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The influence of controlled fires on a plant community in the south of the Caldenal, and its relationship with a regional state and transition model

Influencia del fuego controlado sobre una comunidad vegetal del sur del Caldenal, y su relación con el modelo regional de estados y transiciones

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Abstract. Fire plays a fundamental role in the structure of vegetation communities in the Caldenal. However, this effect has decreased considerably since the introduction of domestic cattle, which reduces the amount of fine combustible material. Objectives of this study were (1) to analyze the diversity and composition of a typical vegetation community in the south of the Caldenal after exposure to different fire frequencies, and (2) to show the convenience of using controlled fire for reversing the processes of scrub formation to states with more diverse and productive grassland communities. Forty-five herbaceous and woody species were recorded. Treatment **C** (control) showed the greatest richness and diversity in December 2006 and 2007. After the last controlled fire, the composition of the vegetation community differed significantly between treatment **C** and treatments $\mathbf{T_1}$ and $\mathbf{T_2}$ (with burns every 3-4 and 7-8 years, respectively). This change was mainly due to the proliferation of palatable perennial grasses. Vegetation composition was similar for **C** and $\mathbf{T_2}$ (ANOSIM, R=0.01, p=0.32 and R=0.06, p=0.01, respectively) in 2006 and 2007. However, treatment $\mathbf{T_1}$ showed significant changes (ANOSIM, R=0.42, p=0.01). *Nasella clarazii*, which is a characteristic palatable grass in the region, was the perennial forage grass with greatest cover in treatment $\mathbf{T_2}$, whereas it was scarce in treatments **C** and $\mathbf{T_1}$. Unpalatable grasses and bushes grew at sites without fire, e.g. treatment **C** in this study. Our results show that use of controlled fire of intermediate frequencies would favor the aerial cover of palatable perennial grasses in states that are most useful for sustainable cattle production.

Keywords: Vegetation communities; Post-fire effects; Caldenal; Semi-arid region; Cattle production.

Resumen. El fuego cumple un rol fundamental en la estructura de las comunidades vegetales del Caldenal. Éste ha disminuido notablemente desde la introducción del ganado doméstico debido a la reducción de combustibles finos. Los objetivos del presente trabajo fueron (1) analizar la diversidad y composición de una comunidad vegetal típica del sur del Caldenal expuesta a diferentes frecuencias de fuego, y (2) demostrar la conveniencia del uso de fuegos controlados para revertir los procesos de arbustización a estados con pastizales más diversos y productivos. Se registraron 45 especies vegetales herbáceas y leñosas. El tratamiento **C** (control) mostró la mayor riqueza y diversidad en diciembre 2006 y 2007. La composición de la comunidad vegetal, luego de la última quema controlada, difirió significativamente entre el tratamiento **C** y los tratamientos $\mathbf{T_1}$ y $\mathbf{T_2}$ (con quemas cada 3-4 y 7-8 años, respectivamente). Este cambio es conducido principalmente por la proliferación de gramíneas perennes deseables. La composición vegetal fue similar para el **C** y $\mathbf{T_2}$ (ANOSIM, R=0,01, p=0,32 y R=0,06, p=0,01, respectivamente) en 2006 y 2007. En cambio, el tratamiento $\mathbf{T_1}$ mostró cambios significativos (ANOSIM, R=0,42, p=0,01). *Nasella clarazii*, cuya presencia caracteriza a los estados más deseables de los pastizales de la región, fue la gramínea perenne forrajera con más cobertura en el tratamiento $\mathbf{T_2}$. Sin embargo, su presencia fue escasa en los tratamientos **C** y $\mathbf{T_1}$. En los sitios con ausencia de fuego (es decir, **C**), se desarrollan arbustales acompañados de gramíneas perennes no palatables. Por lo tanto, este estudio indica que el empleo de fuegos controlados con una frecuencia intermedia de fuego, favorecerían la cobertura aérea de gramíneas perennes deseables en aquellos estados definidos como más apreciados para la producción ganadera sustentable.

