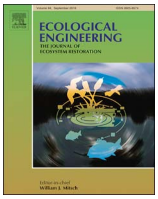
Ecological Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ecological Engineering

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



Prospecting the potential of ecosystem restoration: A proposed framework and a case study

Alexandre Marco da Silva*, Ludmila Araujo Bortoleto, Karen Regina Castelli, Rosiane Argenton e Silva, Pablo Bettio Mendes

Department of Environmental Engineering, Institute for Science and Technology of Sorocaba, São Paulo State University, 511, Tres de Marco Avenue, Altos da Boa Vista, Sorocaba, SP, 18087-180, Brazil

ARTICLE INFO

Keywords:
Assisted restoration
Ecological restoration
Environmental degradation
Landscape connectivity
Multi-scale model
Passive restoration

ABSTRACT

Projects focusing on the restoration of degraded ecosystems have to be financially appealing, spatially multi-scaled, and ecologically efficient. Considering such premises, a model was elaborated to assess the locals in relation to the kind of management to be adopted (conservation or restoration) and, for locals indicated for restoration, the kind of restoration to be adopted (assisted or passive). Furthermore, we propose a set of ecologically-based alternatives at medium- and local-scale to assist the restoration of areas considered unsuitable for passive restoration. Such techniques are: install artificial connectors among forest fragments near each other, or, for areas where forest fragments are far each other, install nucleation techniques, revitalization of concrete-lined urban rivers, and the control of erosion and invasive plant species. We tested the potential of our model through a case study carried out in Sorocaba, Sao Paulo State, Brazil. The study area is predominantly occupied by pasture lands, but urbanization also is an important land cover category. There are 661 forest fragments, being 25 of them larger than 50 ha. From the area considered "non-habitat", i.e., modified due to human usage, 35.5% of the total study area and 45.5% of the study area classified as non-habitat is suitable for passive restoration, and the rest of the area needs is suitable only for assisted restoration techniques. We verified that the facility and low cost of installation are advantageous features of such techniques and the results obtained by mean of application of the assisted techniques indicate that the alternatives tend to accelerate the process of establishing connectivity of the landscape in locals devoid of connections.

1. Introduction

Humans are transforming the biosphere in unprecedented ways, and changes in land cover are one of the main pathways of this transformation (McGill et al., 2015). One of the main impacts of this change involves impacts on biodiversity, usually by impoverishing the number of species (Lambin and Geist, 2008). The number of species is usually diminished because of habitat fragmentation and the invasion (or intentional introduction) of exotic species (Tilman et al., 2017).

Hence, we are faced with two alternatives: conserving the remaining natural habitats and restoring the ecosystem functions of those already degraded. Ecosystem functions relate to the structural components of an ecosystem (e.g. soil, water, vegetation, biota, and atmosphere) and how they interact with each other, within ecosystems and across ecosystems (Jax, 2005; Poschlod and Braun-Reichert, 2017), and might be exemplified as soil generation and fertility, regulation of hydrological flow and purification of water, dispersal of seeds and other propagules, manufacture of organic materials from inorganic ones by producers, among others (Marcot and Vander Heyden, 2001; Schulze and Mooney, 2012; Traveset et al., 2013).

Given the urgency with which management problems need to be tackled, habitat managers are frequently unable to wait for rigorous tests of threshold theory to determine whether the systems they are attempting to manage exhibit threshold or hysteresis dynamics (Suding and Hobbs, 2009).

To be attractive and viable in terms of management, ecological restoration projects should be financially appealing, ecologically efficient, multifaceted, and incorporate realistic disturbance frequencies (Whisenant, 1999; Walker et al., 2007). These projects require technical and ecological knowhow to address threats to soil and species loss and to support ecological succession and ecosystem health (Suding and Hobbs, 2009; Murcia et al., 2015).

Ecological restoration can be achieved via two main approaches (Prach and Hobbs, 2008; Speed et al., 2016). The first, called passive

---

* Corresponding author.
E-mail address: amsilva@sorocaba.unesp.br (A.M.d. Silva).

http://dx.doi.org/10.1016/j.ecoleng.2017.07.024
Received 6 May 2017; Received in revised form 16 July 2017; Accepted 18 July 2017

Please cite this article as: da Silva, A.M., Ecological Engineering (2017), http://dx.doi.org/10.1016/j.ecoleng.2017.07.024

restoration or unassisted natural succession, requires no intervention; it is a low-cost restoration option and may be considered suitable when a degraded system appears to have the capacity to recover unaided (Hobbs and Cramer, 2008). The second, called technical or assisted restoration, is usually considered based on the need to manipulate either physical environmental conditions or biota in order to accelerate the process of restoration and drive the process to the desired goal (Jackson and Hobbs, 2009).

There are several GIS-based models for various types of environmental analyses, including erosion (Beskow et al., 2009), environmental risk (Yin et al., 2014), landscape connectivity (Liu et al., 2014), and restoration measures (Piniewski et al., 2012; Patel et al., 2015). GIS-based models that support the indication of suitable areas for passive or assisted restoration actions also exist (O'Neill et al., 1997; Bortoleto et al., 2016; Vettorazzi and Valente, 2016). The development of a multi-scaled and integrated project, embracing both passive and assisted restoration, might be useful for indicating suitable areas to receive both types of actions for restoration and for identifying the best point or local alternatives to restore ecosystem functions.

