Forest Ecology and Management 402 (2017) 29–36

Contents lists available at ScienceDirect

Forest Ecology and Management

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

To chop or not to chop? Tackling shrub encroachment by roller-chopping preserves woody plant diversity and composition in a dry subtropical forest

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ARTICLE INFO

Keywords:
Chaco ecoregion
Roller-chopping
Seasonally dry forest
Shrub encroachment
Woody plant diversity

ABSTRACT

Shrub encroachment is a frequently observed phenomenon in the arid and semi-arid biomes. In the dry forests of the Argentine Chaco ecoregion that are affected by shrub encroachment, the growing demand for grazing areas has led to the creation of a silvopastoral system. Under the Chaco silvopastoral system, a commonly used treatment to disrupt the excessive shrub layer and promote the growth of grasses is roller-chopping by a tractor-pulled iron drum. While previous studies evaluating the effects of roller-chopping on diversity have focused mostly on the herbaceous stratum as the primary source of forage, much less is known about the effects of roller-chopping on woody plants. To fill this gap, we measured woody plants of the shrub layer in a low-intensity roller-chopping experiment in northern Argentina after applying different frequencies of roller-chopping in a semi-arid Chaco forest area with a well-developed shrub layer. Data were collected in an experiment in which 3 different roller-chopping treatments were applied: a single two-pass roller-chopping in the summer of 2006/2007 (RCh1); a one-pass roller-chopping in the summer of 2006/2007, repeated in the summer of 2014/2015 (RCh2); and no treatment (Control). In each treatment, 16 circular, randomly placed plots with a radius of 9 m were sampled, and all woody plants in the shrub layer with a diameter ≥10 mm at the base were recorded. The diversity was analysed using profiles of alpha and beta diversity and by calculating the average distance from an individual circular plot to the treatment group centroid defined in the principal coordinate space. In total, 26 species of woody plants were recorded, of which 24 were found in Control, 22 in RCh1, and 23 in RCh2. Although the alpha diversity differed only slightly among the treatments, the beta diversity of the roller-chopped treatment areas was generally higher than that of the untreated plots. The species composition of the roller-chopped plots differed little from that of the control plots. Our study revealed little overall effect of roller-chopping on the species diversity and composition of woody plants. The transformation of the Chaco forest degraded by shrub encroachment to a silvopastoral system by roller-chopping is changing the structure of the forest but to a large extent has retained the presence and the relative abundance of woody plant species. We conclude that roller-chopping is a good management tool to reduce woody plant encroachment and create a silvopastoral system while preserving ecosystem functions.

1. Introduction

Dry forests compose nearly half of the world's tropical and subtropical forests (Murphy and Lugo, 1986). Unfortunately, the majority of these forests is currently threatened, largely by human activities (Miles et al., 2006), and their habitat loss has been the greatest among the world's terrestrial biomes (Hoekstra et al., 2005; Hansen et al., 2013).

In regions, where most dry forests have been converted into pastures, a conservative approach to obtaining new areas for cattle production is the adoption of a silvopastoral system, which represents a trade-off between keeping most ecosystem functions of the former forest and allowing for grazing (Dagang and Nair, 2003; Perfecto and Vandermeer, 2008). Silvopastoral systems, which are combinations of livestock grazing and timber operations occurring in the same place (Kunst et al., 2016), are used around the world (Dagang and Nair, 2003; Bergmeier et al., 2010) and can be based either on planted trees or on an already existing native tree layer (Kunst et al., 2016).

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http://dx.doi.org/10.1016/j.foreco.2017.07.032
Received 4 May 2017; Received in revised form 17 July 2017; Accepted 19 July 2017

Another phenomenon frequently reported in arid and semi-arid biomes (though not restricted to them) is the encroachment of woody plants, mainly shrubs (van Auken, 2000; Eldridge et al., 2011). This process affects mostly open habitats such as grasslands or open woodlands (van Auken, 2000; Eldridge et al., 2011) but also occurs in dry forests (Adámoli et al., 1990). Shrub encroachment can be caused by several mechanisms, including climate warming, an increase in the atmospheric CO_2 concentration, and changes in fire and grazing management (D'Odorico et al., 2012) and can be accelerated by positive feedback between these mechanisms and the vegetation response (D'Odorico et al., 2012), resulting in changes in ecosystem structure and functioning (Eldridge et al., 2011). From the perspective of rangeland management, shrub encroachment is regarded as a degradation process that decreases the amount of available forage for livestock (Zarovali et al., 2007). Given the non-linear nature of the vegetation response following a disturbance, the changes in vegetation can be described by state-and-transition models (Briske et al., 2005): the vegetation dominated by woody plants following shrub encroachment represents an alternative stable state, and the transition back to a state where the herbaceous component dominates is not possible without an external driver (Briske et al., 2005; D'Odorico et al., 2012).

The establishment of a silvopastoral system in a forest degraded by shrub encroachment must be preceded by an anthropogenic disturbance that reduces the shrub layer and increases the amount of grass forage without endangering the sustainability of the forest. A commonly used method for shrub layer destruction in rangelands is roller-chopping, a mechanical treatment that reduces the shrub cover and promotes herbaceous vegetation (Bozzo et al., 1992; Throop and Archer, 2007; Willcox and Giuliano, 2010; Kunst et al., 2016) by crushing shrubs and small trees with a tractor-pulled iron drum equipped with blades.

