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Effects of past and present land use on vegetation cover and regeneration in a tropical dryland forest

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A B S T R A C T

Brazilian Caatinga is one of the most diverse dryland ecosystem of the world and is threatened by strong land use pressure and poor protection. In this study, we investigate the effects of past and present land use on plant community richness and structure. We used satellite information to identify 55 Caatinga forest plots with and without past vegetation clearing. We also quantified current land use, i.e. grazing by domestic animals, and selective logging. Caatinga vegetation structure, measured as vegetation cover, vegetation height, basal area and woody plant density, as well as recruitment, measured as woody plant seedling density and species richness, were negatively affected by both past and current land use. Past clear-cut not only had strong effects on most vegetation measures, but also increased current grazing which further negatively affected vegetation structure. Selective logging had little measurable effects but increased recruitment in plots previously clear-cut. Increasing time since the last clear-cut increased negative effects on vegetation, presumably because of a prolonged negative effect of grazing. Our results suggest that grazing needs to be prevented in areas degraded by clear-cut to allow vegetation restoration through natural succession and avoid further degradation and desertification.

1. Introduction

Land use change is the main cause of land degradation worldwide, but the degree of degradation will depend on land use type and on the resilience of the impacted ecosystem (Gunderson, 2000; Htun et al., 2011). The use of native forests for livestock grazing or logging not only directly impacts the vegetation but also modifies environmental conditions such as the light reaching the soil, soil compaction and wind exposure (Coffin et al., 1996; Conant et al., 2001; Zaady et al., 2013). A common consequence of such land uses in many forests is an impoverished vegetation with a lower average tree height, tree basal area, plant density and species number. This might occur either due to direct effects of land use and through indirect effects of enhancement of stressful conditions (Dorrough and Scroggie, 2008).

In dryland ecosystems, maintenance of vegetation cover critically depends on plant recruitment within existing vegetation patches, as seedlings can rarely establish on bare ground (Vieira et al., 2013). Even chronic low-intensity disturbances such as selective logging or grazing can have pervasive effects on plant diversity and composition of vegetation patches (Ribeiro et al., 2015). For example, selective logging for charcoal production may alter woody species composition because species with high wood density are preferred (Ramos et al., 2008). On the other hand, small gaps formation from selective logging can promote seedling density and diversity if the understorey is light limited (Costa and Magnusson, 2002). Grazers can modify the native vegetation by favoring unpalatable species or by causing overall mortality of seedlings due to trampling (Aschero and García, 2012; Cipriotti and Aguiar, 2005; Pereira et al., 2003). However, positive effects of grazing on native species seed dispersal and consequently seedling establishment have also been reported in dry ecosystems (Aschero and García, 2012).

The intensive and chronic land-use leads to formation of isolated vegetation patches surrounded by bare ground in several drylans around the world (Kéfi et al., 2007; Maestre and Escudero, 2009). After land abandonment, secondary forest dynamics will

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drive the assembly of a new plant community (Foster, 1992). The regeneration of a highly impacted area will depend on the presence of seed sources, vegetation cover and soil quality after land use (Verheyen et al., 2003). If regeneration does not occur because of continuous land use pressure, bare soil continuous exposure can lead to increased vegetation degradation over time and initiate a process of land desertification (Kéfi et al., 2007; Maestre and Escudero, 2009). In drylands, desertification is often the consequence of poor land management (D'Odorico et al., 2013).

The *Caatinga* is a dryland region covering most of the Brazilian Northeast and is threatened by increasing land use intensity (Leal et al., 2005; Ribeiro et al., 2015). Caatinga vegetation is characterized by a mixture of woody and herbaceous plants, with dominance of xerophytic and deciduous forest species. A common type of land use at the Caatinga is livestock grazing where animals are usually raised freely to feed on native vegetation that grows during the rainy season. In most cases, some areas are clear-cut to stimulate the growth of palatable herbaceous vegetation that livestock feed on. Other areas are converted to agriculture. Continued timber removal together with grazing are, however, considered the main causes of degradation of the Caatinga vegetation (Leal et al., 2005). Caatinga covers an area of 826 411 km^2, but around 375 116 km^2 or 45.4% have been deforested until 2009 and desertification processes have been observed in up to 15% of the area (Leal et al., 2005; MMA, 2011).

While the main drivers of degradation of Caatinga vegetation have been identified, little is known about how these drivers interact, and the relationship between land use intensity and the damage on vegetation. Understanding the effect of the different drivers of the changes on Caatinga's vegetation structure and regeneration in more mechanistic detail can help elucidating better management actions to avoid desertification and achieve conservation goals.

