Applied Geography 82 (2017) 93–100

Contents lists available at ScienceDirect

Applied Geography

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

Forest transitions in tropical landscapes: A test in the Atlantic Forest biodiversity hotspot

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ARTICLE INFO

Article history:
Received 19 September 2016
Received in revised form
15 March 2017
Accepted 17 March 2017

Keywords:
Fragstat
Forest transition
Macacu Basin
Multitemporal

ABSTRACT

Analyzing temporal changes in forest amount and configuration is paramount to better design future forest management interventions. Such analyses are especially required for tropical biomes, which are usually subject to dynamic and heterogeneous land uses. Recent studies have suggested that many tropical biomes are passing through the process of “forest transition”, i.e. an overall change from forest loss to forest gain. However, this hypothesis remains scarcely tested, due to the difficulty of obtaining detailed, quantitative historical records of forest cover. In this study, we investigate 38 years of land use change in Brazil's Atlantic Forest, a biodiversity hotspot, from 1976 to 2014, using multitemporal datasets from aerial photographs and satellite images. We classified the historical series to produce land use maps and calculated a set of landscape metrics, including total forest cover, patch size, patch shape and patch connectivity. Our results indicated non-linear changes through time in forest loss and gain and also in landscape structure, which can be classified into two distinct periods. The first period (1976–1996) was marked by expressive forest loss and fragmentation, whereas the second (1996–2014) was characterized by a much less intense forest dynamics, with little deforestation being balanced by forest regeneration. We attribute the forest dynamics observed to temporal changes in socioeconomic factors, such as an increasing human settlements and changes in environmental protection policies. Our results show that current forests are a heterogeneous mosaic of forests with different ages, and support the hypothesis that forest transition is occurring in Atlantic Forest landscapes.

1. Introduction

Habitat loss and fragmentation are regarded as central causes of biodiversity loss in landscapes worldwide (Butchart et al., 2010; Fahrig, 2003; McKINNEY, 2002). The conversion of large areas of habitat into a set of small patches affects the distribution and abundance of species in the landscape, with negative effects on most species (Fahrig, 2003; Ewers & Didham, 2006; Debinski & Holt, 2000). To reduce the impact of habitat loss and fragmentation on biodiversity, it is essential to understand the mechanisms linking such processes to the corresponding biological changes (Ewers & Didham, 2006; Didham, Kapos, & Ewers, 2012).

Habitat loss causes profound changes in landscape composition, due to the replacement of native habitats, such as forests, by an array of human-made habitats, such as grasslands and cities (Foley, 2005; Tritsch & Le Tourneau, 2016; McKINNEY, 2002). Furthermore, habitat loss leads to changes in landscape configuration, including changes in the size, shape and degree of isolation of habitat patches (Ewers & Didham, 2006). Several studies have shown that the size, shape and isolation of patches affect the richness and abundance of species in landscapes (Ewers & Didham, 2006; Didham et al., 2012; Tapia-Armijos, Homeier, Espinosa, Leuschner, & De La Cruz, 2015). In general, larger, more compact, and less isolated habitat patches harbor a greater abundance and richness of species (Ewers & Didham, 2006).

The composition and configuration of landscapes, as well the abundance and richness of the communities that inhabit them, are a result of the historical use and changes in land cover in these

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http://dx.doi.org/10.1016/j.apgeog.2017.03.006

landscapes (Ewers et al., 2013). In forest landscapes, for example, remnant fragments may be composed of forests of different ages, depending on the history of use and disturbance they experienced (Lira, Ewers, et al., 2012). Different parts of a same landscape may have experienced successive processes of deforestation and regeneration, which can only be known by reconstructing the history of land cover in the landscape (Lira, Ewers, et al., 2012; de Rezende, Uezu, Scarano, & Araujo, 2015; Lira, Tambosi, et al., 2012).

The analysis of the history of land cover change is especially important to understand biodiversity patterns in very heterogeneous and dynamic biomes, such as the Atlantic Forest (Ferreira, Alves, & Shimabukuro, 2014; Ribeiro, Metzger, Martensen, Ponzoni, & Hirota, 2009; Silva, Batistella, Moran, 2016). The Atlantic Forest is considered one of the main world's biodiversity hotspots (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000), as it hosts a large number of endemic species and has already lost about 88% of its original distribution area (Ribeiro et al., 2009). This extensive devastation is the result of extensive human occupation in landscapes, especially over the last two centuries (Cabral, 2014; Dean, 1997).

Despite the extensive historical devastation of the Atlantic Forest, recent studies have suggested that, over the past two or three decades, this biome has been experiencing a positive balance of forest change (Rudel, Bates, & Machinguiashi, 2002; de Rezende et al., 2015; da Silva et al., 2016, pp. 1–14; Lira, Tambosi, et al., 2012). In other words, the Atlantic Forest may be at the beginning of a 'forest transition', i.e., the transition from forest loss (deforestation greater than regeneration) to forest gain (regeneration greater than deforestation) (Rudel et al., 2002; Lira, Ewers, et al., 2012; Lira, Tambosi, et al., 2012). Forest transitions have been documented for other tropical biomes around the world, and their causes and consequences are still under debate (Redo, Grau, Aide, & Clark, 2012; Rudel et al., 2005; Lambin & Meyfroidt, 2010). In the Atlantic Forest, forest transition could have resulted from the enforcement of environmental legislation and the abandonment of degraded land, which reduced deforestation and allowed forest succession in open areas (de Rezende et al., 2015; Lira, Tambosi, et al., 2012). However, the hypothesis that a forest transition is occurring in Atlantic Forest landscapes remains scarcely tested, due to the difficulty of obtaining detailed, quantitative historical records of forest cover (de Rezende et al., 2015; Lira, Tambosi, et al., 2012).

