Forest Ecology and Management 257 (2009) 1219–1230

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Modeling landscape dynamics in an Atlantic Rainforest region: Implications for conservation

Ana Maria G. Teixeira [a], Britaldo S. Soares-Filho [b], Simone R. Freitas [a,c], Jean Paul Metzger [a,*]

[a] Department of Ecology, Institute of Biosciences, University of São Paulo, Rua do Matão, 321, travessa 14, 05508-900 Sao Paulo, SP, Brazil
[b] Center of Remote Sensing, Federal University of Minas Gerais, Av. Antônio Carlos, 6627, 31270-901 Belo Horizonte, MG, Brazil
[c] Federal University of ABC, R. Catequese, 242, 09090-400 Santo André, SP, Brazil

ARTICLE INFO

Article history:
Received 18 August 2008
Received in revised form 3 October 2008
Accepted 7 October 2008

Keywords:
Landscape dynamics
Atlantic Rainforest
Deforestation
Regrowth
Land-use and land-cover simulation
Biodiversity conservation
DINAMICA

ABSTRACT

The dynamics of the Atlantic Rainforest loss and recovery are still not fully understood despite its long history of human occupation. In this study, we investigated changes in an Atlantic Rainforest region due to major biophysical and human proximate causes. First, we modeled land-cover and land-use changes from 1962 to 2000, including deforestation and forest regrowth, and thereby simulated future landscape trajectories to assess their possible effects on the conservation of forest species of the Ibiúna Plateau, a region located in Southeastern Brazil within the Atlantic Rainforest biome. We modeled four scenarios (*status quo*, *random*, *law enforcement*, and *land-use intensification*) and simulated their resulting landscape trajectories for the year 2019 using DINAMICA. The landscape dynamics in the study region were particularly intense. During the first period of 1962–1981, the rate of forest regrowth (3% $year^{-1}$) was greater than the rate of deforestation (2% $year^{-1}$), whereas in the latter period of 1981–2000, increasing urbanization and the spreading of rural establishments resulted in more deforestation (2.9% $year^{-1}$) than regrowth (1% $year^{-1}$). These dynamics imprinted a heterogeneous landscape, leading to the predominance of progressively younger secondary forests with increasingly less capacity of hosting sensitive forest species. The influence of proximate causes on the dynamics of deforestation and forest regrowth showed consistent patterns, such as higher forest regrowth rates near rivers, on steep slopes and far from dirt roads, whereas losses in young secondary vegetation and forest were far from rivers, on gentle slopes and near urban areas. Of the modeled scenarios, only the *law enforcement* scenario may lead to the recovery of a network of interconnected forest patches, suggesting that simply the enforcement of current forest laws, which prohibit deforestation on unsuitable agricultural areas and along river margins and establish a minimum of 20% of forest remnant per rural property, may effectively favor forest species conservation in the short term (two decades) without the need of any forest restoration effort.

1. Introduction

The Atlantic Rainforest is internationally recognized by its large number of species (1–8% of the world's species), of which a large amount is endemic (Myers et al., 2000; Galindo-Leal and Câmara, 2003). The last estimation from Mittermeier et al. (2005) identified 8000 endemic plant species (40% of endemism), 148 birds (16%), 71 mammals (27%), 94 reptiles (31%) and 286 amphibians (60%), to cite only the most studied taxonomic groups.

Nonetheless, the Atlantic Rainforest is probably one of the most threatened tropical biome. Originally, its extent reached out 1.48 million km^2, totalizing 17% of the Brazilian territory. However, by 2005, only 160,000 km^2 of its forests, equivalent to 11–12% of its original forest cover, remained (Fundação SOS Mata Atlântica and INPE, 2008; Ribeiro et al., submitted for publication). Historically, deforestation of the Atlantic Rainforest was closely related to the major Brazilian economic cycles, beginning with the exploitation of Pau-Brasil, *Caesalpinia echinata* (16th century) and succeeded by the expansion of sugar cane (from 18th century) and the widespread conversion to pasturelands and coffee plantations (19th and 20th). More recently, deforestation has been related to urban sprawl and the expansion of *Eucalyptus* plantations (Dean, 1997; Drummond, 2004). Even today, despite legal restrictions on deforestation, the rate of forest loss is still high, *ca.* 0.25% per year (Fundação SOS Mata Atlântica and INPE, 2008).

As a consequence of five century of intense occupation, the Atlantic Rainforest is highly fragmented, holding forest fragments in average lesser than 100 ha (Jorge and Garcia, 1997; Viana et al., 1997; Ranta et al., 1998; Morellato and Haddad, 2000; Galindo-Leal and Câmara, 2003; Ribeiro et al., submitted for publication).

* Corresponding author. Tel.: +55 11 3091 7564; fax: +55 11 3091 8096.
E-mail address: jpm@ib.usp.br (J.P. Metzger).

0378-1127/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2008.10.011

Currently, more than 500 Atlantic Rainforest endemic species of different taxa are considered highly vulnerable to extinction (Conservation International do Brasil, 2000; Galindo-Leal and Câmara, 2003). Despite the high risk of species extinctions, the dynamics of Atlantic Rainforest loss and recovery have not yet been fully investigated, contrary to the large number of studies for the Brazilian Amazon (e.g. Skole and Tucker, 1993; Dale et al., 1996; Walker and Homma, 1996; Alves et al., 1999; Laurance et al., 2001; Achard et al., 2002; Metzger, 2002; Soares-Filho et al., 2002, 2004, 2006; Ferraz et al., 2005).

