Land Use Policy 75 (2018) 486–493

Contents lists available at ScienceDirect

Land Use Policy

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

Ecological restoration efforts in tropical rural landscapes: Challenges and policy implications in a highly degraded region

Renato Miazaki Toledo[a,b,*], Rozely Ferreira Santos[a], Kris Verheyen[b], Michael P. Perring[b,c]

[a] LEPaC, Departamento de Ecologia, Instituto de Biociências, Universidade de São Paulo, Rua do Matão, 321, Travessa 14, CEP:05508-090, São Paulo-SP, Brazil
[b] Forest & Nature Lab, Department of Environment, Ghent University, Geraardsbergsesteenweg 267, 9090 Melle-Gontrode, Belgium
[c] Ecosystem Restoration and Intervention Ecology Research Group, School of Biological Sciences, The University of Western Australia, 35 Stirling Highway, Crawley WA, 6009, Australia

ARTICLE INFO

Keywords:
Tropical agroecosystems
Land-use change
Restoration policies
Global targets
Effectiveness

ABSTRACT

Ecological restoration has received increasing attention as international agreements have set ambitious goals to mitigate environmental change and reshape degraded landscapes. However, current restoration activities sometimes remain modest in their success. In particular, tropical forest restoration has had mixed outcomes with variable cost-efficiency. Here, we address the need for taking into account the spatial context of restoration to inform policy initiatives that aim to improve the ecological and economic effectiveness of restoration. We accessed the spatial distribution of relevant characteristics for ecological restoration in an emblematic heavily degraded tropical region: São Paulo state, Brazil. We compared statewide patterns in soil erosion risk, distance to remnant habitat, and agricultural land use, to their characteristics in land voluntarily offered for active restoration. Based on this comparison, active restoration is likely to take place through small, low-priced parcels of land, usually in the context of substantial soil erosion risk and exacerbated deforestation. Restoration ecology predicts the need for expensive actions to assist a limited recovery process in such highly degraded conditions. This general pattern also suggests the necessity for long-term commitment among a broad set of social actors, combined to mitigation of degradation in adjacent remnants and agricultural lands. Active restoration may be complemented by spontaneous regeneration in areas with less adverse conditions. Policy makers therefore need to consider the complementarity of lands voluntarily offered for restoration, and land made available for restoration through other mechanisms. Our findings, likely applicable to other densely populated tropical regions, suggest that land-use policies need to address drivers of restoration success at a fine-scale to enable effective strategies. We suggest this can be achieved by spatial analyses that incorporate biophysical features that determine restoration opportunities and the likelihood of success.

1. Introduction

Ecological restoration is increasingly gaining prominence as a means to address concerns around biodiversity loss and availability of ecosystem services (Suding, 2011; Trabucchi et al., 2012; Brancalion et al., 2013). Accordingly, extensive restoration endeavors have been implemented in degraded habitats, such as grasslands, wetlands, rivers and forests (Jonson, 2010; Koebel and Bousquin, 2014; Mansourian and Vallauri, 2014; Theiling et al., 2015). Large-scale restoration projects have also been proposed to recover neotropical hotspots for biological conservation (Chazdon, 2008; Calmon et al., 2011; Durigan et al., 2013). These regional programs are interconnected by collaborative networks (Echeverría et al., 2015), such as the Global Partnership on Forest and Landscape Restoration, and are associated with global agreements such as the 2010 Aichi Convention on Biological Diversity, the 2011 Bonn Challenge, and the 2014 New York Declaration (Suding et al., 2015). Efforts of such magnitude imply a substantial land use conversion. For instance, the global commitment of the Bonn Challenge embraces the restoration of 150 million hectares of degraded and deforested lands, and the Aichi target encompasses the restoration of 15% of degraded ecosystems. The high demand of areas for restoration necessitates land use policies that reflect the ecological reality of land being allocated for restoration. Implementing appropriate policies has the potential to reverse environmental degradation associated with the widespread non-compliance with habitat protection laws (Payés et al., 2013; Terra et al., 2014).

