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Ecological outcomes of Atlantic Forest restoration initiatives by sugar cane producers

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ABSTRACT

Brazilian environmental law (the Forest Code) compels large landowners to conserve a proportion of forest on their properties, often necessitating restoration of degraded habitat. Sugar cane producers have been active participants in these restoration projects, especially in the northeast region where sugar cane has largely replaced the exceptionally biodiverse Atlantic forest. Despite the potential conservation importance of such restoration projects there have been few evaluations of their outcomes. Here, we assess sugar cane company restoration projects in an Atlantic rainforest region of northeast Brazil. Specifically, we assess the ability of restoration projects to: (i) restore species diversity and vegetation structure; (ii) increase connectivity between forest fragments, and; (iii) restore assemblage composition. Restored areas contained approximately half the species richness of remnant fragments and had a substantially different species composition. Moreover, the density of trees in restored areas was a third of that in remnants, despite a very similar height profile. The currently poor outcomes of Atlantic Forest restoration projects in northeast Brazil are a consequence of a severely limited capacity for natural regeneration and poor restoration practices. We conclude by identifying possible strategies to improve the quality of privately financed restoration projects.

1. Introduction

Brazil has some of the most complex and broad-ranging environmental legislation in the world (Ometto et al., 2006). One of the key pillars of this legislation is the much debated "Forest Code" (Federal Law 4771). The original Forest Code (1965) required that (for most biomes) 20% of the area of any rural property be managed as a Legal Forest Reserve (LR) and that riparian forest (=at the margins of rivers) and forest on steep slopes become Areas of Permanent Protection (APPs). For properties that are underneath the forest area threshold for an LR there are three broad alternatives: (i) recover the area through planting with native species; (ii) allow natural regeneration (if viability has been demonstrated), and; (iii) compensate for the shortfall by establishing an LR of equivalent extension and ecological importance in another part of the property.

The Forest Code has thus obliged many landowners to restore functioning forests with acceptable levels of biodiversity and ecosystem services on land that has often been seriously degraded (Brancalion and Rodrigues, 2010). In addition to the legal requirements, restoration has also been adopted as a strategy to secure water sources for irrigation and to add value to products through environmental certification (Tabarelli and Roda, 2005). Of course, legally obliging landowners to restore degraded and deforested land does not necessarily ensure that the restoration will be done well. Given that not all landowners are enthusiastic conservationists, many may (understandably) try to fulfill their obligations using the absolute minimum of resources (Melo et al., 2013).

One of the biomes in greatest need of extensive restoration is the Atlantic forest of South America, which once covered an area of about 1.5 million km^2 in a latitudinal strip (3–30° S) from Northeast Brazil (Rio Grande do Norte) to northern Argentina and eastern Paraguay (Tabarelli et al., 2010). The Atlantic Forest has been subject to enormous levels of deforestation since the 16th century, following arrival of European colonists (Urban, 2011). Today, Brazil retains only ∼13% of its original cover of Atlantic Forest and what remains is highly fragmented (Ribeiro et al., 2009). Moreover, high

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levels of deforestation continue in most regions (Teixeira et al., 2009).

The Atlantic Forest in northeast Brazil is one of the most degraded, having been extensively cleared during the late 20th century for the expansion of the sugar cane industry (Ribeiro et al., 2009). Since the 1970s, successive Brazilian governments have strongly supported the planting of sugar cane for biofuel (Macedo, 1992), citing environmental benefits such as the reduction in greenhouse gases due to the high capacity of sugar cane to absorb atmospheric carbon (De Souza et al., 2008; Pacca and Moreira, 2009). Whatever the wider environmental benefits, the huge increase in sugar cane production has had a negative effect on native Atlantic forest in the northeast of Brazil (Araujo and Moura, 2011), and has probably discouraged the development of more sustainable horticulture and silviculture.

In addition to the massive loss of habitat in this region, almost half of the remaining fragments are <10 ha and very few are larger than 1000 ha (Ranta et al., 1998). The ecological consequences of such radical changes in landscape characteristics and other human actions (e.g., hunting) have been severe (Roda, 2006), with considerable loss of biodiversity (Silva and Tabarelli 2000) and associated ecosystem functioning (Kapos, 1989; Didham and Lawton, 1999; Rodrigues et al., 2004).

