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Vegetation composition and structure changes following roller-chopping deforestation in central Argentina woodlands

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A B S T R A C T

Driven by the pressure of increasing forage production, dry forests and woodlands of Argentina are suffering one of the highest deforestation rates in the world. In this study we combined field work and a remote sensing approach to assess the successional trajectory in terms of functional group diversity and ecosystem phenology, following roller chopping deforestation in a woodland of central Argentina. The first year after disturbance, shrub cover decreased at the same proportion than grass cover increased while tree cover was drastically reduced. After 3 years, shrubs recovered 70% of the original cover and grasses maintained a relatively high proportion, but tree cover remained low. Roller-chopping favoured early over late successional species in the case of woody plants, but had the inverse effect in the case of grasses. At ecosystem scale the length of the growing season was drastically shortened by 100 days following disturbance. Roller chopping improves ecosystem services of provision by enhancing forage's offer but at the same time deteriorated the system by reducing functional plant diversity and by shortening the growing season, with potential cascade-consequences on other ecosystem processes such as the carbon and water dynamics.

1. Introduction

In central Argentina, like in many semiarid regions around the world, deforestation is advancing in order to increase forage production and accessibility to cattle (Gasparri et al., 2013; Rueda et al., 2013; Bestelmeyer, 2014). Argentinean dry Chaco is the largest remaining continuous dry forest unit in the continent (Eva et al., 2004) and one of the fastest expanding agriculture frontiers of the world (Zak et al., 2008; FAO, 2010).

The ecological succession after deforestation has been object of extensive literature (Noble and Slatyer, 1980; Guariguata and Ostertag, 2001; Staus et al., 2002; Lohbeck et al., 2012, 2014a, 2014b). Classical studies have shown that this disturbance usually follows a succession with a first occurrence of shade intolerant and annual species followed by shade tolerant, perennials and endemic species (White, 1979; Connell and Slatyer, 1977; Dorrough and Scroggie, 2008). These changes are generally accompanied by other changes in ecosystem functioning. For example, a reduction in functional group diversity could affect primary production and ecosystem phenology with significant-cascade effects at all trophic levels (Tilman, 1997; Clark and McLachlan, 2003; Leniére and Houle, 2009). Additionally, changes in the length of the growing season could eventually affect the carbon cycle and water balance (Körner and Basler, 2010).

Trees and shrubs represent the biomass-dominant plant life form in dry forests and woodlands. Traditionally, climatic conditions have restricted the use of these semiarid areas of central Argentina to extensive grazing and selective logging. In the last decades, however, increments in regional precipitation along with livestock expansion and new technologies have intensified land use in these areas (Oesterheld, 2005; Viglizzo et al., 2010) promoting the reduction of shrubby vegetation and the consequent increment on grass production (Rueda et al., 2013). Like in other dry

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woodlands around the world, shrub cover is reduced by using "roller choppers", heavy cylinders equipped with transversal blades and moved by bulldozers that chop and crush small- and medium-size woody vegetation. This practice promotes grass production and facilitates cattle foraging (Kunst et al., 2012). However, some woody species in our study area have re-sprout capabilities and they readily initiate new growth from their base (Villagra et al., 2004; Fernández and Maseda, 2006). Although thousands of hectares of dry forests are cleared every year in the Chaco's region (Boletta et al., 2006; Hoyos et al., 2013), few studies have analysed the impact of this disturbance on vegetation composition, phenology and primary productivity.

In this study we assess the successional trajectory, in terms of species and functional group composition, and its associated phenological shifts, in response to roller-chopping deforestation in a woodland area of central Argentina. We selected contiguous deforested sites, which vary on the elapsed time from disturbed (1, 2 and 3 years after rolled-chopping), and adjacent undisturbed sites, to assess impacts on vegetation composition, productivity and phenology; combining *in situ* and remote sensing observations.

2. Methods

2.1. Study area

Field work was performed in San Luis province, on the west-central region of Argentina (33.5° S 66.49° W, 420 m.a.s.l.). Vegetation is a xerophytic woodland of shrubs and emergent trees (*Prosopis flexuosa*), with a discontinuous gramineous understory layer. Dominant woody species includes the genera *Larrea, Prosopis, Condalia, Lycium and Senna*. Common grass genera are *Pappophorum, Trichloris, Setaria, Aristida, Chloris,* and *Neobouteloua* and represent the main forage resource in the area (Morello, 1955, 1958). Growing season generally extends from September to April for woody species and from November to March for grasses. Growing season matches the seasonal precipitation distribution. Precipitation is 400 mm per year and usually occurs in events exceeding 20 mm (Salinas del Bebedero, Weather Station). Mean annual temperature is 24 °C. Soil has been classified as regosol with a low content of organic matter and sandy-loam texture (Kirby et al., 2001).

