



## Fire–rainfall relationships in Argentine Chaco savannas

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### ABSTRACT

We used dendroecological techniques to date fire scars in woody species growing in a subtropical savanna of the Argentine Chaco dry forests, and to explore the temporal trends of fire with rainfall variability at different temporal scales during the 20th century. Eight sampling sites were located along an ecotone between savanna and a dry forest, and a composite chronology was developed for a savanna, based on a total of 21 fire dates. The mean fire frequency was 0.18 fires year<sup>−1</sup> and the mean fire interval was 3.3 years. The period post 1971 (which had 22% more rainfall) experienced a fire frequency more than two times higher than the period 1925–1970 ( $p < 0.05$ ). Decadal fire frequency was correlated to 10-years moving average rainfall ( $R^2 = 0.58$ ). Superposed Epoch Analysis showed that fires occur during years of above-average rainfall, and extensive fires tend to follow two years of above-average rainfall, all these associations being statistically significant. These results indicate a climatic control of fire regime, associated to enhanced fine fuels production during years of high rainfall, and imply that regional increase in rainfall associated to global changes in atmospheric circulation are affecting local ecosystems by significantly changing their disturbance regime.

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### 1. Introduction

Fire is a disturbance influencing the structure and dynamics of vegetation because of its frequent occurrence in seasonal climatic regimes (Agee, 1993; Engelmark et al., 1993; Gignoux et al., 1997; Grau et al., 2003; Harris et al., 2008). In the dry Chaco region of Argentina, fires usually start in grasslands and savannas, and may spread to surrounding forests and shrublands, depending on the amount of available fine fuel and wind speed (Bravo et al., 2001; Tálamo and Caziani, 2003). Bravo et al. (2001) estimated a high frequency and a medium to high intensity fire regime over the last century for a typical savanna of the Chaco region.

In the Chaco region, fire is considered an anthropogenic disturbance, mainly used as a tool for vegetation clearing and for the improvement of the nutritive quality of savannas and grasslands by promoting regrowth and eliminating unpalatable woody species (Boletta et al., 2006; Kunst et al., 2003; Tálamo and Caziani, 2003). There are no quantitative assessments of ignition sources in

the Chaco region and lightning seems to be the main cause of natural fires in early spring.

However, even when ignition sources are purely anthropogenic, climate has a strong impact on fire frequency by regulating growth and desiccation of fuels (Baisan and Swetnam, 1997; Di Bella et al., 2006; Duffin, 2008; Engelmark et al., 1993; Grau and Veblen, 2000; Guyette and Cutter, 1991; Kitzberger et al., 1997; Swetnam and Baisan, 1996). During the last few decades, fires seem to have increased in the Chaco region along with the increasingly intensive use of the land, including deforestation for soybean and plantation of subtropical grass species (Boletta et al., 2006; Grau et al., 2005). These land use changes have happened almost simultaneously with regional climate changes and could also be affecting the fire regime. Total annual rainfall has increased in Northwest Argentina since 1956 (Minetti and Vargas, 1997). In other regions of Argentina, greater water availability modified fire frequency and other parameters of the fire regime, affecting the dynamics and characteristics of native vegetation (Grau and Veblen, 2000; Kitzberger et al., 1997).

We examined the hypothesis that the fire regime of the semiarid Chaco ecosystems are influenced, among others factors, by an increase in water availability, which generates over time a major increase in fine fuel availability for fires. This hypothesis derived from, a) research conducted in other savannas worldwide, which

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showed a relationship between rainfall, fuel production and changes in fire regime parameters (Harris et al., 2008; Hély et al., 2003; Swetnam and Baisan, 1996; Grau et al., 2001), and b) the increasing fire frequency in other seasonal environments of Argentina concurrently with a period of greater water availability (Grau and Veblen, 2000; Kitzberger et al., 1997). The objective of this study was to use dendroecological techniques recently developed for native woody species to estimate the relationship between fire frequency and rainfall variability at different time scales and resolutions during the last century in savanna ecosystems of the semiarid Chaco region.

## 2. Materials and methods

### 2.1. Study area

The study area was located in the western Chaco region, province of Santiago del Estero, Argentina, in the “La María” Experimental Ranch belonging to the Santiago del Estero Experimental Station, Instituto Nacional de Tecnología Agropecuaria (28° 3' S latitude, 64° 15' W longitudes). The area lies on a transitional plain between the Guasayán Mountains and the alluvial plain of the Dulce River. The plain is 190 m above sea level and was created in a sedimentary basin covered by fluvial and loess materials. The soils of the study area correspond to Eutric Regosol, order Entisols (Lorenz, 1995).

The climate is semiarid and seasonal, with dry, cold winters and hot, rainy summers (Boletta et al., 2006). The mean annual temperature is 19.8 °C, and the means of the warmest (January) and coldest (July) months are 26.1 °C and 10.6 °C, respectively. Freezing temperatures can occur from May to October, reaching extreme temperatures of –10 and –12 °C (Torres Bruchmann, 1981). The average annual rainfall is 579 mm.

