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Response of woody species to different fire frequencies in semiarid rangelands of central Argentina[#]

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Abstract. The aim of the study was to assess the effect of different controlled fire frequencies on cover, density and mortality of the most common woody species in semiarid rangelands of the Caldenal district of central Argentina over a 20-year period. The study comprised three fire treatments: (1) high fire frequency (controlled burns every 3–4 years; HFF); (2) low fire frequency (controlled burns every 8 years; LFF); and (3) unburned control. Repeated burns of moderate intensity, regardless of frequency, reduced the cover and the individual height and canopy area of the most common woody species. Their density was barely affected and the mortality rates were negligible with woody species producing new sprouts after each burn. The woody species under study had a similar response to the high- and low fire frequency treatments. A controlled burn every 3–4 years, permitted the control of woody species cover, height and canopy area, which in turn may favour the production of desirable perennial grasses. The important managerial implication is that the repeated use of controlled fires of moderate intensities in the autumn, given appropriate grazing management, is likely to be essential to maintain these rangelands.

Additional keywords: Caldenal, *Condalia microphylla*, controlled burning, *Larrea divaricata*, *Prosopis caldenia*.

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Introduction

Fire as a natural factor in rangelands has occurred for as long as vegetation has been present on earth. Fires have occurred historically when fuel accumulation and weather conditions make ignition and burning possible (Vallentine 1989), and have long been recognised as a disturbance that prevents invasion of woody species into grass-dominated ecosystems (Wright and Bailey 1982; Whelan 1995).

In the semiarid rangelands of the southern Caldén District (Caldenal) (Cabrera 1976), situated in central Argentina, wildfires are a common feature during the hot and dry summer months. The present-day interval between fires in this region is ~10 years (Lell 1990). It has been suggested that the reduction in grass biomass due to long-term grazing by domestic livestock and the building of firebreaks have increased the fire-free period (Bóo *et al*. 1996).

Fire plays a key role in determining floristic composition in the Caldenal, mainly by keeping woody species in check (Bóo 1990). Some ranchers have conducted controlled fires in late summer or early autumn with the aim of reducing the abundance of woody species and increasing forage quality. Despite this, information on the effects of a single fire event on the native woody species is very scarce (Willard 1973; Braun and Lamberto 1976; Cano *et al*. 1985; Bóo *et al*. 1997). Moreover, information

[#]This paper is dedicated to the memory of our dear friends Dr Roberto M. Bóo (1944–2007) who, as the leader of our research team, directed this project until his passing, and Mirta D. Mayor (1957–2008), an excellent professor and an endeared member of our team.

on the cumulative effects of a particular sequence of fires on these species is lacking. In addition, the impact of fire on the ground flora, particularly on grasses, needs to be understood before recommendations on fire's effects on woody plants can be made. While the specific objective of this study was to assess the effect of different controlled fire frequencies on cover, density and mortality of the most common woody species in the Caldenal over a 20-year period, comments on the possible effects of impact of a reduced cover of woody species on ground flora are also made.

Materials and methods

Study site

The study was conducted at a representative site of the Caldenal, situated in the south-eastern corner of the province of La Pampa in central Argentina (38°45′S, 63°45′W). A level 12-ha site was located within a 600-ha pasture with no recent fire history and which had been fenced since 1989 to exclude livestock grazing.

Climate, soil and vegetation of the region have been described in detail elsewhere (INTA 1980; Bóo and Peláez 1991; Peláez *et al*. 2011). In summary, the climate is temperate and semiarid. Annual mean temperature is 15.3°C, June being the coldest month (7°C) and January (23.6°C) the warmest. Average annual precipitation is 344 mm, concentrated in the autumn and spring. Annual water deficit is ~400 mm. The soil at the site is a well drained Calciustoll of a medium to heavy texture. A petrocalcic horizon ('tosca') is usually found at 40–60 cm depth. The herbaceous layer is dominated by perennial, cool-season grasses such as *Piptochaetium napostaense* (Speg.) Hack., *Nassella tenuis* (Phil.) Bark., *Nassella clarazii* (Ball) Bark. and *Poa ligularis* Ness ex Steud. Other common grasses at the study site include *Jarava ichu* (Ruiz et Pav.) and *Pappostipa speciosa* (Trin et Rupr.) Rom. The shrub layer is represented by warm-season caducifolius species and evergreen species, the former being mainly represented by *Prosopis caldenia* Burk. and *Prosopis flexuosa* DC., and the latter by *Larrea divaricata* Cav., *Condalia microphylla* Cav., and *Chuquiraga erinacea* D. Don (Bóo and Peláez 1991).