2.2. Experimental design

The study was based on the existence of areas that were subject to roller chopping (disturbed areas) and adjacent "untreated" woodlands (undisturbed areas). Roller chopping deforestation was performed by using a cylindrical 18 T roller or drum, 4 m in length and 1.8 m in diameter, pulled by a bulldozer. The roller was equipped with 20 cm high blades running parallel to the axis and spaced 50 cm apart around the cylinder surface. *In situ*, field measurements were performed in March 2007 on contiguous large forest extensions that were roller-chopped in August-December 2004 (29 ha), 2005 (132 ha), and 2006 (91 ha), and on their adjacent undisturbed-control sites (<100 m from them, and >100 ha of extension). On each one of these large rolled-chopped and undisturbed sites we set 3 permanent experimental transects to measure changes in plant life forms and ecological strategies. Thus, there were 3 replicates per each roller-chopped treatment and 3 control-undisturbed sites transects. Until deforestation began, the area was covered by natural woodlands and experienced the same land use history with no intense grazing, logging or fire activity over the last decades. No differences were found between soil texture (*$n=3$ boreholes per site, $F=2.79$, site x depth $P=0.12$*) and bulk density (*$n=2$ boreholes per site, $F=1.15$, site x depth $P=0.37$*) between treatment and control sites.

2.3. Plant life forms and ecological strategies

We measured plant species cover (%) by using the line intercept method (Canfield, 1941), on three-100-m linear transects randomly located in each disturbed and control site. Percentage of bare soil and litter was also estimated from each interception line. Each species was later categorized by life forms (trees, shrubs, grasses and forbs) and plant ecological strategies (early and late successional). Plant ecological strategies were defined considering shade tolerance, growth rate, number and size of seeds and seed dispersion strategies (Steinaker *pers. communication*).

2.4. Dynamics of NDVI and ecosystem phenology

We evaluated ecosystem seasonality and changes in phenology by analysing the dynamics of the Normalized Difference Vegetation Index (NDVI) in undisturbed and disturbed areas, throughout eight growing seasons (2001–2009). We used MODIS-TERRA images with 6.2 ha and 16 days of spatial and temporal resolution respectively. The sites for assessing NDVI dynamics were selected considering two criteria: a) They had to be located in the same areas that the experimental transects and b) they had to cover a minimum of four pure MODIS pixels. Both criteria were met since all roller-chopped sites were larger than the required extension. Ecosystem seasonality was characterized by the start, end and length of growing season, and the moment of maximum NDVI "greenness". We also measured the inter-annual stability of NDVI by using the temporal coefficient of variation (CVt = (standard deviation/mean)*100). All the analyses were performed by using TIMESAT software (Jönsson and Eklundh, 2004) which process time series data by considering 23 images per year. Maximum, minimum and peak values of NDVI and the start, end and the length of the growing season before and after disturbance were calculated using a filtering function (Savitzky-Golay) that suppress extreme values produced by extraordinary events. Starting from the NDVI integral curve as 100%, the beginning or the end of the growing season is then calculated as the time for which the left/right edge of the curve has increased to a user defined level. NDVI thresholds for the beginning and the end of the growing season were defined following Jobbágy et al. (2002).

2.5. Statistical analysis

As measurements were conducted on the same experimental unit over time, we used the PROC-MIXED repeated measurement analysis to compare NDVI dynamics of each treatment over time. For texture and bulk density we performed a repeated measurement analysis considering depth as a repeated measure and using the same procedure. Comparisons of plant cover (%) among different sites (disturbed and undisturbed sites) were performed using a one-way ANOVA. All analyses were completed using SAS version 6.12 (SAS Institute, Cary, North Carolina, USA).

3. Results

Plant life-form considerably changed after roller-chopping, mainly from woody to herbaceous vegetation. The first year after disturbance, shrub cover decreased almost at the same proportion (3:1) than grass cover increased (shrubs from 80 to 26% and grasses from 24 to 87%, Fig. 1). However, after 3 years, shrubs recovered 70% of their initial cover while grasses maintained a relatively high cover (74%, Fig. 1). Trees were the most affected group with their cover being reduced from the 20%–2% in the first year and no recovery found afterwards. Forbs showed a variable pattern, without significant differences between undisturbed and disturbed areas