Palabras clave: Comunidad vegetal; Efectos post-fuego; Caldenal; Región semiárida; Producción ganadera.

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INTRODUCTION

The Calden Phytogeographical District, known as the Caldenal, extends from the centre of San Luis to the southwest of the Province of Buenos Aires, including the centre of La Pampa Province (Cabrera, 1976). Fire is an important component of the disturbance regime which, together with grazing and precipitation, shapes the vegetation communities in this semiarid, temperate region in the centre of Argentina (Boó, 1990; Distel & Bóo, 1995; Busso, 1997). The high grazing pressure altered the natural fire regimes. As a result, grasslands were transformed to shrublands, or areas of tall grass species, unpalatable to animals (Peláez et al., 2003). The different responses of various life forms directly alter the composition and cover of the vegetation communities, and indirectly affect the availability of nutrients in the soil (Wellington & Noble, 1985). The magnitude of these changes are due to conditions at the time of the fires. For example, the season of the year, and the frequency and intensity of fire greatly influence succession and the structure of plant communities (Whelan, 1995).

Thousands of hectares of natural grasslands are burnt every year in the south of the Caldenal. However, the frequency of fire occurrence has decreased notably since the introduction of domestic livestock, due to the reduction of fine combustible material (Peláez et al., 2003). When the effect of fire was studied, a relationship was detected between the abundance of woody and herbaceous species (Bóo et al., 1996; Bóo et al., 1997; Peláez et al., 2003); it was shown that frequent fires reduce growth of young woody plants. These plant individuals develop a better competitive capacity and form a very dense stratum when frequency of fire is reduced and grazing increased at the same time. This phenomenon, known as scrub formation, may be either reverted to former states or changed to more desirable states by managing the ecosystem with controlled burns (Distel & Bóo, 1995; Busso, 1997). Therefore, fire may be considered as a pulsating event, part of a sequence that is repeated indefinitely, and is a factor of disturbance in a resilient, but unstable system (Holling, 1973). Thus, aspects such as maximum production, maximum diversity and even the concept of climax are transitional stages within a cycle. Paradoxically, the greatest alteration to the system might be the interruption of this cycle if fire occurrence is avoided.

Distel & Bóo (1995) proposed a state and transition model (Westoby et al., 1989) for the semi-arid temperate region of Argentina. It includes several relevant considerations for planning sustainable systems of cattle raising. These authors considered five states, two desirable, composed of palatable grasses, and three undesirable with different mixtures of unpalatable grasses and bushes. The model proposes that appropriate management of the frequency and intensity of fire can revert the processes of scrub formation and the proliferation of unpalatable grasses to a state with less bushes and a greater diversity of grassland. The aim of the present study was to analyze the composition of a typical vegetation community in the south of the Caldenal district exposed to different fire frequencies. This would show whether it is convenient to use controlled fire for inducing changes from undesirable to desirable states in the landscape, and assist in the design of sustainable production systems for cattle production in the region.

MATERIALS AND METHODS

This study was carried out at a representative site in the south of the Calden Phytogeographical District (Caldenal; 38° 45'S, 63° 45'W), within the Espinal Biogeographical Province (Cabrera 1971), Department of Caleu Caleu, in La Pampa Province. Mean annual precipitation is 400 mm, mainly concentrated in spring and autumn. The annual water deficit is 400 mm, very pronounced from December to March. Mean temperature in the coldest month (June) is 7.4 °C and in the hottest month (January) is 23.6 °C, with a frost-free period of 180 days anually.

Vegetation at the study site consists of two strata: a woody layer of variable density, dominated by *Prosopis caldenia* Burk. ("caldén"), and a herbaceous layer where *Nassella tenuis* (Phil.) Barkworth (ex *Stipa tenuis*; "flechilla fina") and *Piptochaetium napostaense* (Speg.) Hack. ("flechilla negra") are the dominant grasses (Peláez et al., 2001). Soil texture is a sandy loam throughout the profile, and it shows active limestone due to the leaching of carbonates (Castelli & Lazzari, 2002).