Hence, we elaborated a model to assess the locals in relation to the kind of management to be adopted (conservation or restoration) and, for locals indicated for restoration, the kind of restoration (assisted or passive). Furthermore, we propose, conjugated with a study case, a set of suitable ecologically-based alternatives at medium- and local-scale to assist the restoration of areas considered unsuitable for passive restoration.

2. Materials and methods

2.1. Background on the model

The framework was designed following guidelines from Higgs (1997) and Bergen et al. (2001), aiming to:

- take into account the principle of a top-down model in terms of scale, i.e., starting from a generalized, broad scale and moving towards a local, point scale;
- not be species-specific, but rather to focus on the structure and particularly the functionality of the ecosystems;
- allow for local and adaptive management practices, using the maximum resilience potential of the local area;
- encourage interaction between scientists and stakeholders, while aiming to be socially feasible and acceptable;
- be easily understandable by those without expertise in ecological recovery and restoration;
- be based on scientifically established knowledge and considering financially realistic and attainable alternatives, although the use of local, indigenous knowledge might also be taken into account; and
- require material that is easy to obtain in order to begin the analysis (i.e. satellite images) and that can be developed straightforwardly, regardless of the GIS package used.

2.2. Case study development

The case study approach allowed us to test the proposed conceptual framework in a real-world situation; it was adopted and is described as follows.

2.2.1. Local features of the case study area

The area considered in this study was the Sorocaba municipality, in southeast Brazil, (Fig. 1 – see link to Google Earth), which covers an area of 449.8 km^2 (IBGE, 2016). Summers in this region are usually rainy and warm (mean monthly precipitation of 176 mm and mean monthly temperature of 24.6 °C) while winters are usually moderately cold and dry (47.6 mm, 19.0 °C). Oxisols and Alfisols are the major soil types; both are typically brown and deep with very low or no stoniness, Gleysols and Cambisols also occur within the region (Oliveira et al., 1999). The terrain is predominantly gently sloped, and in some areas, it is moderately or even strongly sloped. In geological terms, the bed rocks are generally fine- to medium-grained sandstones (IGSP, 2009).

The study region contains a dense river network, with at least 2332 headwaters and approximately 1199 km of river channels (Silveira et al., 2009). The area was originally an ecotonal region combining Atlantic Rain Forest and Brazilian Savanna vegetation (Kronka et al., 2005); however, most of the vegetation was removed, especially in the second half of the last century, to establish agricultural land and residential districts.

In 2016, the population of Sorocaba was approximately 650,000, with over 98% of its residents living within urban zones (IBGE, 2016). Land cover changes, for human purposes, have been occurring in this area for the past 400 years; in the last three decades in particular, considerable changes have occurred, principally to increase urbanization and expand road networks. Such shifts in landscape patterns have provoked a strong reduction in ecological connectivity at both the local and regional levels (Smith et al., 2014). Currently, hundreds of forest fragments are dispersed throughout the study area (Bortoleto et al., 2016). In the past five years, municipal staff has demonstrated more concern regarding the loss of natural areas and connectivity among the remaining forest fragments, as well as for other environmental problems (for example, pollution of the Sorocaba River, the major river crossing the city). This has generated opportunities for dialog between local universities and municipal staff, with the goal of elaborating and executing projects focusing on environmental conservation and recovery. This interaction has seen the creation of at least two municipal parks, the strengthening of conservation efforts in existing parks, and the restoration of riparian vegetation along several streams within the municipality, among others. In addition, opportunities have arisen for the development of ecological and engineering-related projects at local and regional scales.

2.2.2. Case study methodology

We selected a Landsat-8 image satellite (path/row 220/76, April 9, 2016) and classified it using the supervised maximum likelihood classification method, following the steps described in Bortoleto et al. (2016). In brief, land cover data on 176 georeferenced points were collected through several field visits and were used during the classification. The mapping was validated, with the map reaching an 85% similarity with field data, as assessed using Cohen's kappa coefficient (Lillesand et al., 2014). The land cover categories used were wood sites, water bodies, pasture land, agricultural fields, bare ground, and urban settlements.

Following the completion of these steps, the land cover map was ready for use in testing the model.

3. Results

3.1. The model

The model is summarized as a flowchart (Fig. 2) and is described literatim ahead. We assume that users of the model are in possession of a digital, georeferenced land cover map of the region of interest to be studied.

The first step was to categorize the map into areas classified as habitat and non-habitat. This simplification of the analysis process allows the identification of areas with the potential to host natural biodiversity. We proceeded with the steps systematically, as described below.

The steps:

A – Develop the land cover map: The analysis began with the classification of the digital image satellite to generate a land cover map. We understand that different users of the model may create different categories of land cover; regardless of the classes of anthropogenic