Landscape dynamics studies and models have been widely used to understand the proximate causes and underlying driving forces of tropical deforestation (see review in Geist and Lambin, 2002), to detect structural thresholds in deforestation patterns (Oliveira-Filho and Metzger, 2006), and also to forecast outcomes from different scenarios of land-use management, such as potential carbon emission and habitat loss (Soares-Filho et al., 2006), alterations in the hydrological cycle (Costanza et al., 2002), and climate change (Sampaio et al., 2007).

In this context, this study aimed: (i) to model the dynamics of deforestation and forest regrowth in a fragmented Atlantic Rainforest region in order to understand the major biophysical and human proximate causes controlling the dynamics from 1962 to 2000; (ii) thereby to simulate future changes in the landscape structure and composition to assess their potential effects on species conservation under a range of plausible land-use management scenarios.

2. Study site

The study site is located on the Ibiúna Plateau, 60 km west from the city of São Paulo (23°41′S–23°47′S; 47°02′W–47°07′W). This area belongs to the Serra do Mar ridge, a bio-geographical region (Silva and Casteleti, 2003) with the highest level of endemism for several taxonomic groups in the whole Atlantic Rainforest biome (Manne et al., 1999; Costa et al., 2000; Brown and Freitas, 2000). The study site encompassed an area of 7800 ha of which 31% is forested (Fig. 1). The Ibiúna Plateau is situated just above the Paranapiacaba Serra, in a transitional zone between the continuous (>80%) coastal rain forest in the south, and the highly deforested (<3%) and fragmented mesophyllous semi-decidual forest of inland São Paulo State (Kronka et al., 2005). The forests of study site may be classified as "lower mountain rain forest" (Oliveira-Filho and Fontes, 2000), but also contain species from the *Araucaria* mixed forest, the semi-deciduous forest and Cerrado (woody savanna) regions (Catharino et al., 2006).

The region's substrate is predominantly composed of Pre-Cambrian crystalline rocks, essentially with high metamorphic grade, such as migmatites and granites (Almeida, 1964). Different relief systems can be observed, such as mountain plateau with steep slopes, mountain with moderate to gradual slopes, and alluvial plains ranging from 860 to 1060 m of elevation (Ross and Moroz, 1997; Oliveira, 1999). According to the American Soil Taxonomy, the main soils in the region are alfisols, ultisols, oxisols and inseptisols (Ross and Moroz, 1997). The climate of Ibiúna is mild hot and humid *Cfa* type according to Köppen system (Köppen, 1948). Mean month temperatures range between 27 and 11 °C. The average annual precipitation is about 1300–1400 mm, with the driest months and the lowest average temperatures from April to August (30–60 mm/month) and the wettest (200–260 mm/month) and warmest months from November to March (SABESP, 1997).

On the Ibiúna Plateau, the dynamics of deforestation and forest regrowth have been strongly linked to the growth of the city of São Paulo, in terms of supply of charcoal for power generation, mainly during the Second World War, and lately for agricultural products (Seabra, 1971). More recently, better access to the region has led to an intense periurban expansion as well as to the proliferation of weekend country houses for middle-class families.

The boundaries of the study site were defined by a buffer zone surrounding 21 fragments that have been object of undergoing researches aiming to assess the effects of forest fragmentation on several taxonomic groups and ecological processes (e.g. Pardini et al., 2005; Uezu et al., 2005; Silva et al., 2007; Durigan et al., 2008; Martensen et al., 2008; among others).

3. Methods

3.1. Mapping landscape dynamics

We used aerial photographs from 1962 (1:25,000), 1981 (1:35,000) and 2000 (1:10,000) to map land-use and land-cover changes. As explained below, the same mapping procedure was applied to all imagery products to allow comparisons regarding classification accuracy and to reduce errors in the subsequent analyses.

The photos were scanned at 1 m resolution and georeferenced with an *RMS* error ranging from 5 to 12 m. Five land-use and land-cover classes were defined based on the level of detail available for the smallest scale imagery (1:35,000, Table 1). These classes included (1) buildings, (2) crops fields, (3) forest plantation, (4) forest and (5) young secondary vegetation (Fig. 2). Photo interpretation was performed by only two trained people in order to reduce errors related with different abilities of interpretation. All subsequent analyses and simulations were performed using raster layers at 15 m resolution.

We evaluated the mapping accuracy by visiting 65 vegetation points randomly distributed throughout the study area. As a result, we obtained an overall accuracy of 88% for the native vegetation classes and higher than 95% for the other land-use classes of the 2000 map (Silva et al., 2007). First, all five land-use and land-cover classes were used to quantify the changes in the landscape and to analyze the influence of proximate causes on them. Finally, in the scenario modeling process, the three land-use classes: (1) buildings, (2) crop fields, (3) forest plantation—were merged into

Table 1
Land-use and land-cover classes specified in the aerial photograph classification (Ibiúna Plateau, Brazil).

Land-use and land-cover classes	Description
Land-use	
Urban and rural buildings	Isolated buildings, hedges, grouped buildings, condominia, settlements
Crop fields	Mostly crop fields or fallow fields, but also with some areas used for cattle ranching or some abandoned/disturbed herbaceous vegetation, with or without shrubs
Forest plantation	Forest plantation with exotic species, *e.g. Pinus* spp. and *Eucalyptus* spp.
Land-cover	
Young secondary vegetation	Shrub to arboreal vegetation with up to 5–6 m height continuous canopy
Forest	Intermediate to old secondary forest with canopy height usually >10 m, with or without emergent trees up to 30–35 m