Fire treatments

The study comprised three fire treatments replicated twice: (1) high fire frequency (controlled burns every 3–4 years; HFF); (2) low fire frequency (controlled burns every 8 years; LFF); and (3) unburned control (C). Treatments were randomly assigned to 1-ha experimental units enclosed within the 12-ha research area and separated from one another by 20-m firebreaks. The HFF treatment experimental units were burnt in 1991, 1994, 1999, 2003 and 2007, while the LFF treatment experimental units were burnt in 1991, 1999 and 2007. Burns were conducted in accordance with a safe fire prescription guide (Wright and Bailey 1982).

Air temperature, relative humidity and wind speed were measured before and immediately after each burn with field instruments. Mean values were between 22 and 25°C, 32 and 43%, and 12 and 20 km h^{-1}, respectively.

All burns were conducted as headfires usually starting at 3–4 p.m. in autumn (March–June). Fine fuel loads ranged from 2500 to 4000 kg ha^{-1}. Fine fuel was considered as all material on the ground, including litter, less than 3 mm in diameter.

Six thermocouples type K (chromel-alumel) connected to a Campbell 21 XL datalogger (Logan, Utah, USA) were used to record temperatures during the controlled burns at 1-s intervals. Thermocouples were randomly located in each experimental unit immediately above the soil's surface.

Vegetation sampling

Ten 20-m transects were randomly placed in each experimental unit at the beginning of the experiment and were used to estimate woody species cover and density at the end of each growing season throughout the study period (i.e. from 1990 to 2009). Woody species cover was estimated by the line intercept method (Canfield 1941). Density data were collected by counting the number of individuals whose canopy was more than half-included in a quadrat (2 × 20 m) centred along each transect. Except for the abovementioned species, all other woody species [i.e. *Baccharis ulicina* Hook & Arn, *Acantholippia seriphioides* (A. Gray) Mol., *Baccharis crispa* Spreng., *Prosopidastrum globosum* Burk., *Schinus fasciculatus* (Griseb.) Johnst., etc.] were considered as a whole group (others).

In addition, 40 plants of *P. caldenia*, *P. flexuosa*, *C. microphylla*, *L. divaricata* and *C. erinacea* were randomly selected in each experimental unit. At each sampling date, the height of each plant was measured and the individual canopy area of each plant was estimated by measuring two projections (N–S and E–W) of the aerial parts on the ground to estimate an ellipse surface area. Dead plants were also recorded to calculate mortality rate of each species.

The impact of fire on ground flora, while not a direct aim of the present research, has been studied on the same site over the same period of time and a summary of this information is used in discussing the results.

Statistical analyses

Prior to statistical analysis, data corresponding to woody species cover, density and individual height and canopy area were subject to arcsine, square root and log-transformations, respectively. Data were analysed using residual maximum likelihood mixed models. The fixed model effects were fire frequency and year. The random model effect was replication (transect or plant) within each fire treatment. The Tukey HSD test was used to separate means when significant differences were found. Mortality data based on the number of individuals were analysed using Chi-square (Snedecor and Cochran 1980). All statistical analyses were performed with JMP 7.0 (SAS Institute 2007).

Results

Fire temperatures

Time-temperature curves obtained during the controlled burns were all similar in shape. Time-temperature curves, obtained during the last controlled burn (June 2007) in the HFF and LFF treatments, are shown in Fig. 1. Maximum soil surface temperatures reached in the HFF and LFF treatments were 391.6 and 390.2°C, respectively.