The high levels of historical deforestation in the northeast have left many landowners with properties containing an insufficient area of native forest, forcing them to initiate extensive programs of reforestation (Tabarelli et al., 2010), often with little or no prior experience. Not all landowners are necessarily adopting best practice guidelines and, in any case, there is a general lack of monitoring of restoration projects on private lands. Nevertheless, there is a long history of restoration interventions in the Atlantic forest (reviewed in Ref. Rodrigues et al., 2009, 2011), especially in the Southeast region of Brazil. Such projects initially focused on replanting to protect water and soil resources, progressing to the use of a limited number of fast growing native species to rapidly restore forest structure. Some landowners have recently started to adopt more functional approaches, using a greater number of native species in an attempt to restore basic ecological functioning while retaining floristic and intraspecific genetic diversity (Rodrigues et al., 2009; Blignaut et al., 2014).

In this study, we use various biodiversity and landscape metrics to assess the current ecological outcomes of reforestation programs of sugar cane producers in a highly threatened and high diversity region of the Atlantic Forest in northeast Brazil. The northeast is relatively under-represented in analyses of Atlantic Forest restoration in Brazil (cf. Rodrigues et al., 2009, 2011) and is also among the regions most devastated by deforestation (Ribeiro et al., 2009).

2. Methods

2.1. Study area

We studied seven sugar cane plantations located within a highly fragmented area of the Atlantic forest in northeast Brazil (Fig. 1). Within the study area all of the surviving Atlantic forest fragments are surrounded by an agricultural matrix most composed of sugar cane. The seven plantations were chosen on the basis that they had heavily invested in native seedlings for their reforestation projects (in contrast to other plantations in the region)—information on stocking was retrieved from the Institute for the Preservation of the Atlantic Forest (IPMA), which sells the seedlings. Field visits to the study areas were conducted between June 2007 and February 2008. The sugar cane companies voluntarily took part in the study on the condition that they would remain anonymous.

In each plantation the oldest restored areas were chosen for the assessment, representing sites that had been planted between 2001 and 2002. This choice provides longer term data on ecological changes, but inevitably includes some of the first attempts at restoration which may not represent how the sugar cane industry is currently restoring their land. It is also important to recognize that several training programs and consultations (e.g., *Programa de Adequação Ambiental*—Training Programme in Environmental Legal Standards [for restoration]) about restoration have been carried out in this region since these initial efforts, and that current restoration protocols might therefore have improved.

2.2. Conservation outcomes

In order to evaluate the ecological outcomes of the reforestation initiatives we assessed species diversity, community composition and vegetation structure of native shrubs and trees in each of the studied landscapes. Specifically, we compared biodiversity and structural metrics in the largest available area of reforested vegetation (treatment group) and the closest fragment of remnant forest (reference group). Data were collected from four randomly positioned plots of 50 m^2 (5 × 10 m) in both the reforested and the reference areas (up to 600 m distant)—e.g. eight plots in total for each of the seven study areas. To verify the sufficiency of the sampling, we constructed a rarefaction curves (Gotelli and Colwell, 2001) based on the abundance data matrix and including standard errors. Analyses were performed using the PAST (Paleontological Statistics Software Package for education and Data Analysis) software (Hammer et al., 2001). In each plot, all plants were identified and height and diameter at breast height were measured. Plants were classified as allochthonous (non-planted species native to the biome that had arrived by natural dispersal) or autochthonous (planted species that are native or non-native to the biome). It was possible to identify the latter plants since the plantation scheme (i.e., the regular spacing between plants) could still be easily observed in the field.

At least one voucher specimen of each morphotype was collected from each plot and botanical material was identified using taxonomic keys, through comparison with preserved material and, where necessary, through consultation with taxonomic experts. Voucher specimens were deposited in the collection of the MAC Herbarium of the Institute of Environment Alagoas/IMA and the UFP-Geraldo Mariz Herbarium at the Federal University of Pernambuco. To avoid pseudo-replication (cf. Hurlbert, 1984), the four plots in each study area were grouped into a single sampling unit for analysis—each farm containing a treatment and a reference group. In order to evaluate the capacity of each reforestation project to recover the natural diversity of plant species, we performed a paired comparison between the total richness of plant species in the reforested and in the remnant plots using the Wilcoxon test (Zar, 1999).

We tested differences in tree species composition between these two assemblages with a multi-response permutation procedure (MRPP) using the Bray–Curtis Index as a measure of floristic dissimilarity. We used this approach to compare restored areas with remnant forest fragments, and significance levels were assessed using 5000 permutation runs of randomized data. We also assessed the variation in tree species composition by performing non-metric multidimensional scaling (NMDS) (McCune and Grace, 2002) using the relative density of each species in each plot (see Costa et al., 2009). We calculated the percentage of variation explained by the two NMDS axes using the same Bray–Curtis Index as used for the ordination. Capacity of restored areas to recover natural vegetation was evaluated through a comparison of the density of individuals (number of individuals per 200 m^2) and the density of species (number of species per 200 m^2) in four height classes