Journal of Arid Environments xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Arid Environments

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

Restoration ability of seasonal exclosures under different woodland degradation stages in semiarid Chaco rangelands of Argentina

S.M. Cotroneo[a,*], E.J. Jacobo[a], M.M. Brassiolo[b], R.A. Golluscio[a,c]

[a] *Universidad de Buenos Aires. Facultad de Agronomía. Departamento de Producción Animal. Cátedra de Forrajicultura, Buenos Aires, Argentina*
[b] *Universidad Nacional de Santiago del Estero. Facultad de Ciencias Forestales. Instituto de Silvicultura y Manejo de Bosques. Cátedra de Agrosilvicultura, Santiago del Estero, Argentina*
[c] *Universidad de Buenos Aires. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET). Instituto de Investigaciones Fisiológicas y Ecológicas Vinculadas a la Agricultura (IFEVA). Facultad de Agronomía, Buenos Aires, Argentina*

ARTICLE INFO

Keywords:
Xerophilous forest
Rehabilitation
El niño southern oscillation (ENSO)

ABSTRACT

Exclosures are widely used for rangeland restoration in semiarid woodlands. However, grass recovery could be hampered if degradation exceeded certain thresholds. In this study we assessed four years effects of seasonally grazed exclosures –vs. open rangelands– on understory cover (grasses, low shrubs and litter) and peak standing biomass in three increasing degradation stages –mature forests, secondary forests and shrublands– in semiarid Chaco woodlands. We found that grass cover and biomass increased tenfold in four years in mature and secondary forests but remained virtually null in shrublands. In rested forests, the grass cover increments remained relatively constant regardless the annual rainfall amount, both in the driest year 2013 (531 mm) and the wettest year 2015 (924 mm). Only in an extraordinarily wet year (2015) did grass biomass increased in rested shrublands. In that wet year, low shrubs cover –higher at higher overstory degradation– decreased in all woodlands. Our results suggest that shrublands may constitute a new steady state unable to recover by grazing exclusion itself, but probably by its combination with wet periods.

1. Introduction

Dry rangelands cover over 39,000,000 km^2 (one quarter of the Earth's land surface) and are inhabited by almost one billion rural people (MAE, 2005). In many cases rangelands are susceptible to degradation driven by overgrazing, and also by selective logging and deforestation, linked to crop expansion, in dry forest and woodlands (Hoekstra et al., 2005). Deforestation, which involves the most drastic change in ecosystems, environment and society (Mustard et al., 2004; Viglizzo and Jobbágy, 2010), also displaces livestock to drier areas, thus increasing pressure on these lands, often unproductive and already degraded after a history of continuous grazing and other anthropic actions (Morello et al., 2012). Hence, addressing rangeland degradation is a complex and challenging priority, because of its ecological, economic and social implications.

Rangeland degradation has been reported in many semiarid areas of South America (Adámoli et al., 1990), North America (Jones, 2000), Africa (Downing, 1978), Asia (Mirzabaev et al., 2016) and Oceania (Yates et al., 2000). Overgrazing reduces grass cover, density and biomass (Yayneshet et al., 2009; Verdoodt et al., 2010), increases bare soil and promotes shrub encroachment (Van Auken, 2009). These changes in vegetation structure often reduce soil moisture (Branson and Reid, 1981) and nutrient cycling (Golluscio et al., 2009). This mainly affects the upper soil layer (Abril and Bucher, 1999), and thus herbaceous plants with shallow roots.