During the summer, continental warming creates low-pressure centers in the center and north of Argentina that attract air masses associated with oceanic anticyclones. The contact of air masses with different humidity and temperatures produces intense, frontal rainfalls characterizing the summer season. During the winter, oceanic anticyclones move northward and form on the continent. These weather systems prevent the entry of humid air masses from the north and north-east, resulting in cold, dry winters. During late winter and early spring, the predominant winds are dry and warm, alternating from the south and north (Boletta et al., 2006), causing air humidity to drop below 20% at noon and in the early afternoon (Kunst and Bravo, 2003). These climatic features last for approximately six months, during which time the atmospheric conditions favor fire occurrence. The fire season stretches from May to October coinciding with the dry season.

The vegetation of the Chaco region is a mosaic of thorny semi-deciduous forests, savannas and grasslands (Brassiolo et al., 1993; Bucher, 1982; Morello and Adámoli, 1974). The tree species *Schinopsis lorentzii* (quebracho colorado santiagueño) and *Aspidosperma quebracho-blanco* (quebracho blanco) dominate in upper layers of the forests (c. 15 m tall). *Prosopis nigra* (algarrobo negro), *Ziziphus mistol* Griseb. (mistol), *Cercidium praecox* (brea), and *Geoffroea decorticans* (chañar) are common species in the medium strata. Several species of *Acacia* and *Capparis*, *Jodina rhombifolia* (sombra de toro) and *Portieria microphylla* (piquillín), characterize the shrubby lower strata (Brassiolo et al., 1993; López de Casenave et al., 1995).

Natural grasslands occupy interfluvial homogeneous soils and are dominated by *Trichloris crinita*, *Trichloris pluriflora*, *Gouinia paraguayensis*, *Gouinia latifolia*, *Setaria argentina*, *Setaria gracilis*, *Digitaria sanguinalis*, *Papophorum pappiferum*, *Papophorum mucronulatum* (Herrera et al., 2003). In savannas, the dominant grass

species is *Elionorus muticus* Spreng. (“aibe”, “espartillo”, “paja amarga”) a caespitose plant commonly between 30 and 40 cm tall. Trees such as *A. quebracho-blanco*, *P. nigra*, *Acacia aroma*, *Schinus* sp., *Celtis* sp. are scattered across the savannas in small patches or as isolated trees (Kunst et al., 2003).

### 2.2. Sample collection

Fire chronologies were based on dendroecological analyses (Kitzberger et al., 2000; Medina, 2003) of samples of *S. lorentzii*, *A. quebracho-blanco*, *A. aroma* and *A. furcatispina*, which are useful for dendroecological studies (Bravo et al., 2008). Eight sampling sites were located along an ecotone between the *E. muticus* savanna and an open-canopy dry forest. The distance between sampling sites varied from 600 to 800 m.

Sampling was guided by external signals of fire (fire scars, charred barks) on bole or/and branches of living individuals. At least three individuals were sampled in each sampling site. Wood samples were extracted from a total of 6 individuals of *S. lorentzii*, 8 of *A. quebracho-blanco*, 8 of *A. aroma* and 8 of *A. furcatispina*, respectively. Bole cross-sections of a width at least 0.02 m were cut using a chainsaw at approximately 0.3 m from the ground. In the tree species (*S. lorentzii* and *A. quebracho-blanco*), additional cross-sections were cut every meter up to 4.3 m height. In the shrub species, cross-sections were cut every 0.3 m due to a smaller development in the length of fire scars. In multi-stemmed forms, the biggest branch was sampled. Cross section samples were sanded and observed under a binocular magnifying glass following standard dendrochronological procedures (Barrett and Arno, 1988; Kitzberger et al., 2000).

Fire dates were determined by counting tree rings backwards from the outermost ring (corresponding to the sampling date) to the ring showing the fire scar or mark. This fire dating was made due to the lack of master dendrochronologic curves of width growth rings in Chaco native woody species. We exclusively sampled live individuals, and considered an error of  $\pm 1$  year. Fire years were cross-dated, comparing fire data of each individual with the closest individual data in each sampling site (Bravo et al., 2008; Kitzberger et al., 2000).

### 2.3. Data analysis

A composite chronology was developed for the entire savanna by pooling data from all sampling sites (Agee, 1993). Fires dated in a single individual tree were included as fire years in the composite chronology of the *E. muticus* savanna. Longevity of the selected tree species exceeded one century and the short life span of the shrub species generated an unequal number of fires dated along the fire chronology. To avoid biases generated by an unequal number of fire events, we developed a second composite chronology considering only the fire events recorded in the tree samples (i.e. excluding *Acacia* species).

Fire frequency (FF) was defined as the ratio between the number of fires registered and the period of time comprised between the first recorded fire at each site and the sampling year. Fire frequency was determined for each sampling site and then averaged in order to calculate a mean FF for the entire savanna. The mean fire interval (MFI) was defined as the mean time period between two consecutive fires (Agee, 1993; Payette et al., 1989). In this work, fire interval analysis was based on site information using the program FHx2 (Grissino-Mayer, 1999). This analysis determined the fit of fire intervals to a Weibull distribution using the Kolmogorov–Smirnov Test and changes in MFI and other statistical descriptors of a fire regime.

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