This study aims to investigate the effects of past and present land use on woody plant community regeneration, cover and structure. We asked the following questions: (1) how does a past clear-cut affect current vegetation structure and regeneration? (2) does increasing land-use intensity, in particular increasing intensity of grazing and selective logging, lead to increasing negative effects on plant community regeneration, vegetation cover and structure? (3) are there interactions between past and current land uses in their effect on the vegetation? and, (4) After a clear-cut, is the vegetation able to recover through time?

2. Material and methods

2.1. Study area

The study was conducted in the Caatinga vegetation located at the Brazilian northeast region (Fig. A.1a). In the typical Caatinga vegetation, ground vegetation only consists of very few grass species and the tree canopy is continuous and permanent. There are some parts of the Caatinga that are classified as deciduous thorny savanna, however, it is not the case for our study site. Specifically, the study was carried out in the State's Sustainable Development Reserve (SDR) *Ponta do Tubarão* (Fig. A.1b). The herbaceous layer is mostly composed of woody perennial herbs many of which of the Malvaceae family, and small stature cactis. Because grass species are more resilient to grazing and fire we expect the effects of land-use in our study area to be different from savannas.

The SDR is within the category IV according to the IUCN and in these types of reserves local people are allowed to live and exploit resources in a sustainable way. Yearly mean rainfall in the Caatinga is very variable and ranges from 240 to 1500 mm per year. Inside the reserve, average rainfall is 508 mm year^{-1} and rain mostly falls between January and May while on average less than 20 mm falls between October and December (data available at http://www.inmet.gov.br). The SDR has an extent of 12 960 ha that encompasses three main vegetation types: i) a Caatinga vegetation with a closed canopy cover of ~4 m height, dominated by the woody species *Mimosa tenuiflora*, *Poincianella pyramidalis*, *Pytirocarpa moliniformis* and *Croton sonderianus*; ii) a restinga vegetation, with a sparse canopy dominated by the woody tree *Sideroxylum obtusifolium*, and open spaces dominated by the small stature herbaceous species, and iii) a mangrove located near the coastline dominated by *Rhizophora mangle*. The Caatinga part of the reserve, where we carried out our study, covers 2779 ha, i.e. 21% of the total reserve area. There are also some dune areas inside the Caatinga which were excluded from our study, so that the study areas encompasses 2.010 ha of Caatinga vegetation.

There are eight traditional settlements inside the reserve boundaries with a population of ~5000 people. Families income in the three settlements at the coastline traditionally derives from fishing and wood extraction from Caatinga vegetation, to build houses, fences and boats. The families from the five countryside settlements live on small scale subsistence agriculture including raising sheep, goat and cattle, and also use wood from Caatinga vegetation for house and fence building, as well as charcoal production. Families let their animals foraging freely on vegetation (including donkeys and horses). Sometimes small forest areas are clear-cut using burning to encourage herbaceous vegetation growth.

2.2. Selection of sampling plots

Selection of sampling plots was carried out in two steps using a stratified random selection of plots' locations to ensure that we would select plots occurring in a wide range of vegetation cover. This approach assumes that vegetation cover would be negatively affected by land-use. In the first step, we classified the Caatinga vegetation inside the reserve according to current forest cover. We used Landsat TM5 satellite images of 2008 (http://www.dgi.inpe.br/CDSR/) with a resolution of ca. 30 × 30 m to classify the SDR Caatinga's vegetation into different degrees of current vegetation cover. To do so, a classification algorithm was trained using 28 control points that were first identified from satellite pictures and then visited in the field. These represented three types of areas: *open* areas with only very few remaining single trees or shrubs, *intermediate* areas with ca. 50–70% cover of trees and shrubs and a tree height up to 2 m, and *closed* areas with a dense forest canopy and tall trees with a mean canopy height of about 3–4 m. The 28 control areas were classified as one of the three types and used to train a classification algorithm based on Maximum Likelihood (ML) using all five Landsat bands (supervised classification procedure in ArcGis v10 ESRI, 2011). After training, the entire reserve was classified into the three cover classes. We classified the vegetation into cover classes only to select plots in a wide range of our vegetation and land-use variables. The land use classes did not enter the statistical analyses.

In a second step, we randomly selected 55 sampling points in the Caatinga part of the SDM, 20 in closed, 20 in intermediate, and 15 in open areas, as only 17% of the area had no forest cover. As a constraint for plot selection we set a minimum distance of 100 m between points. After selection, the minimum distance between two adjacent sampling points was 142 m (mean 3207 ± 2444 (sd) m). Each selected sampling point then served as the center of a circular sampling plot with 25 m radius (1962 m^2). This circle was used to measure current land use. Assessment of vegetation structure and plant species richness variables was carried out in a square 10 × 10 m sub-plot (100 m^2) placed at the center of the