Conversion of deforested lands has been addressed using native tree plantations as a central restoration technique (Lamb et al., 2005;

---

[*] Corresponding author at: Departamento de Ecologia - USP, Rua do Matão, 321, Travessa 14, CEP:05508-090, São Paulo-SP, Brazil.
E-mail address: rmt@usp.br (R.M. Toledo).

https://doi.org/10.1016/j.landusepol.2018.03.053
Received 28 June 2016; Received in revised form 15 January 2018; Accepted 30 March 2018

Rodrigues et al., 2009). Generally, these interventions intend to foster regulating ecosystem services by converting agricultural fields into natural forests. However, the success of these plantations are still highly uncertain (Costa et al., 2016; Wuethrich, 2007). Varied outcomes have been reported for tropical forest restoration, even when similar protocols are implemented (Melo et al., 2007; Toledo et al., 2018). This empirical evidence is consistent with theory, once it is taken into account that the recovery process is forged by the interplay of biotic and abiotic legacies (Flinn and Vellend, 2005; Hobbs et al., 2009) and also by disturbance regimes, which are often variable at local and landscape scales (Holl and Aide, 2011; Suding, 2011), and affect how costly and how successful recovery interventions tend to be (Chazdon, 2008). These findings strongly suggest that land use policies for these tropical rural areas should be contextualized by taking into account the often neglected distribution of environmental conditions. This neglect is amply demonstrated by regulations demanding forest restoration to offset deforestation in São Paulo (Resolution 17 SMA-SP, 2017). In the State of São Paulo, each hectare of old-growth forest deforested in an area that is not a priority for conservation is compensated with two hectares of restoration. However, this rule doesn't take into account any feature of the area to be restored, so it embodies the belief that restoration is likely to be successful everywhere, which is inconsistent with ecological findings (Chazdon, 2008; Benayas et al., 2009).

Considering biotic constraints in a landscape context in the first place, it is well established that the amount of remnant habitat surrounding a restoration parcel is crucial for bolstering the supply of ecological functions in the parcel itself (Holl and Aide, 2011; Tscharntke et al., 2012). During the restoration process, biotic connectivity is required for reintegrating remaining and/or reintroduced biota into the landscape, thus supporting the recolonization of native biota and their interactions with surrounding populations (Barbosa and Pizo, 2006; Zahawi et al., 2013). An absence of habitat adjacency is particularly restrictive for the recovery of highly diverse ecosystems, since the reintroduction of a relevant portion of the pre-disturbance species richness is likely unfeasible by relying on costly and time-consuming actions such as numerous translocations (Banks-Leite et al., 2014). Under isolation, biotic arrivals may only include ruderal species, that are abundant in the disturbed surroundings, indicating that a biotic threshold to restoration, at least through passive means, may have been surpassed (Hobbs et al., 2009). Finally, the landscape moderates the flow of energy, resources and organisms across habitats (Tscharntke et al., 2012), such as between regenerating forests and pastures or crops. Therefore, the outcomes of restoration measured in a particular land use context are unlikely to be accurately transferable to other landscapes with alternative compositions and/or configurations. For instance, deficient recovery found in restoration actions in northeastern Brazil was in part attributed to particular conditions related to sugarcane dominated landscapes (Costa et al., 2016).

Estimating the extent of soil degradation will also aid anticipation of restoration results. Previous agricultural land-uses in tropical soils change their properties in different directions. For instance, Hunke et al. (2015) compared soil properties in different land-uses in the Brazilian Midwest: pastures had soil that was more compacted, lower in total nitrogen and higher in phosphorus and potassium, than sugarcane plantations. They also observed considerable macronutrient accumulation under soybean plantations. Weill and Spavorek (2008) and Ferraz et al. (2013) recorded intensifying soil loss rates under sugarcane plantations. Rodrigues et al. (2011) documented that anthropogenic wet fields created by siltation double in frequency at sugarcane farms, compared to mixed-use landscapes. Clearly, the interaction between soil and land-use promotes different legacies for recovery. In addition, soil erosion is recognized as a main agricultural legacy in the tropics. For example, studies show total soil loss in Brazil often exceeds 50 t $ha^{-1} y^{-1}$, or 3.5 times the global mean, indicating this region as a global hotspot for soil loss (Guerra et al., 2014).