In this study, we tested the hypothesis that the process of forest transition is currently occurring in Atlantic Forest landscapes. To do so, we analyze aerial and satellite imagery available to quantify changes in forest cover over the past four decades, in a landscape located in the state of Rio de Janeiro, at the core of the Atlantic Forest hotspot. To your knowledge, this is the first historical land cover analysis in the Guapi-Macacu area. Specifically, we quantify changes in landscape composition (amount of forest) and configuration (size, shape and degree of isolation of forest fragments), from 1976 to 2014. We also explain the observed forest dynamics through an historical analysis of the major changes in socioeconomic development and environmental protection policies in the study area.

2. Methods

2.1. Study area – geography and history

We analyzed a stretch of the Guapi-Macacu Basin, which is located within Guanabara Basin, in Rio de Janeiro State, Brazil (Fig. 1). The Guapi-Macacu Basin results from the union of the Macacu and Guapimirim river basins, with approximately 1.260 Km^2, composed by plains, hills, mangroves, rivers, massive coasts and scarps of the 'Serra do Mar'. The altitude varies from sea level to 1.700m in the direction of the 'Serra dos Orgãos National Park'. The climate of Macacu River Basin is tropical Aw type according to Köppen classification (Koppen, 1948), The average temperature is 23,1 °C and average annual rainfall is 1.307 mm. Specifically, the area analyzed comprised 147 km^2 and was composed by small hills, forest patches, pasture areas, agricultural areas, flooded areas (Southern portion) and human settlements. Macacu river delimits the southern limit of the area, whereas the northern limit corresponds to the RJ-122 road (Rio de Janeiro to Nova Friburgo).

During the 16th and 17th centuries, this area was economically explored mostly for sugarcane and especially cassava flour production, with local rivers being harnessed for grinding and transportation (Oliveira, 2011). Most of the region remained scarcely occupied until the 19th century, mostly by smallholders and non-titled agriculturalists producing staple crops (Junior & Cesco, 2013). Despite low human density during this early period, local forests were explored for timber and firewood intensively (De Carvalho Cabral & Fiszon, 2004). During the 20th century, specifically between the 1930's and 1950's, the area was extensively modified by river rectification, aiming to reduce flooding. This enabled the paving of the roads, leading to greater human occupation (De Carvalho Cabral & Fiszon, 2004), and the corresponding loss and fragmentation of most native forests. Nowadays, the Macacu River Basin is the largest contributor of Guanabara Basin and the region have a considerable hydrological relevance provides water to most of the nearby cities. According to (Benavidez, Cintrao, Fidalgo, Pedreira, & Prado, 2009) this region is responsible for the water supply of about two million people. In 2002 the study area was included into an Environmental Protection Area, the APA Estadual da Bacia do Rio Macacu. Recently the construction of a major petrochemical complex started close to the study area, occupying an area of approximately 45 km^2 (Hatched area in Fig. 1). The cost of the complex is estimated at 21 billion Reais and currently 85% of the construction are completed (Petrobras, 2017).

2.2. Time series landscape datasets

To investigate the recent history of land use and land cover change in the study area, we compiled historical aerial photography and satellite imagery of the Guapi-Macacu region. Initially we obtained datasets for four distinct decades: 60′, 70′, 90′ (black and white aerial photos), 2000' (colored aerial photos), and satellite images for the last decade (2014). More specifically, we analyzed 4 photos from 1969 (1:60.000), 27 photos from 1976 (1:40.000), 35 photos from 1996 (1:20.000) and 23 photos from 2003 (1:33.500). These photos were obtained, respectively, from the U.S. Air Force, FUNDREM[2] and the last two series from CIDE Foundation.[3]

Each aerial photo was scanned with a resolution of 400 DPI's (dots per inch), and georeferenced using at least 220 control points homogeneously distributed, with Root Mean Square Error (RMS) $<$ 5m. We used the orthorectified historical series of 2003 as a base map to georeference each mosaic, with a minimum of 520 points to adjust the angulation error and homogenize the historical series. The estimated accuracy in our datasets was 80%. The mosaics were visually vectorized using ArcMap version 10.1 (ArcGIS Network Analyst, 2009) with inspection of the stereoscope to verify the doubts about the polygons vectorized. Subsequent analyses were performed without the 1969 dataset, due to the gaps in mosaic reconstruction. Thus, we used the 1976 mosaic to represent the first study year in our subsequent quantitative analysis. For 2014, we

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[2] Extinct Foundation.

[3] Currently CEPERJ: http://www.ceperj.rj.gov.br/.