Woody species cover and density

By the end of the study period, the cover of *C. microphylla*, *L. divaricata*, *C. erinacea* and *P. flexuosa* in the C treatment was

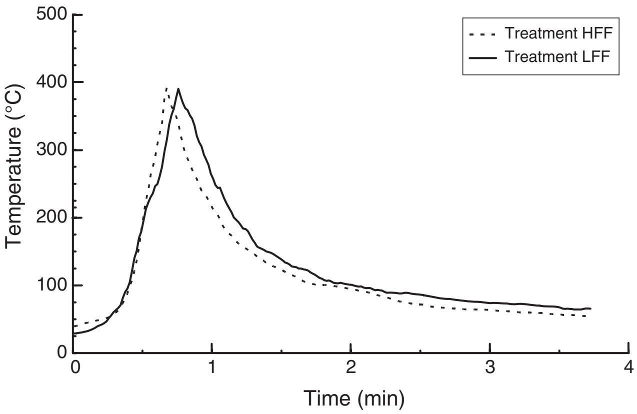

Fig. 1. Time-temperature curves at the soil surface in the high fire frequency (HFF) and low fire frequency (LFF) treatments during the last controlled burns (June 2007). Each curve is the mean number of 12 thermocouples.

higher ($P < 0.05$) than in the HFF and LFF treatments. However, no significant differences ($P > 0.05$) were detected between the HFF and LFF treatments (Fig. 2*a*). Cover of *P. caldenia* in the HFF treatment was significantly lower ($P < 0.05$) than in the LFF and C treatments, but there were no significant differences ($P > 0.05$) between the LFF and C treatments (Fig. 2*a*). The percentage cover of the remaining woody species group was also lower on the HFF and LFF treatments, but significant differences ($P < 0.05$) were only found between the HFF and C treatments (Fig. 2*a*).

At the end of the study period, the density of *L. divaricata* in the LFF treatment was lower ($P < 0.05$) than in the HFF treatment which was lower again ($P < 0.05$) than the C treatment (Fig. 2*b*). *Chuquiraga erinacea* showed a similar response but a significant difference was only found between the LFF and C treatments. Densities of *C. microphylla* and *P. flexuosa* in the C treatment were slightly lower than those in the HFF and LFF treatments, but no statistical differences ($P > 0.05$) were found (Fig. 2*b*). Density of *P. caldenia* in the LFF treatment was higher than that in the HFF treatment ($P < 0.05$), whereas density in the C treatment was similar ($P > 0.05$) to that in the HFF and LFF treatments. A similar response was observed in the remaining woody species group (Fig. 2*b*).

Woody species height, canopy area and mortality

At the end of the study period, the height and canopy area of *C. microphylla*, *C. erinacea*, *L. divaricata*, *P. caldenia* and *P. flexuosa* exposed to the HFF and LFF treatments were significantly lower ($P < 0.05$) than those exposed to the C treatment (Fig. 3); however, in general there were no significant differences ($P > 0.05$) between the HFF and LFF treatments. The strongest reduction in height and canopy area was observed immediately after the first controlled fire in both HFF and LFF treatments. Afterwards, all woody species tended to recover their height and canopy area until the next controlled burn (Fig. 3). A severe reduction in the canopy area of woody species was also observed in the C treatment at the March 1993 sampling date, the only exception being *C. erinacea*. At this point, some leaves had fallen off and others, still attached to the plants, were apparently dead.

Mortality rates of woody species, regardless of fire treatment and species, were low (Table 1). There were no significant differences ($P < 0.05$) between the fire treatments in *C. microphylla*, *P. caldenia* and *P. flexuosa*. In *C. erinacea*, significant differences in mortality rates ($P < 0.05$) were only found between the HFF and C treatments (Table 1). The highest mortality rate (LFF treatment: 7.95%; HFF treatment: 8.72%) was observed for *L. divaricata*. In this species, the mortality rates in the LFF and HFF treatments were higher ($P < 0.05$) than in the C treatment (Table 1).