The study was carried out in an area of approximately 12 ha that had been closed to domestic animals since 1989. Six one-ha experimental plots were established within this area, and separated by firebreaks 20 m wide. These plots were randomly assigned to different frequencies of controlled fire treatments: no fire (control; **C**); controlled fires every 3-4 years ($\mathbf{T}_1$), and controlled fires every 7-8 years ($\mathbf{T}_2$). Two plots were assigned to each treatment (n=2). Plots assigned to $\mathbf{T}_1$ were burnt in 1991, 1994, 1999, 2003 and 2007, while those assigend to $\mathbf{T}_2$ were burnt in 1991, 1999 and 2007. All controlled burns were carried out in the autumn (March-June) when mean environmental conditions were: air temperature: 22-25 °C; relative humidity: 32-43% and wind speed: 12-20 km/hr. Fine combustible material was 2500-4000 kg dry matter.

Species richness and cover of herbaceous and woody plants were determined in each fire frequency treatment before (December 2006) and after (December 2007) the last controlled burn (June 2007). Ten round plots (3 m^2) distributed at random were used for these measurements within each of the two replicates per treatment. The number of species within each plot was counted to estimate richness, and the Braun-Blanquet (1979) method was used for estimating cover.

The Shannon-Wiener (H') indexes (Kindt & Coe, 2005) were calculated for making comparisons. The analysis of similarity (ANOSIM) was performed for the analysis of species

composition, using the Bray-Curtis similarity index. This allowed to produce the similarity matrix between the fire frequency treatments. ANOSIM is not a parametric, but a permutation procedure that results in an absolute measure of distance between the groups, the R statistic; the values 1 to 0.26 indicate separation, and from 0.25 to 0 indicate similarity (Clarke, 1993). The level of significance is calculated with permutations of the sites between the groups. These analyses were performed with the Biodiversity R packet from the R-project statistical programme (Kindt & Coe, 2005).

RESULTS

Forty-five herbaceous and woody plant species were recorded. Treatment **C** showed the greatest species richness with 34 and 35 species in December 2006 and 2007, respectively. There were five species less in the $\mathbf{T}_1$ and $\mathbf{T}_2$ treatments both before and after the controlled burn as compared with **C** treatment**.** Diversity was also greater in treatment **C** than in the other treatments**,** on both sampling dates. The greatest difference among treatments was recorded after the recent controlled burn. Indexes (mean ± 1 S.E.) were H'=2.75 ± 0.17 in the control; H'=2.44 ± 0.25 in $\mathbf{T}_2$**,** and H'=2.20 ± 0.13 in $\mathbf{T}_1$.

There was a significant difference in the composition of the vegetation community between treatment **C** and the $\mathbf{T}_1$ and $\mathbf{T}_2$ treatments after the controlled burn; the greatest difference was shown between treatments **C** and $\mathbf{T}_1$. No changes were detected in the vegetation composition between the different treatments before the controlled burn (Table 1).

Table 1. Analysis of similarities (ANOSIM) for the plant community between the control and treatments with fire every 3-4 years ($\mathbf{T}_1$) or every 7-8 years ($\mathbf{T}_2$) in December 2006 and 2007. The dotted line shows the burn in June 2007. R values greater than 0.25 indicate separation between the groups; p values higher than 0.05 are shown in black.
Tabla 1. Análisis de similitudes (ANOSIM) para la comunidad vegetal entre control, y tratamiento con fuego cada 3-4 años ($\mathbf{T}_1$) o cada 7-8 años ($\mathbf{T}_2$) en diciembre de 2006 y 2007. La línea punteada indica la quema de junio de 2007. En las columnas, los valores de R mayores a 0.25 indican separación entre grupos; los valores de p mayores a 0.05 se indican en negrita.