Concordantly with the aforementioned loss of dry forests, the area of seasonally dry subtropical forests of the Chaco ecoregion in northern Argentina is gradually decreasing due to agricultural expansion (Zak et al., 2004; Grau et al., 2008; Gasparri and Grau, 2009; Volante et al., 2016). Economic globalization in recent decades (Lambin and Meyfroidt, 2011) has further accelerated the deforestation of Argentina's Chaco region mainly because the growing demand for soybean products in China and Europe has created a need for new croplands (Grau et al., 2008; Garrett et al., 2013; Gasparri et al., 2013). Another cause of deforestation in Chaco is cattle production, which is partially coupled with soybean cultivation because as pastures are turned into soybean fields, a need for new pastures emerges (Gasparri et al., 2013; Gasparri and le Polain de Waroux, 2015). As a result, among the South American regions, the dry forests of Chaco are experiencing the second-highest rate of deforestation after the Amazonian moist forests (Aide et al., 2013).

The adoption of a silvopastoral system based on maintaining the native tree layer in the Chaco forests is an approach to obtaining new areas for livestock grazing while retaining the ecosystem functions and biodiversity of the former forest. These forests, however, are among the ecosystems affected by shrub encroachment (Adámoli et al., 1990), due mainly to mismanagement in the past (such as overgrazing, indiscriminate felling, and fire suppression; Adámoli et al., 1990). The dense shrub layer not only eliminates herbaceous forage plants but also prevents livestock movement because it is impenetrable (Bregaglio et al., 1999). Therefore, the reduction of this layer is crucial for the facilitation or maintenance of cattle grazing operations in the Chaco forest, and roller-chopping is the main method used for this purpose in the Chaco region (Kunst et al., 2008, 2016). However, although the shrub layer is an obstacle for management, in terms of plant diversity, it is the richest layer, hosting the greatest number of plant species, of all the Chaco forest layers (de Casenave et al., 1995). Therefore, roller-chopping or similar shrub-destroying management methods may have a negative impact on the plant diversity and composition of the Chaco forest by suppressing or eliminating species that are not well adapted to frequent disturbances. In addition, the destruction of the shrub layer may hamper the natural regeneration of valuable tree species, as young trees form part of this layer. However, although the elimination of encroaching shrubs in arid areas has received much attention in the literature, comprehensive information on the impacts of anthropogenic shrub-destroying methods on the woody plant community is lacking.

To fill this gap, we measured the woody plants of the shrub layer in a randomized roller-chopping experiment in northern Argentina in which different frequencies of so-called 'low-intensity roller-chopping' (Kunst et al., 2015, 2016) were applied to the semi-arid Chaco forest with a well-developed shrub layer. Low-intensity roller-chopping uses the disturbance theory to plan the intensity, severity and frequency of treatment to retain viable populations of woody species in the treated areas (Kunst et al., 2015). Unlike the conventional roller-chopping, which removes all or majority of woody vegetation in the treated area, the low-intensity roller-chopping aims to preserve valuable trees (Kunst et al., 2008). By analysing the differences between treated and untreated plots in woody species abundances, diversity and composition, we aimed to address the following questions:

(1) Does roller-chopping decrease the alpha and beta diversity of woody plants?
(2) Does roller-chopping change woody plant species composition?

2. Methods

2.1. Study area

The study was carried out at the 'La María' Experimental Ranch within the Santiago del Estero Experimental Station of the Instituto Nacional de Tecnología Agropecuaria (INTA), Argentina (28°02′25″S, 64°17′37″W, Fig. 1). The area belongs to the Chaco Seco (dry Chaco) ecoregion (Burkart et al., 1999). The altitude is approximately 200 m a.s.l., and the soils are Eutric Regosols (Lorenz, 1995). The climate is subtropical semi-arid, with hot, rainy summers and cold, dry winters (Boletta et al., 2006). The mean total annual precipitation is 574 mm (Anriquez et al., 2005), and the mean annual temperature is 19.8 °C, with January being the warmest month (mean monthly temperature 26.1 °C) and July the coldest (10.6 °C) (Bravo et al., 2010).

The vegetation of the study area represents the forest of upland sites (Kunst et al., 2006). The upper layer is formed by the tall tree species *Aspidosperma quebracho-blanco* Schltdl. and *Schinopsis lorentzii* (Griseb.) Engl., while *Cercidium praecox* (Ruiz & Pav. ex Hook.) Harms, *Prosopis nigra* (Griseb.) Hieron. and *Ziziphus mistol* Griseb. are common trees in the middle layer. The shrub layer is rich in species and is dominated by *Acacia gilliesii* Steud., *Capparis atamisquea* Kuntze and *Celtis ehrenbergiana* (Klotzsch) Liebm.

2.2. Data collection

Data on woody vegetation were collected in a roller-chopping experiment run by INTA beginning in 2006 in which 3 different roller-chopping treatments were applied to 24 randomized blocks (8 blocks for each treatment) with a total area of approximately 60 ha. The treatments were single roller-chopping with two passes of the roller-chopper in the summer of 2006/2007 (RCh1); roller-chopping with one pass of the roller-chopper in the summer of 2006/2007, repeated in the summer of 2014/2015 (RCh2); and no treatment (Control). The roller-chopping was applied using an iron drum roller-chopper 2.5 m in width and 1.4 m in diameter, equipped with blades and pulled by a tractor (Kunst et al., 2016). Unlike in conventional roller-chopping, the iron drum was not filled with water (otherwise commonly used to increase drum weight) and the tractor driver avoided not only large main canopy trees but also larger understory trees (with a diameter ≥ 15 cm), which serve as basis for regeneration of the main canopy layer. Cattle grazing is regularly applied in the whole area. Due to little abundance