Discussion

The shape of the time-temperature curves obtained during the controlled fires (Fig. 1) was similar to those reported by Wright *et al*. (1976) and Bóo *et al*. (1996). Regardless of fire frequency, maximum soil surface temperatures reached during the burns (~400°C) were slightly higher than those reported for other fires with similar fine fuel loads which, for grassland headfires with fine fuel loads between 1685 and 7865 kg ha^{-1}, normally range from 102 to 388°C (Wright and Bailey 1982). The higher soil surface temperatures recorded in this study are probably associated with local heavy fuel accumulation and/or intense winds created by the fire itself.

Overall, percentage cover of woody species was significantly reduced by controlled burns, irrespective of frequency. This reduction in cover became evident after the first controlled burn and persisted throughout the study period (Fig. 2*a*). There was no consistent difference between the HFF and LFF treatments except those attributable to plant recovery after each controlled burn. The only exception was *P. caldenia*, in which percentage cover was significantly reduced solely in the HFF treatment. These results reinforce those obtained by Bóo *et al*. (1997) who found a significant reduction in the cover of *C. microphylla*, *C. erinacea*, *P. caldenia*, *P. flexuosa* and *L. divaricata* after a wildfire, and two controlled fires of different intensities. On the other hand, after conducting a summer controlled fire, Peláez *et al*. (2010) observed that the cover of *C. erinacea* and *C. microphylla* had been significantly reduced by fire while the cover of *L. divaricata* remained unaffected.

The unusual cold weather in the study region in the first week of November 1992, with temperatures ranging from –8 to 0°C for 10-h periods (Bóo *et al*. 1997), might have been the cause of the severe reduction in the canopy area of woody species observed at the sampling in March 1993. However, only the new sprouts of the woody species were affected, there being no record of dead plants.

Density of the woody species was only slightly affected by the controlled burns. The increase in density of *C. microphylla* and *P. flexuosa* following fire might have been due to the decision to consider some clustered plants as one individual at the beginning of the study but as more than one after the controlled burns. Furthermore, the clustered nature of the woody species in the study site, with no occurrences in several sampling plots, produced a high experimental error. A more intensive sampling or a different sampling design might have produced more conclusive results. Nevertheless, the results are in partial agreement with those obtained by Bóo *et al*. (1997) who reported that the density of woody species, with the exception of *L. divaricata*, was not