Comparison of frecuencies	December 2006		fire	December 2007	
	R	p		R	p
C vs. T_1	0.12	0.02		**0.39**	0.01
C vs. T_2	0.11	0.01		**0.30**	0.01
T_1 vs. T_2	0.25	0.01		0.25	0.01

The most relevant woody species in treatment **C**, at both sampling dates, were *Schinus fasciculatus*, *Prosopis caldenia*, *Condalia microphylla*, *Prosopidastrum globosum* and the perennial grass *Jarava ichu* (Fig. 1 a and b, **C**). The vegetation composition of treatment **C** was similar in the 2006 and 2007 samples (ANOSIM, R=0.01, p=0.32). *Acantholippia seriphioides* and *P. caldenia* were the woody species with the greatest cover before the last controlled burn in those plots exposed to treatment $\mathbf{T}_1$. However, after the burn these species did not show an important cover, and the percentage of bare ground was dominant. On the other hand, a few herbaceous species were present at both sampling dates, e.g. the grasses *Poa lanuginosa*, *P. ligularis* and *P. napostaense* (Fig. 1 a and b, $\mathbf{T}_1$). There were significant changes in the composition of the plots assigned to treatment $\mathbf{T}_1$ between 2006 and 2007 (ANOSIM, R=0.42, p=0.01). All plots assigned to treatment $\mathbf{T}_2$ contained the same predominant species. However, cover of these species changed from one year to the next; the woody species showed less percentage cover after the controlled burn, whereas the cover of some perennial grasses and the percentage of bare ground increased (Fig. 1 a and b, $\mathbf{T}_2$). Compostion was similar in the plots exposed to treatment $\mathbf{T}_2$ (ANOSIM, R=0.06, p=0.01) in 2006 and 2007.

