Ecological Engineering 103 (2017) 191–197

Contents lists available at ScienceDirect

Ecological Engineering

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

Key plant indicators for monitoring areas undergoing restoration: A case study at the *Das Velhas* River, southeast Brazil

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ARTICLE INFO

Article history:
Received 17 November 2015
Received in revised form 10 March 2017
Accepted 1 April 2017
Available online 12 April 2017

Keywords:
Ecological restoration
Model selection
Monitoring indicators
Urban forests

ABSTRACT

In restoration ecology, the search for key variables which allows an informative and concise diagnosis on areas undergoing restoration is still a challenge. Choosing which indicators to use is a fundamental decision when proposing monitoring of any restored area. Here, we have aimed to contribute with the selection of key indicators by identifying plant parameters that are useful to assess restored areas in using a 5-year-old rehabilitated riparian forest as a case study. Initially, we used 14 descriptors to assess the ecosystem attributes of structure, diversity and ecological processes, and then we conducted a model selection to identify variables that best explained the restoration success (defined as the richness of native tree species). Our final model contained six parameters: native tree species (the response variable), native and exotic species of other life forms, basal area, tree density, and canopy openness) and an adjusted R^2 of 92%. As the predictive model doesn't contain variables related to ecological processes, we included seedling recruitment or litterfall production to evaluate this attribute. The selected indicators evidenced that the tree layer has yet to develop and accumulate biomass, the forest has been enriched by species of other life forms (although many of them were exotic and invasive), and exotic tree and shrub species were dominating seedling recruitment. Such a scenario is likely to occur because the forest is located in an anthropogenic region, and highlights the importance of conserving remnant areas as propagule sources. We suggest some managing actions for the area, and conclude that not all measured indicators were necessary to facilitate good vision about the studied forest (because many had collinear responses), which may be important for directing other monitoring projects and save time and money.

1. Introduction

Ecological indicators play an important role in monitoring, evaluating and managing (Lin et al., 2009) both natural remnant ecosystems, or sites undergoing restoration. Ecological indicators are an attempt to avoid complicated measures and reduce ecosystem complexity, selecting simple parameters that can lead to satisfactory representation from a complex relationship (Müller and Lenz, 2006). In ecological restoration, indicators are generally used after project implementation, aiming to understand the current situation of the area, and to verify if some type of intervention is needed to accelerate the restoration process (Martins, 2011).

The discussion over the use of monitoring indicators has been increasing, mainly considering the requirements for establishing good parameters (Rodrigues and Gandolfi, 1998). In this sense, some studies have been trying to find indicators that better evaluate restoration success; for example, litterfall structure, species richness of plants, birds and ants (Ruiz-Jaén and Aide, 2005), canopy cover, basal area, and seedling recruitment (Suganuma and Durigan, 2015), etc. Even so, establishing key monitoring indicators is a challenge because implementing many parameters is expensive and does not always reach a proper/effective diagnosis of the area under restoration (Brancalion et al., 2012). Nevertheless, at the same time that monitoring indicators are desirable, it is hard to select which parameters to use due to (1) the complexity and individuality of each ecosystem and (2) because there are many indicators available.

Here, we address the problem of which indicators to use for monitoring areas undergoing restoration. We used a lot of plant indicators to evaluate a newly restored riparian forest in southeastern Brazil and then asked: Would it be necessary to use all the descriptors to make a good diagnosis of the area? Could some of them be removed? Which are collinear? Which indicators should be used? This study aimed to contribute to selecting key indicators for

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http://dx.doi.org/10.1016/j.ecoleng.2017.04.012
0925-8574/