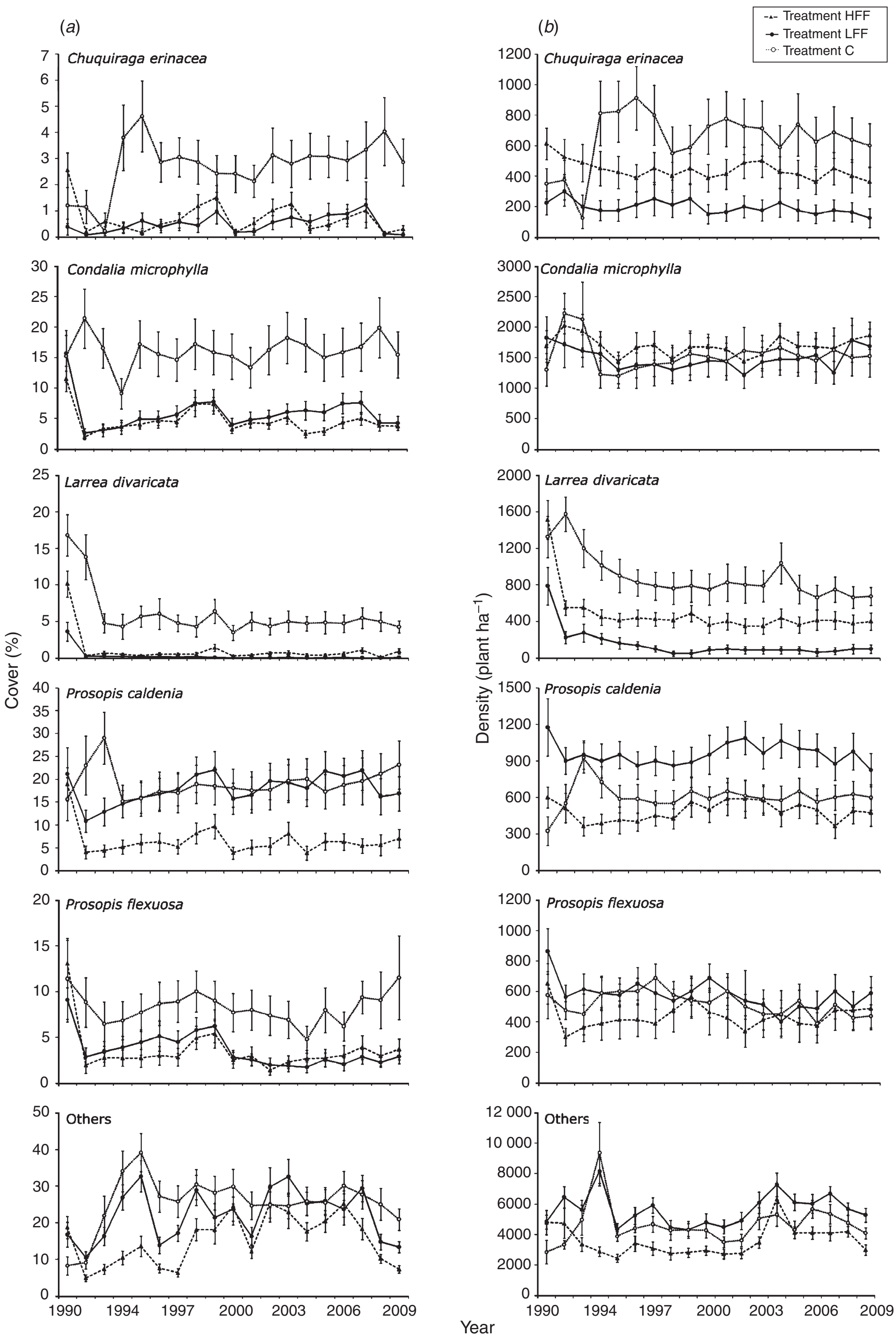

Fig. 2. Woody species percentage cover (*a*) and density (*b*) in the high fire frequency (HFF), low fire frequency (LFF), and unburned control (C) treatments at the beginning of the study (December 1990) and yearly at the end of the growing season (March 1992–March 2009). Values are means of 20 replicates. Bars represent the standard error of mean.