DISCUSSION

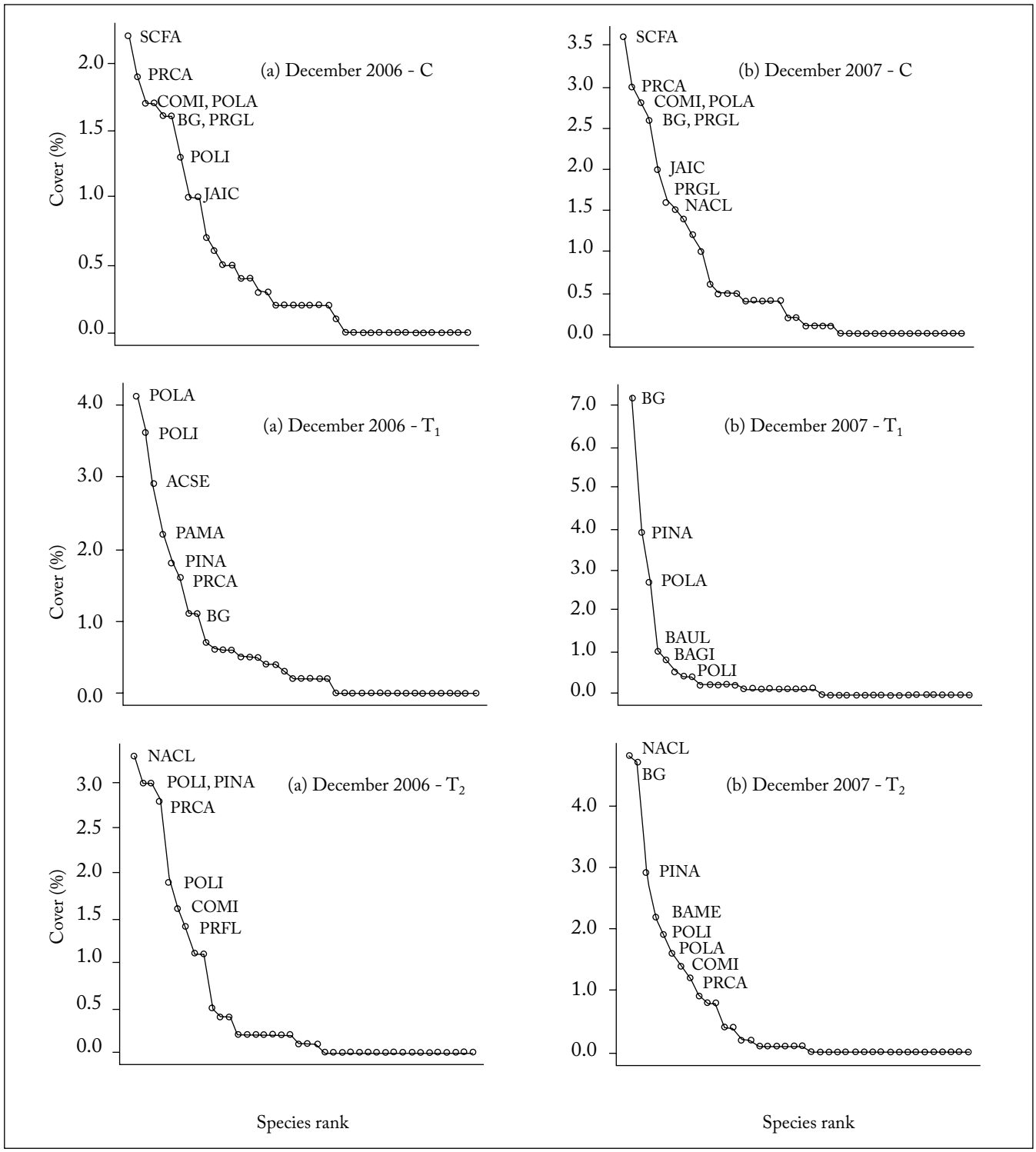
In general, results of this study are consistent with the state and transition model proposed by Distel & Bóo (1995) for the Caldenal district. Shrubs and unpalatable perennial grasses, e.g. *J. ichu,* became established in the vegetation communities at sites where no fire occured, i.e. treatment **C.** A significant decrease in the cover of woody species and undesirable perennial grasses was observed in the different treatments of controlled burning. This is in agreement with that seen in other studies undertaken in the area 10 years earlier, using different sampling techniques and analysis (Bóo et al., 1996; Bóo et al., 1997).

The significant changes between the different frequencies of controlled fire ($\mathbf{T}_1$ and $\mathbf{T}_2$) and the control (**C)** are due to a marked reduction in the cover of *P. caldenia* and *J. ichu* and a notable increase in the percentage of bare ground after the last controlled burn in June 2007. Although the percentage of bare ground in treatment $\mathbf{T}_1$ was twice that in treatment $\mathbf{T}_2$, species composition was similar in both treatments (Fig. 1 b). This might be due to the ocurrence of previous intense fires that might have affected the seed bank, and favored wind and water erosion with the consequent loss of soil structure and nutrients (Bran et al., 2007).

Nassella clarazii, which is one of the most desirable grasses in the Caldenal (Distel & Bóo, 1995), was the perennial grass with the greatest cover in treatment $\mathbf{T}_2$, whereas it was scarce in treatment $\mathbf{T}_1$. Therefore, the use of frequent fire control (e.g., every 3 years) would be less favourable for this grass, and then less likely to lead to a species composition and diversity compatible with the most desirable state of the grassland. Bóo et al. (1997) and Peláez et al. (2003) reported a lower cover of woody species after controlled burns in grasslands of the southern Caldenal. The cover of *A. seriphioides* and *P. caldenia* in treatment $\mathbf{T}_1$ was markedly reduced after the controlled fire, whereas the desirable perennial grasses maintained a similar

Fig. 1. Plant species cover (%) before fire in 2006 (a) and after fire in 2007 (b) by treatment. ACSE*: Acantholippia seriphioides*, BAGI: *Baccharis gilliesii*, BG: Bare ground, BAME: *Baccharis melanopotamica*, BAUL: *Baccharis ulicina*, COMI: *Condalia microphylla*, JAIC: *Jarava ichu,* NACL: *Nassella clarazii*, PAMA: *Pappostipa major*, PINA: *Piptochaetium napostaense*, POLA: *Poa lanuginosa*, POLI: *Poa ligularis*, PRCA: *Prosopis caldenia*, PRGL: *Prosopidastrum globosum*, SCFA: *Schinus fasciculatus*.

