEHP, 2014a). Operational permits commonly specify conditions to be attained in different parts of a mined area (e.g., mine pits, waste rock storage and process waste areas) and at various stages of the operation (ANZMEC/MCA, 2000; DEHP, 2014a). The progress of rehabilitation is judged against objectives that may change with time but often equate eventually with the pre-disturbance condition (Grant, 2006; Grant and Koch, 2007; Suding and Hobbs, 2009; Koch, 2015; Wiens and Hobbs, 2015) or with specified reference or analogue sites (DEHP, 2014a). Therefore, the selection of these analogue sites and the evaluation of the differences between them and rehabilitated areas become critical components of mine closure (Doley and Audet, 2015).

Where environments are generally favourable for plant growth, it is possible to re-establish stable and productive landscapes (Parrotta and Knowles, 1999; Koch and Hobbs, 2007; Zipper et al., 2013; Burger, 2015) and pre-existing biodiversity (Cristescu et al., 2012; Humphries, 2013). It is critical to set the highest possible rehabilitation standards (Hobbs et al., 2013; Murcia et al., 2014; Perring et al., 2014; Koch, 2015; Wiens and Hobbs, 2015), but their attainment may be difficult where physical resources (e.g., soil, water and nutrient quantity and quality) are limited, as in many semi-arid environments in Australia (e.g., Vickers et al., 2012; Audet et al., 2013; Commander et al., 2013; Gwenzi et al., 2014). Where introduced species were not abundant prior to disturbance, native species may re-occupy sites (Koch and Hobbs, 2007; Gwenzi et al., 2014), so that pre-disturbance ecosystems can represent attainable targets for mined land rehabilitation. However, the biodiversity of many ecosystems in arid and semi-arid Australia has been threatened by invasive, stress resistant and vigorous introduced pasture grasses such as *Cenchrus ciliaris* (buffel grass) (Grice et al., 2012; Marshall et al., 2012; Firn et al., 2013) and mined lands are no exception, especially where buffel grass has been used in the rehabilitation seed mix. Species assemblages on rehabilitated mine sites surrounded by rangelands may differ considerably from undisturbed native arid woodlands (Low et al., 2012) and semi-arid grasslands (Vickers et al., 2012) for several years after treatment and they may show little evidence of returning to the reference condition (Erskine and Fletcher, 2013). Therefore, it is necessary to consider how the broad objectives of ecological restoration can be interpreted and applied to mine site rehabilitation in resource-limited environments where introduced and managed forage species are dominant components of pre-mining plant communities.

This report describes the development of grassland and woodland vegetation over an eight-year period on waste rock dumps from a phosphate mine in semi-arid Queensland, Australia. Quantitative vegetation attributes were evaluated in order to identify and test progress towards mine closure and lease relinquishment goals imposed by two fundamentally different regulatory regimes.

2. Materials and methods

2.1. Bioregional description

A rock phosphate mine and fertiliser production facility is operated by Southern Cross Fertilisers Pty Ltd at Phosphate Hill, Queensland, Australia (−21.88, 139.97, 270 m a.s.l.). The mine sources fine-grained siliceous and calcareous phosphorite deposits near the edge of a Cambrian sedimentary basin bounded by granitic and volcanic rocks (Russell and Trueman, 1971). The landscape is characterised by low stony ridges separated by broad valleys and plains drained by intermittent streams of low gradient (Neldner et al., 2014). Soils in the area are sandy loams with a stony surface layer on hill slopes and loams to clay loams on surfaces of very slight inclination (<5 degrees) (Merry, 1999). The native vegetation in the area is described as low open woodland, of the Southwestern Downs sub-unit of the Mulga Downs biogeographical region (DSEWPC, 2012; Neldner et al., 2014).

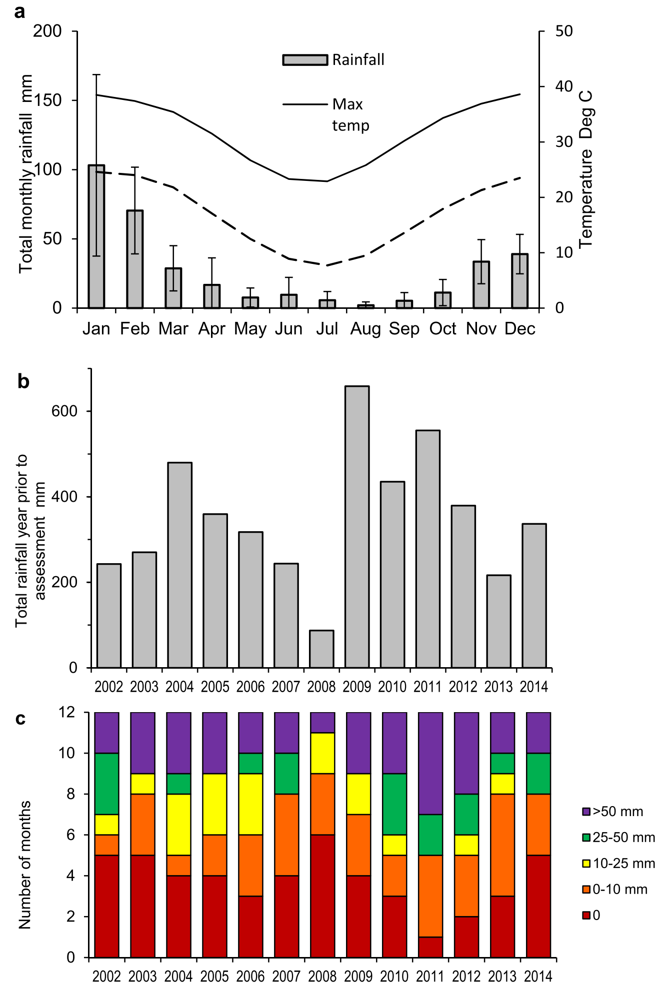

Fig. 1. Climate data relevant to Phosphate Hill, Queensland. (a) Mean monthly rainfall (mm) for The Monument Airport (−21.82, 139.92, approximately 9 km north-west from Phosphate Hill) between 2001 and 2013 and mean monthly maximum and minimum temperatures at Boulia Airport (−22.91, 139.90, 116 km south from Phosphate Hill) between 1888 and 2013 (BOM, 2014a). Vertical bars indicate rainfall confidence limits (P = 0.05); (b) total rainfall and (c) distributions of monthly rainfall totals at The Monument Airport in 12 months prior to rehabilitation establishment or vegetation monitoring at Phosphate Hill between 2002 and 2014.

The climate is classified as *BSh* (B = arid, S = steppe, h = hot) in the Köppen and Geiger Classification (Kottek et al., 2006). Mean annual rainfall is 352 ± 83 mm (P = 0.05), with large variations between years and frequent long rainless periods (Fig. 1; BOM, 2014a). The estimated annual evaporation at Phosphate Hill is about 3000 mm (BOM, 2014b). Vegetation assessment was carried out between July and September each year, so the distribution of rainfall in the 12 months prior to inspections was classified into months with 0, 0–10, 10–25, 25–50, and <50 mm of rainfall (Fig. 1c).