Poverty and social conflicts are often found with the aforementioned altered environmental conditions in regions with demand for tropical forest restoration (Ceccon et al., 2015). Financial support for restoration, from offsetting agreements and payments for ecosystem services (PES), could balance the need for people to make a livelihood with the financial outcomes of restoration actions and resulting land use change (Banks-Leite et al., 2014). Nevertheless, economic valuation of environmental assets under restoration can be especially controversial when restoration is expected to be constrained by altered environmental conditions (see Bullock et al., 2011; Maron et al., 2012). Hence, identifying regions with adverse conditions for restoration, and their frequency, may aid strategic financial investment to maximize social and ecological returns.

Despite the recognition of these three inter-related variables (i.e. habitat distribution, soil erosion susceptibility and land use) as relevant predictors of biotic and abiotic constraints to tropical forest restoration, their distribution remains poorly evaluated within landscapes targeted for restoration programs, especially with regards to spatial inter-relationships. The literature provides rare examples of quantitative evaluation on this topic (e.g. Ceccon et al., 2015), but to the authors' knowledge, lacks spatially explicit approaches. Here, we address this knowledge gap by elucidating the spatial distribution of these three variables across São Paulo State, as well as in lands offered by their owners for active restoration. We then discuss the implications of these patterns for restoration success, both ecologically and societally. Finally, we suggest how land use policy can be formulated to account for spatially variable conditions, including through lands voluntarily offered for restoration and via spontaneous regeneration from land abandonment.

2. Methods

Our study region, São Paulo state, hosts over 45 million inhabitants (IBGE, 2017). The state comprises 2.9% of the national territory but supplies 32.6% of Brazil's gross domestic product (IBGE, 2013). Human activities, while promoting the GDP, have exposed this region to severe deforestation, fragmentation and soil degradation (Dean, 1997; Hansen et al., 2013; Guerra et al., 2014). Human land-uses encompass 83.6% of the state (CETESB, 2012), mostly with assorted agricultural uses, settled over two biodiversity hotspots: Brazilian Atlantic Forest and the "Cerrado" savannas (Myers et al., 2000). The widespread ecological degradation in conjunction with its threatened biodiversity makes São Paulo state an ideal candidate for large-scale ecological restoration. To evaluate the geographical distribution of lands offered for restoration we assessed the "restoration land bank of São Paulo", an administrative tool to which private landholders voluntarily offer areas to restoration actions. We had access to a list from 2013 with 399 enrolments, encompassing 2,896 ha from 87 municipalities. Surprisingly, 558 municipalities offered no enrolments. From 2014, this land bank was incorporated into the compulsory rural environmental cadastre (CAR), a much larger information system, which endeavours to include all rural properties of Brazil. However, this system is still being implemented, and so data were not available for the analysis herein. Furthermore, the spontaneous enrollments from 2013 provide a sample of engagement strictly related to an active restoration program.

We assessed spatial relationships between land offered for restoration and three predictors of restoration success: (a) distribution of remnant habitat, as an indicator of biotic conditions for recovery; (b) soil erosion susceptibility, as an indicator of edaphic vulnerability; and (c) land-use, as it defines legacies on a local scale and characterizes the neighbourhood context once a restoration action takes place. We therefore created a geodatabase, including remnant habitat distribution from the São Paulo State Forest Inventory of Natural Vegetation (1:25,000) (IF, 2010), a map detailing susceptibility to soil loss in São Paulo State (1:500,000) (IPT, 1994), and records from the restoration land bank. The forest inventory we used (IF, 2010) is a remote sensing product that classifies natural habitat patches according to vegetation