Fig. 1. Cobertura de las especies (%) antes del fuego 2006 (a) y luego del fuego 2007 (b) por tratamiento. ACSE*: Acantholippia seriphioides*, BAGI: *Baccharis gilliesii*, BAME: *Baccharis melanopotamica*, BAUL: *Baccharis ulicina*, COMI: *Condalia microphylla*, JAIC: *Jarava ichu,* NACL: *Nassella clarazii*, PAMA: *Pappostipa major*, PINA: *Piptochaetium napostaense*, POLA: *Poa lanuginosa*, POLI: *Poa ligularis*, PRCA: *Prosopis caldenia*, PRGL: *Prosopidastrum globosum*, SCFA: *Schinus fasciculatus*.



cover to that observed previously. Moreoever, the cover of *P. napostaense* was doubled after the controlled burn. Treatment $\mathbf{T_2}$ showed a similar tendency to $\mathbf{T_1}$, although the observed changes in the cover of woody species were less drastic. Among the desirable perennial grasses, *N. clarazii* showed the maximum cover of all the species present at both sampling dates. This species is considered to be highly competitive in the absence of grazing, or at low stocking rates (Saint Pierre & Busso, 2006), as was the case in this study, which is associated with the pristine conditions of the community (Distel & Bóo, 1995; Busso, 1997).

The detected modification of the vegetation community resulting from the use of controlled burning of moderate intensity and different frequencies over a period of 16 years (1991-2007) seems to support the hypothesis proposed by D´antonio & Vitousek (1992) of positive retroalimentation between fire and grasses. The frequency and intensity of fires and the quantity of liberated energy in a burn (Whelan, 1995) are factors that might affect various life forms in different ways. Perennial grasses that are tolerant to fire show regrowth from axillary buds which are not affected either by the high temperatures or direct fire, due to their position on the plants (Peláez et al., 2001). At the same time, the aerial structures of woody species are drastically reduced by the direct fire effects, and regrowth takes place from meristems that are several centimetres underground. Consequently, the reduction in the aerial cover of woody species, and eventually the reduction in their abundance, leads to an appropriate environment for the development of perennial grasses; this is the result of less competition for light, water and available nutrients (Peláez et al., 2003). According to D´antonio & Vitousek (1992) these competitive advantages favor dispersion, and the subsequent increase in grass cover. This allows the necessary accumulation of fine combustible material for initiating and propagating fire, thereby sustaining the fire/grass cycle. If fire frequency increases the aerial cover of both woody and herbaceous species, then the risk of soil erosion might be reduced (Bran et al., 2007). This situation might therefore favor the development of woody species that are more tolerant to fire, slowly leading to an increase of shrubby vegetation in the natural grassland.

The effects of fire on perennial grasses (for example, mortality) depend on abiotic and environmental factors. A species that is greatly affected by one fire might not be affected by another because of different fire and/or post-fire conditions rather than to plant factors. Therefore, the final state of the perennial grasses is the result of the interaction between (1) fire characteristics and processes that occur after fire [e.g., climatic conditions (mainly rain) and herbivore intensity] and (2) factors that make plants tolerant to fire and post-fire processes (Busso, 1997). Even considering these restrictions, our results offer some evidence that endorses, at least in part, the state and transition model proposed by Distel & Bóo (1995) for the southern Caldenal.

This study indicates that use of controlled fires at the historical frequency (corresponding to the one which occurred in the region before the introduction of domestic livestock) favors the aerial cover and diversity of desirable perennial forage grasses in those states that are most appropriate for cattle production.

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