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From forest to shrubland: Structural responses to different fire histories in *Prosopis flexuosa* woodland from the Central Monte (Argentina)

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ABSTRACT

We estimated post-fire population trajectories, and analyzed the effect of fire recurrence on the post-fire recovery of seven different fire histories in the Central Monte. The structure of stems showed that unburned woodlands and woodlands with the longest post-fire recovery time, presented higher proportion of stems with basal diameter (BD) > 5 cm. On sites with higher recurrence of fires, the stems with BD > 5 cm almost disappeared. Tree height and crown diameter showed a significant decrease at sites recently burned, and this pattern was reinforced in areas with recurrent fires. Results suggest that the structure of woodland in the southeast of the Province of Mendoza in Argentina has been strongly controlled by fire history. Fire generates a population dominated by individuals with numerous smaller-sized stems, which becomes more evident in environments where fire recurrence is higher. Structural changes induced by fire indicate that logging may not be possible in the area. The development of forestry practices for post-fire management is needed for the burned areas. An increase in fire frequency is expected in the area, therefore this would cause the modification in the structure of the *Prosopis flexuosa* population. Furthermore, this will lead to the conversion from woodland to shrubland, and the loss of its capacity for natural recovery.

1. Introduction

Fire has played an important role in shaping the structure, function and composition of terrestrial environments worldwide (Pausas and Keeley, 2009; Wright and Bailey, 1982). In recent decades, fires recorded in many parts of the world have affected millions of hectares. This has lead to national, regional and international action to detect, prevent and manage fires (Liu et al., 2014). Wildfires are globally considered among the primary causes of the degradation of forest ecosystems (F.A.O, 2010).

In the traditional concept of ecological succession, protection of the system from disturbance has been suggested as a tool to promote recovery of the structure and function of burned forests. Several studies, however, have suggested that modification of the disturbance regime can generate non-linear responses and new stable states, which prevent the natural recovery of forests, as well as other systems (Bestelmeyer, 2006; Rostagno et al., 2006; Suding et al., 2004). Knowledge of the post-fire trajectories of tree populations with different fire histories can help generate models of long-term dynamics applicable to the management and recovery of burned forests.

The consequences of fire on successional trajectories depend on the season, intensity, frequency, and extent of the fire event (Wells, 2004; Whelan, 1995). They also depend on the generation of new stable communities (e.g., shrublands), and on the occurrence of the processes necessary to drive the transitions between them, such as, protection from grazing, germination from surviving seed banks, seed dispersal, etc (Beckage et al., 2011; Rostagno et al., 2006).

From a forest perspective, fire modifies the population structure of woody plant species, since it causes changes in the natural regeneration and growth habits of individuals (Scholes and Walker, 1993; Álvarez et al., 2009). Resprouting of live buds in the crown, roots or trunks of the burned plants can generate a higher number of stems with lower commercial value (Barbour et al., 1998). In arid

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environments, fire combined with grazing has been suggested to promote the conversion of a woodland system to shrubland (Abril et al., 2005; Roig, 1987), thus reducing its commercial worth. The net primary productivity of woodlands may decline after a fire, reducing wood production; whereas in other cases productivity can increase because of reduced competition from understory vegetation (Carter and Foster, 2004).

In Argentina, different bioclimatic regions are affected by fire. The arid and semiarid regions are among the most affected because of the natural conditions and the widespread use of fire for vegetation management (Fischer et al., 2012; Villagra et al., 2009). In the dry Chaco region (500–700 mm of annual precipitation), it has been observed that sapling density is high (nearly 1000 per ha) in the first year following a fire, and that *Aspidosperma quebracho-blanco* has a great ability to resprout from roots (Roth and Giménez, 1997). *Prosopis nigra* is affected by fire, modifying the shape of the tree and causing wounds that reduce the volume between 60 and 90% (Gimenez de Bolzón, 1994). At a *Prosopis caldenia* woodland, it was found that a single fire event reduced the abundance and competitive ability of the woody species, while promoting regeneration of the grass layer (Bóo et al., 1997). Most woody species in this woodland resprout from the base, but very few show aerial resprouting (Cano et al., 1985). In this region, the effect of fire is related to fire intensity, plant community composition and tree age (Bóo et al., 1997).

