Journal of Environmental Management 227 (2018) 386–394

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Topsoil application during the rehabilitation of a manganese tailing dam increases plant taxonomic, phylogenetic and functional diversity

Rafael Almeida Ribeiro, Tereza Cristina Giannini*, Markus Gastauer, Marcelo Awade, José Oswaldo Siqueira

Instituto Tecnológico Vale, Rua Boaventura da Silva, 955, 66055-900, Belém, Pará, Brazil

ARTICLE INFO

Keywords:
Biodiversity
Amazonia
Mining
Sustainable development
Soil rehabilitation
Natural regeneration

ABSTRACT

Rehabilitation of tailing dams poses important challenges because sterile materials and poor or even toxic soils hinder plant development and the regeneration of the pre-mining-activity biota. In this study, we analyzed the effectiveness of rehabilitating a 14-year-old manganese tailing dam by comparing three different regeneration treatments (topsoil application, seedling plantation and spontaneous regeneration) with undisturbed reference sites. We used soil chemical composition, taxonomic, functional and phylogenetic diversity and the above-ground tree biomass as indicators of rehabilitation success. In terms of soil chemical composition, we showed that the seedling and natural regeneration treatments were similar to one another but different from the reference sites. Topsoil application presented an intermediate chemical composition between the reference site and the other two treatments. Moreover, the species richness, Shannon diversity index and phylogenetic diversity indicated faster rehabilitation of ecosystem biodiversity with the topsoil treatment, although levels from reference are not yet achieved. We also observed higher basal area and biomass production in the topsoil treatment. However, these patterns were not observed for functional diversity, for which no differences among treatments were observed. We concluded that topsoil application provided the best results; however, we must emphasize that even this approach was not sufficient to rehabilitate the system to the similar level of biodiversity found in the surrounding ecosystem up to the present.

1. Introduction

The restoration of degraded areas aims to recover the original conditions of the modified habitat or ecosystem, returning these conditions as closely as possible to their historical reference state (Balaguer et al., 2014). Restoration can reconstruct habitats to protect biodiversity, as well as to address global climate change, enhancing carbon sinks and thus helping to reduce the impacts associated with greenhouse gas emissions (Harris et al., 2006; Lal, 2004). However, efforts are not always fully successful in practice due to many constraints, including the difficulty of obtaining viable seeds or seedlings and the high costs of implementing restoration programs (Suding, 2011; Seddon et al., 2014). Additionally, scientific evidence for the better performance of restoration techniques in a wide range of ecosystems is lacking (Boanares and Azevedo, 2014; Holl et al., 2016), especially on tropical habitats under different rates of precipitation and plant succession.

Habitats have been modified rapidly mainly because of land use and climate change (Harris et al., 2006), raising questions about novel ecosystems, defined as unique biotas resulting from human alteration (Morse et al., 2014). In this situation, it is assumed that the original conditions are difficult to accurately replicate and that the ecosystems resulting from human-mediated processes will not be identical to the historical reference sites. In this case, the word "rehabilitation" is applied (SER and PWG, 2004), and the rehabilitation process aims to develop a novel ecosystem with rich biodiversity and intact major ecosystem services (Montoya et al., 2012).

Some practical approaches have been suggested to enhance the chance of successful rehabilitation projects. Passive techniques, such as the removal of anthropic disturbances and the integral protection of disturbed areas leading to natural (spontaneous) revegetation, can be used (Hodacova and Prach, 2003). Active approaches, such as the use of fertilizers (Holmes, 2001; Daws et al., 2013), seeds or seedlings (Holl et al., 2011; Bertacchi et al., 2016) or topsoil (Ferreira et al., 2015; Cristescu et al., 2012), may accelerate ecosystem rehabilitation (Holl and Aide, 2011; Morrison and Lindell, 2011; Holl et al., 2013), but

* Corresponding author.
E-mail addresses: rafael.ribeiro@vale.com (R.A. Ribeiro), tereza.giannini@itv.org (T.C. Giannini), markus.gastauer@itv.org (M. Gastauer), marcelo.awade@pq.itv.org (M. Awade), jose.oswaldo.siqueira@itv.org (J.O. Siqueira).

https://doi.org/10.1016/j.jenvman.2018.08.060
Received 6 April 2018; Received in revised form 16 July 2018; Accepted 14 August 2018
0301-4797/

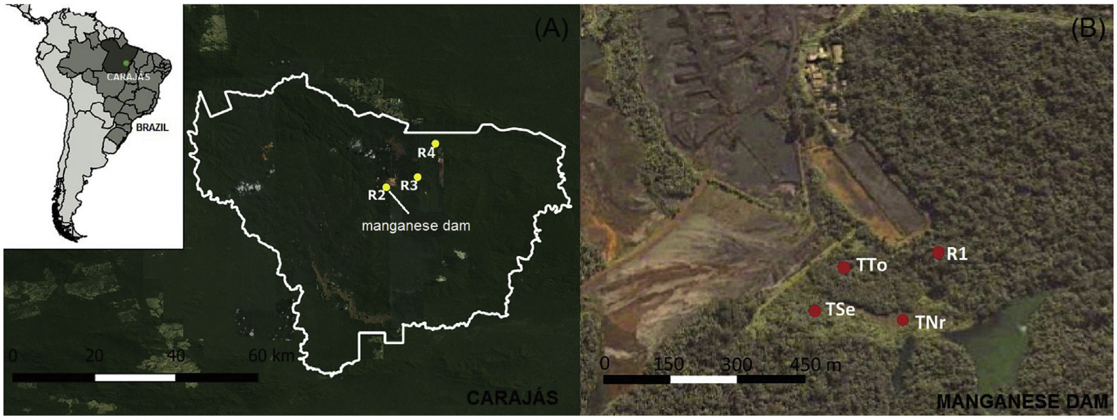

Fig. 1. Study area of manganese Kalunga dam in the National Forest of Carajás (Pará, Brazil) showing the approximate locations of the (A) three reference sites (R2, R3, and R4) and (B) four treatment plots (topsoil application [TTo], seedling plantation [TSe], natural regeneration without human intervention [TNr] and a reference forest remnant near Kalunga dam [R1]). For details, see the Methods.