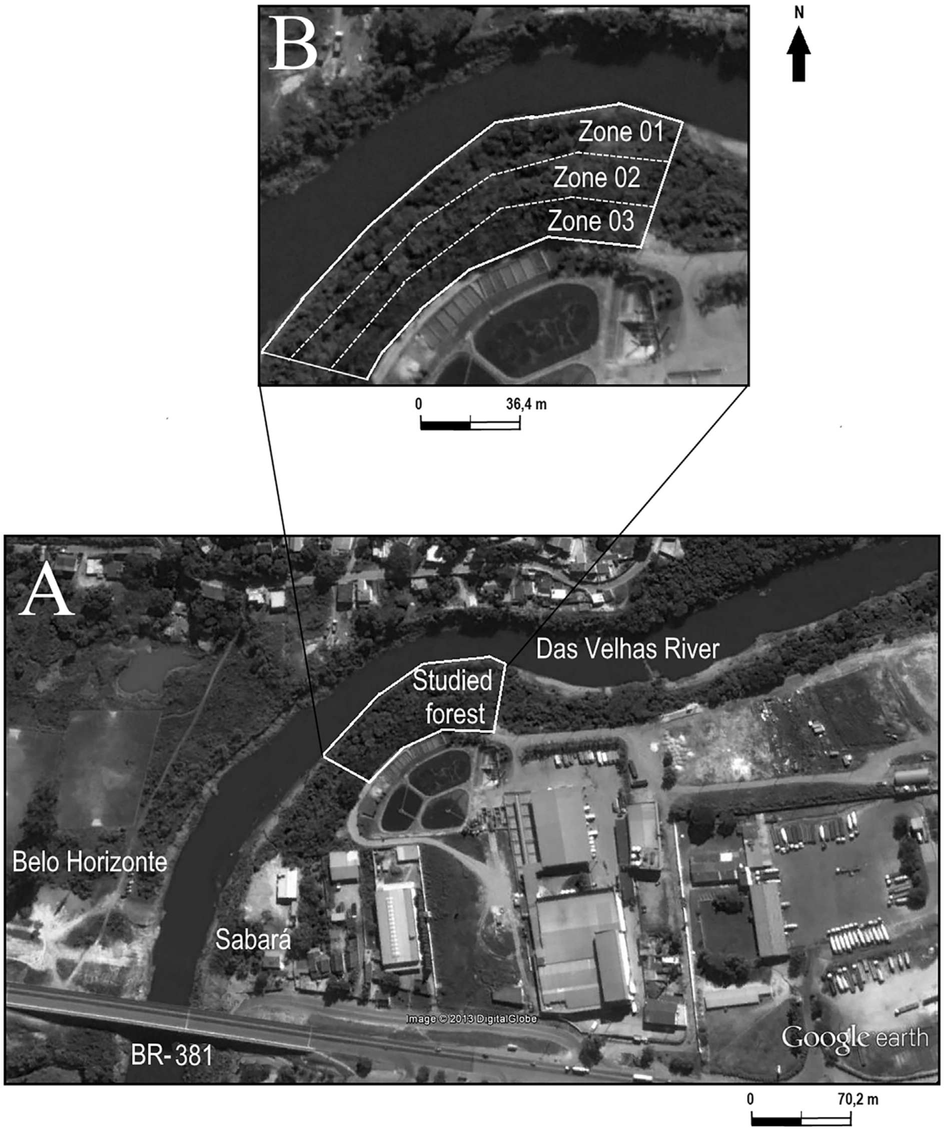

Fig. 1. Location of the studied area at *Das Velhas* River in Minas Gerais State, southeastern Brazil, detailing the anthropogenic region where the forest is located (A), and the three buffer zones where permanent parcels were installed (B). Font: Google Earth 2015, images date: 6/30/2012.

monitoring areas undergoing restoration by identifying the "best" plant attributes from a set of variables taken from a five-year-old riparian forest.

2. Material and methods

2.1. Studied area

We studied a forest at the *Das Velhas* River, a watercourse located in the middle of Minas Gerais State in southeastern Brazil and considered the largest tributary of the São Francisco River (Polignano et al., 2001). Its water sources are in the municipality of Ouro Preto, and its margins become highly urbanized after some kilometers. This is mainly into the metropolitan region of Belo Horizonte where the river is strongly degraded, although it is the main water course of the region (Polignano et al., 2001).

The studied forest is situated downstream of highway bridge BR-381 between the municipalities of Belo Horizonte and Sabará (Fig. 1A). The climate of the region is tropical with two well-defined seasons (a rainy season from November to April, and a dry season from May to October), with an average annual maximum temperature of 27.2 °C, a minimum temperature of 17.9 °C, and an average annual rainfall of 1549.8 mm (INMET, 2016–monthly data from 1986 to 2016, except 1987).

The forest belongs to a Program called the *Manuelzão* Project for the revitalization of the *Das Velhas* River, which is being developed by the Federal University of Minas Gerais (UFMG). The studied area has a slaughterhouse and a residential district around it, and in 2007 due to problems caused by deforestation, siltation and erosion of the riverbanks, a flooded forest (among other actions) of approximately 0.5 ha was implanted in the area aiming to stop soil erosion and reduce risks to nearby residents (Fig. 1A).

First, the area was cleared. Then some physical barriers made of rocks and wood were installed along the watercourse and the ground was leveled, keeping an elevational difference from the watercourse to 50 m at the margin. The restoration method was by total planting (2 × 2 m) and a model of buffer zones based on Schultz et al. (2004) was used to create a riparian forest. In this model three zones are implanted, each one with different species composition and function, namely: zone 1 – an unmanaged area adjacent to the