Until recent decades, grazing was considered the main driver of rangeland dynamics, assumed to be linear and reversible according to the range condition model (Dyksterhuis, 1949). This model predicts that a decrease in grazing intensity will result in secondary succession towards a single equilibrium state or climax that represents the best range condition, driven mainly by biotic (plant-herbivore and plant-plant) interactions. This was questioned for arid and semiarid rangelands since their vegetation and grazing dynamics, strongly driven by stochastic abiotic factors such as remarkably variable rainfall and high spatial heterogeneity, are often discontinuous and irreversible and they may have none or multiple equilibrium states (Ellis and Swift, 1988; Westoby et al., 1989). Accordingly, the state-and-transition model proposes "opportunistic strategies" based on certain environmental conditions and/or management actions (such as grazing rest) to promote system transitions towards more desirable steady states (Westoby

* Corresponding author. Cátedra de Forrajicultura, Facultad de Agronomía Universidad de Buenos Aires, Av. San Martín 4453, C1417DSE, Buenos Aires, Argentina.
E-mail address: cotroneo@agro.uba.ar (S.M. Cotroneo).

https://doi.org/10.1016/j.jaridenv.2018.08.002
Received 14 June 2016; Received in revised form 11 August 2018; Accepted 14 August 2018
0140-1963/

et al., 1989). Since then, the debate on the relevance of equilibrium and non-equilibrium models had emerged, focusing on the relative weight of biotic and abiotic factors on rangeland dynamics (Illius and O'Connor, 1999; Sullivan and Rohde, 2002). Currently, it is proposed that many semiarid rangelands encompass elements of both equilibrium and non-equilibrium paradigms at different spatial and temporal scales (Briske et al., 2003; Vetter, 2005).

Establishment of exclosures, where livestock grazing is excluded during the growing season, has become an important restoration strategy in semiarid rangelands. Seasonal exclosures have both positive ecological and economic effects, at different temporal scales. In the short term, they provide dry season forage for livestock (Mwilawa et al., 2008) and, in the mid-to long-term, they foster vegetation restoration or rehabilitation (Verdoodt et al., 2010). Rest during the growing season enables flowering and seed production, enriches the soil seed bank (Tessema et al., 2012), increases biomass production (Oba et al., 2000) and litter accumulation (Descheemaeker et al., 2006). As a consequence, soil physical, chemical and biological characteristics improve in the long term (Verdoodt et al., 2009; Raiesi and Riahi, 2014).

Despite the beneficial effects attributed to exclosures, in severely damaged rangelands, herbaceous recovery may be hampered by degradation thresholds, both biotic (e.g. shrub competition; Ratajczak et al., 2014) and abiotic (e.g. water shortage; Holmgren and Scheffer, 2001). Such thresholds are strongly determined by the dominant type of plant cover, particularly in heterogeneous woodlands. It is well known that under-canopy patches store more water in the soil and are more productive than inter-canopy patches (Breshears et al., 1998). Furthermore, the type of dominant coverage determines the quantity and quality of litter, biological activity, soil organic matter and nutrient availability (Abril et al., 1993; Raiesi and Riahi, 2014). However, despite their importance, the influence of the woodland patch type on the effectiveness of the exclosure has been scarcely addressed.

In the semiarid portion of the Dry Chaco ecoregion, continuous grazing, selective logging and charcoal production, turned the natural xerophytic thorny forests (comprised of four layers: upper and lower arboreal, shrubby and herbaceous), savannas and grasslands landscape into a more complex matrix of depleted forests, secondary forests and shrublands, with a widely degraded herbaceous layer. In degraded Chaco rangelands, grasses cover less than 2% and yield less than 100 Kg DM ha^{-1} $year^{-1}$, which implies that a potential carrying capacity of about 4–5 ha AU^{-1} is currently reduced to 20–40 ha AU^{-1} (AU = animal units, equivalent to a cow of 400 kg which breeds a calf per year) (Adámoli et al., 1990; Kunst et al., 2006; Morello et al., 2012). This strongly affects livestock production, the main economic activity of traditional herders who represent more than 80% of livestock producers in the Dry Chaco. Degradation in the Dry Chaco began with the permanent settlement of livestock and forestry in the early twentieth century, but sharply worsened in recent decades with deforestation for crop expansion and livestock intensification (Viglizzo and Jobbágy, 2010; Morello et al., 2012). In Argentina, there is recent legislation that aims to protect native forests and foster multiple sustainable uses. As in other semiarid regions worldwide, seasonal exclosure is one of the increasingly promoted strategies. Nevertheless, exclosures are established indistinctly in different woodland patch types, ranging from less to highly degraded, despite understory conditions significantly differing among them (Abril et al., 1993; Abril and Bucher, 1999).