caution is necessary when considering the negative effects of fertilizers on biodiversity (Mozumder and Berrens, 2007; Hautier et al., 2009; Královec et al., 2009; Dickson and Foster, 2011). Incorporating multiple trait approaches to select plants for the rehabilitation of degraded areas (Giannini et al., 2017) and including other taxa than plants (pollinator bees and/or seed dispersers) have been suggested in order to increase the chance of rehabilitation success (Griffin et al., 2017; Kaiser-Bunbury et al., 2017). These approaches can increment the functional diversity and the complexity of trophic networks, thus helping to provide ecosystem services to local human communities.

Tailings are mixtures of crushed rocks and processing fluids that remain after the extraction of metals, minerals, mineral fuels or coal from a mine, which are often stored in impoundments behind dams (Kossoff et al., 2014). Due to the mining process, the original soil is usually lost or damaged, with a consequent lack of organic matter and its associated nutrients such as nitrogen (N), increasing risk of erosion, drought, surface mobility, compaction and temperature fluctuations (Wong, 2003). Tailing pond spills also are relatively common due to embankments filled by diverse materials, insufficient regulation and monitoring of projects, lack of stability of the dam, and high cost of maintenance after the closure of mining activities (Rico et al., 2008). In some cases, the contamination of dam's soil by heavy metals restricts the growth of non-tolerant plants, affecting also the number, diversity and activity of soil organisms (Remon et al., 2005), which may be corrected through biological interventions (Juwarkar and Jambhulkar, 2008). In some cases, post-industrial wastelands can provide important refuges for biodiversity, as already shown for invertebrates (Tropek et al., 2013; Heneberg et al., 2013; Heneberg and Rezác, 2014; Bogusch et al., 2016), including rare species of wasps (Twerd et al., 2017). However, rehabilitation can be jeopardized because industrial wastelands substrates usually contain high metal levels and multi-metal presence, which hinders species accumulation ability (Li et al., 2007), reinforcing the necessity to define thresholds for the species used (Paschke et al., 2005). Specially the rehabilitation of manganese mine areas with different concentrations of manganese in the soil may present additional challenges, due to soil toxicity and manganese accumulation in plant tissues (Yang et al., 2008, 2014). On the other hand, manganese mine rehabilitation was demonstrated as being an important strategy to increase soil organic carbon levels, which potentially can help on buffering local climate change (Juwarkar et al., 2010).

Species richness, a commonly used descriptor to monitor the success of rehabilitation practices, has been associated with other metrics in the search for a more comprehensive definition of the effectiveness of rehabilitation methods. Some studies have estimated functional and phylogenetic diversity to describe the community in functional and evolutionary terms, respectively, and not just taxonomically (Navarro-Cano et al., 2016; Gastauer et al., 2018). For example, taxonomic, functional and phylogenetic diversity were considered good indices to assess the effects of restoration on a Lishan mountain meadow (northern China, Qin et al., 2016). Using functional diversity reinforced the results obtained through more traditional approaches, and helped to identify those functions that are more easily restored in endangered habitats of Central Europe (Engst et al., 2016). In addition, the positive effects of facilitative interactions increased in relation to the evolutionary distance between species occurring in the same areas, reducing niche overlap and, therefore, reducing competition (Verdú et al., 2012). Phylogenetic diversity measures provided information on the processes that affect the successional trajectory of plant species assemblies in rehabilitation programs, aiding in understanding the similarity of phylogenetic structures between restored sites with different ages (Schweizer et al., 2015). Moreover, the use of phylogenetic diversity as a proxy for functionality has been recommended as an effective measure to monitor restoration (Montoya et al., 2012), becoming an important tool for restoration practice (Hipp et al., 2015).

In this study, we aim to compare three different rehabilitation treatments (topsoil application, seedling plantation and spontaneous regeneration) applied 14 years ago in a manganese tailing dam in the Amazon Tropical Forest of Carajás (southeastern Pará State, Brazil). We analyzed the effects of rehabilitation strategies using soil chemical composition and taxonomic, functional and phylogenetic diversity as well as the aboveground tree biomass as indicators and compared these variables with those at reference sites near the manganese tailing dam. This comparison is important to guide the rehabilitation work that has been conducted in the region, as well as to provide a practical approach that can be used in other areas that need to be rehabilitated.

2. Methods

2.1. Study site and rehabilitation strategies

Field work was conducted in the “Kalunga” dam, one of the dams of the “Azul” Manganese Mine located inside the Amazon Tropical Forest of Carajás, a protected area in the southeastern Pará (Brazil) (5°S52′11″ to 6°S32′13″ latitude and 49°W53′28″ to 50°W44′29″ longitude) (Fig. 1). The study site is included in the Aw climate (Peel et al., 2007), under the altitude of 474 m.

The project of Kalunga dam dates from 1987, and was intended to retain solid and liquid waste from manganese ore beneficiation processes. The axis of this dam is located in a section where the area of the hydraulic basin reaches 8.6 km^2. Nowadays, it is exclusively destined to the industrial water supply, since the life of the dam for waste disposal