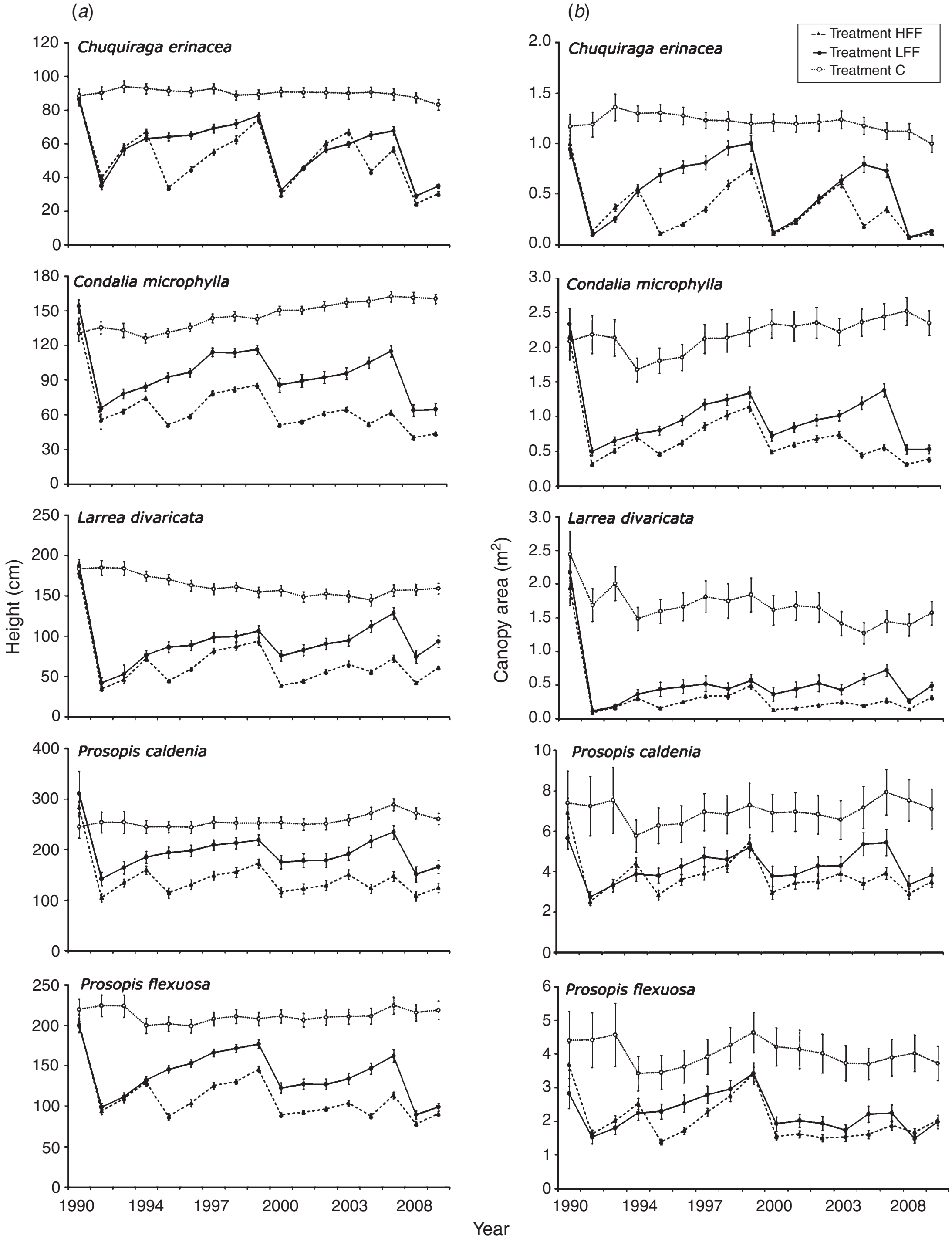

Fig. 3. Woody species height (*a*) and canopy area (*b*) in the high fire frequency (HFF), low fire frequency (LFF), and unburned control (C) treatments at the beginning of the study (December 1990) and yearly at the end of the growing season (March 1992–March 2009). Values are means of 80 replicates. Bars represent the standard error of mean.

significantly affected by controlled fires. Kröpfl *et al*. (2007) found a significant reduction in the density of *C. erinacea* but no significant changes in the density of *C. microphylla* after a summer wildfire. Besides, the density of *C. erinacea*, *C. microphylla* and *L. divaricata* did not show significant differences 4 years after a summer controlled fire (Peláez *et al*. 2010).

The height and canopy area of *C. erinacea*, *C. microphylla*, *L. divaricata*, *P. caldenia* and *P. flexuosa* (Fig. 3) exhibited similar responses to the fire treatments. As expected, a significant

Table 1. Woody species mortality in the high fire frequency (HFF), low fire frequency (LFF), and unburned control (C) treatments at the end of the study period (March 2009)

Within each column, values followed by the same letter are not significantly different ($P > 0.05$)

Treatment	Mortality of woody species (%)				
	Chuquiraga erinacea	*Condalia microphylla*	*Larrea divaricata*	*Prosopis caldenia*	*Prosopis flexuosa*
HFF	1.82a	0.71a	7.95a	0.15a	0.64a
LFF	1.45ab	0.24a	8.72a	0.24a	0.91a
C	0.69b	0.17a	1.39b	0.52a	0.44a

reduction was observed in the first sampling date after each controlled burn as the plants, especially the former three woody species, had been top-killed. The height and canopy area of all woody species tended to increase in the periods comprised between two consecutive burns but, nonetheless, remained lower than at the beginning of the study. The height (Fig. 3*a*) and canopy area (Fig. 3*b*) of *P. caldenia* and *P. flexuosa* were the least affected by fire. The trunks of several individuals of *P. caldenia* and *P. flexuosa*, in spite of some scorching, were little affected by fire and these plants were not top-killed by the controlled burns. The structure of woody plants affects the impact of fire (Whelan 1995; Miller 2000). The woody species under study differed in branch density, ratio of live to dead crown material, location of the base of the crown with respect to surface fuels, and total crown size and height. *Condalia microphylla*, *C. erinacea* and *L. divaricata* have a lower total crown height and a higher branch density closer to the ground than *P. caldenia* and *P. flexuosa*, which could explain their higher susceptibility to fire. On the other hand, according to Gill (1995), fire resistance of woody species stems is most closely related to bark thickness which varies with species, plant diameter and age, distance above the ground, site characteristics, and health and vigour of the plant. Thickness and chemical properties of *P. caldenia* and *P. flexuosa* might have contributed to their resistance to ignition (Bóo *et al*. 1997).