The main objective of this study was to assess the effects of seasonal exclosures on understory cover and biomass in three increasing degradation stages –mature forests, secondary forests and shrublands– in semiarid Chaco woodlands. Throughout a four year experiment, we monitored structural traits in seasonal exclosures and adjacent rangelands under continuous grazing in these woodlands in four sites in Santiago del Estero (NW Argentina).

2. Materials and methods

2.1. Study area

Our study was conducted 20 km away from Añatuya city (28°20′ – 28°35′ S latitude; 62°23′ – 62°42′ W longitude), Santiago del Estero province, Argentina. This area corresponds to the semiarid Chaco ecoregion (Morello et al., 2012). Mean annual rainfall is 640 mm (1912–2012) and mean annual hydric deficit is about 300 mm. Annual rainfall during the study period was 656 mm (2012), 531 mm (2013), 779 mm (2014) and 924 mm (2015), coinciding with a high intensity El Niño Southern Oscillation (ENSO) event, which dramatically increases rainfall in the Dry Chaco region. Climate is subtropical, with wet season occurring during the warm period, between October and April, and dry season occurring during the cold period, between May and September. Average temperature in the coldest months is 16.6 °C, while in the warmest months it is 28.8 °C. However, historical absolute maximum temperatures have reached 49.5 °C. Topography is flat, with slopes lower than 0.5%, consisting of dominant plains crossed by ancient river-beds (Peña-Zubiate and Salazar Lea Plaza, 1982). Soils on the plains are fine-textured loamy entic Haplustols, throughout the profile. Soils of ancient river-beds are coarse textured and shallower. The natural vegetation is closely related to the landscape, with forests predominating in the plains, and open grasslands (dominated by *Elionurus muticus*) in the ancient river-beds.

The native forest of the study area is a semi-deciduous xerophytic forest comprised by four layers: upper arboreal, dominated by *Schinopsis lorentzii* ("quebracho colorado") and *Aspidosperma quebracho blanco* ("quebracho blanco"); lower arboreal, mainly composed by species of the genera *Prosopis* ("algarrobo"); shrubby, consisting of species of the genera *Acacia*, *Atamisquea*, *Celtis*, *Larrea, Prosopis and Schinus*; and herbaceous, composed by C4 grasses, mostly of the genera *Digitaria*, *Pappophorum*, *Setaria* and *Trichloris,* which coexist with low shrubs of the genera *Capparis, Ephedra* and *Celtis*, various forbs of the family *Malvaceae*, *Verbenaceae* and *Acanthaceae* and other *Bromeliaceae* and *Cactaceae* plants. As we mentioned above, natural forest areas have been widely transformed into degraded woodlands with a severely degraded herbaceous layer.

2.2. Woodland degradation stages

Our study was carried out only in the plains (covered by xerophilous forests), where at least three woodland types with increasing degradation stages were described (Tálamo and Caziani, 2003; Bonino and Araujo, 2005; Brassiolo, 2005): (1) Mature forest or "*bosque de dos quebrachos*", dominated by the upper tree layer, it occupies areas that were selectively logged for timber, tannin and charcoal production, almost a century ago; (2) Secondary forest or "*algarrobal*", dominated by the lower tree layer, it develops on areas where agricultural practices, mainly cotton, were abandoned about three decades ago; and (3) Shrubland or "*fachinal*", areas where trees are virtually absent, severely degraded by varied combinations of continuous grazing, recurrent anthropic fires, selective logging and crops.

2.3. Experimental layout and methods

In order to test the effects of seasonal exclosure and patch type on understory vegetation, we performed a factorial experiment between 2011 and 2015 at four sites (true replicates) located close to Añatuya city. We followed a Randomized Complete Block design (RCB) to assign the main plots 'grazing management' (two levels: rest and continuous within each site) and split–plot to the subplots 'patch type' (three levels: mature forest, secondary forest and shrubland), within each grazing level.