In the Central Monte region, large forest areas are affected by different disturbances such as logging, livestock and fire (Rojas et al., 2009; Villagra et al., 2009). Particularly in the southeast of the province of Mendoza, the fire season is between August and January. In this region, over the last 19 years, 88% of the area has been burned, with a mean fire interval of 5.7 years and a fire frequency of 0.18 (Cesca, 2011). This results in a mosaic of patches with various fire recovery times and various fire histories. This mosaic is reflected in the structure of the community and in some soil variables (Cesca, 2011). This region comprises extensive areas with open woodland of *Prosopis flexuosa* ('algarrobales'), which is the dominant tree species in the Monte region and grows on sites with where surplus water is available (Jobbágy et al., 2011). This is the most important species from an economic standpoint, and its stands have been a subsistence source of food, timber and forage for many local communities (Roig, 1993). Its main current use is for forestry and extensive livestock farming. Thus, the fire regime is expected to control the population dynamics of *P. flexuosa* and, consequently, modify its forestry potential. We propose that areas with recurrent fires will show modifications in the population structure and growth habits of *P. flexuosa* individuals, resulting in the system's conversion to shrubland and in a loss of its capacity for natural recovery. The objective of this study was to estimate post-fire population trajectories, and to analyze the effects of fire recurrence on the post-fire recovery of *P. flexuosa* woodlands in the southeast of the province of Mendoza.

2. Materials and methods

2.1. Study area

In the lowlands of Mendoza, there are three main woodland areas which originally covered approximately 40,000 km^2. We selected the Southern area, located in Travesía del Diamante-Atuel (Departments of General Alvear and San Rafael), to perform this study because this area is subjected to recurrent fires, and the status of the plant community denotes an environment that has been modified through fire. The area lying in the SE of the province of Mendoza belongs to the southern portion of the Central Monte and is bound by the Austral Monte (Rundel et al., 2007). Mean annual precipitation is 329 mm, mean annual temperature is 15.4 °C and the predominant wind regime is N–S (Weather Observatory of General Alvear, 35° S and 67°39′ W, at 465 m elevation). This region experiences water deficit most of the year. It also experiences high levels of thunderstorm and hail activity (Capitanelli, 2005). The vegetation has xerophytic features, with the upper stratum represented by *P. flexuosa* and *Geoffroea decorticans*; the shrub stratum represented by *Larrea cuneifolia* and *Larrea divaricata, Atriplex lampa, Atriplex undulata, Prosopis alpataco, Condalia microphylla*, and the herb stratum consists of *Aristida mendocina, Trichloris crinita, Panicum urvilleanum, Hyalis argentea var. latisquama*.

Extensive livestock farming is the major activity in non-irrigated areas, namely breeding of cattle and goats which feed on natural vegetation (grasses and shrubs). There are two major livestock farming systems in the plains of the province of Mendoza: the first is a subsistence system and the second a commercial ranching system. The study area lies within the second system, where producers manage their farms through tenants. Producers consider vegetation resources very important (Guevara et al., 1993).

2.2. Prosopis flexuosa D.C

Most of the species of the *Prosopis* genus occur in South America, and are among the species of highest ecological and economic value in arid and semiarid areas. Within this genus, *P. flexuosa* is a tree species that grows between 5 and 12 m tall, with a low trunk height, deciduous foliage, and which can be multi-stemmed. In Argentina, it occurs in the Monte, dry Chaco and Espinal regions (Alvarez and Villagra, 2009). In the Monte desert, which has a marked water deficit, its populations grow on sites where extra water is available from the subsoil or river beds (Rundel et al., 2007). This species has a tap root that extends vertically, enabling it to reach the water table, and a crown of surface roots that allows it to harness rainwater (Guevara et al., 2010; Jobbágy et al., 2011; Villagra et al., 2010). The 15° isotherm marks the southern border of *P. flexuosa* forest in Argentina; and to the south, the species is represented by the shrub variety *P. flexuosa* var *depressa*, forming a low shrubland.

This variety shows most of their basal branches buried in the earth, semi-buried or creeping (Roig, 1987).

2.3. Experimental design and sampled vegetation units

We studied the post-fire trajectory using a chronosequence of sites with different post-fire recovery times detected by Cesca (2011), based on a multi-temporal analysis of satellite images. In addition, to assess the impact of fire recurrence, we sampled sites with different fire frequencies and similar recovery times since the last fire. Thus, the *P. flexuosa* population was sampled at sites with seven different fire histories: a) unburned (Unburned), b) sites with satellite evidence of burning before 1988 but without precision as to the year of occurrence (Burned before 1988), c) one fire event in season 1993–1994 (Fire 1993–94), d) one fire event in season 2000–2001 (Fire 2000–01), e) one fire event in season 2003–2004 (Fire 2003–04), f) burned twice in the 23 years analyzed with the last fire occurring in season 2003–2004 (2 fires), and g) burned 3–4 times over the last 23 years with the last fire occurring in season 2003–2004 (3–4 fires) (Table 1).

At least three sites were selected for each treatment, and three plots separated by approximately 100 m were established at each site. For selection of the sample sites, we chose different fire events on the map generated by Cesca (2011) at random and then sampled them according to logistic possibilities. In all cases, the distance between sites with the same treatment was over 10 km. Plot size