At the end of the study period, after five controlled burns in the HFF treatment and three controlled burns in the LFF treatment, mortality of all studied woody species was very low (Table 1). The highest mortality (~9%) was recorded in *L. divaricata*. The second most fire-susceptible species was *C. erinacea*, which had a mortality of ~2% (Table 1). A small number of plants (<1%) of the other three species were killed by the controlled burns (Table 1). Similar results were reported by Bóo *et al*. (1997) after a controlled fire conducted in autumn and after a summer wildfire. Nevertheless, these mortality percentages were much lower than those reported by Willard (1973) for *C. microphylla* (65%) and *P. caldenia* (50%) after a summer wildfire that occurred a few kilometres away from the study site. Even though temperatures during the wildfire were not recorded, it is likely that the maximum soil surface temperatures reached during the fire were higher than in this study (400°C), since the wildfire occurred on a hot dry windy summer day (January). In this study the fires were conducted under moderate weather conditions (Wright and Bailey 1982). Therefore, it can be assumed that the controlled burns were of moderate intensities. This could partially explain the low mortality, which is in agreement with previous work (Peláez *et al*. 2010).

Death of plant tissue following fire is usually attributed to heat which is a function of the temperature reached and the duration of exposure. The likelihood of death of a whole plant depends upon both the extent of injury to its component parts and the tissues affected by heat (Whelan 1995). Death may not occur for several years and is often associated with secondary agents of disease. A plant weakened by drought, either before a fire or after wounding, is also more likely to die (Miller 2000).

The response of plants to fire is the result of interactions between fire characteristics, post-fire processes and survival attributes of the plants involved (Peláez *et al.* 2003). In this study, repeated controlled burns of moderate intensities, regardless of frequency, reduced the percentage cover and the individual height and canopy area of the most conspicuous woody species in the region. However, plant density was barely affected and the mortality rates were negligible.

According to Bóo *et al*. (1997), a single fire in this region does not seem to signal the start of a plant replacement sequence. Seedlings do not follow a burn because the soil seed bank is poor and above-normal and well distributed rainfall is needed for successful establishment (Peláez *et al*. 1992, 1996). Rather, the high sprouting ability of these woody species may be the key for their persistence in the Caldenal region and in this regard, the community may be considered resilient to fire (Bóo *et al*. 1996). This, at least in part, is supported by the results obtained in this study.

From a range management perspective, a controlled burn every 3–4 years would permit the containment of woody species cover, height and canopy area, which in turn may favour the production of desirable perennial grasses. Research conducted at a representative site of the Phyto-geographical Province of the Monte (Cabrera 1976), Argentina, has shown that a fire-induced reduction in the cover of woody species favoured an increase in the canopy area of desirable perennial grasses (Peláez *et al*. 2010) and in average cow and calf weaning weights (Giorgetti *et al*. 2009).

Several parameters of the grasses mostly preferred by cattle, namely *P. ligularis*, *N. clarazii*, *N. tenuis* and *P. napostaense*, were evaluated at the same research site as that of the present study from 1989 until 2008. Basal diameter and canopy area of desirable perennial grasses increased in response to the combined effect of fire and rest from grazing (Bóo *et al*. 1996). Further, preliminary results show that controlled burns caused an increase in the canopy area and density of these species (Daniel V. Peláez, Universidad Nacional del Sur, Argentina, unpubl. data).

Possible additional benefits of fire include the release of plant nutrients to the soil, an increase in access and availability of forage to grazing livestock, easier management of cattle and a reduced risk of large catastrophic wildfires.

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