Changes in Woody Plant Structure in Fire-disturbed Caldén Forest of the Parque Luro Reserve, Argentina

José Hernán Sarasola[1]
Department of Applied Biology
Estación Biológica de Doñana
Avda. de María Luisa s/n
Pabellón del Perú
41013 Sevilla, España

Laura Araceli Bragagnolo
Ramón Alberto Sosa
Facultad de Ciencias Exactas y Naturales
Universidad Nacional de La Pampa
Avenida Uruguay 151
6300 Santa Rosa
La Pampa, Argentina

[1] Corresponding author:
sarasola@ebd.csic.es; +34 954 23 23 40

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ABSTRACT: We analyzed differences in vertical plant structure and species composition between three sites with different disturbance levels in caldén (*Prosopis caldenia*) forest in the Parque Luro Reserve, Argentina. One of the sites corresponded to a forest affected by a natural fire 15 years before the study. The remaining two sites, an open forest and a closed forest, were areas where wildfires have never been reported. Woody plant diversity, richness, and shrub density were significantly lower in the open forest than in the closed and burned forests, with the closed and burned forests having similar plant diversity and richness. The burned area also showed the highest percentage of foliage cover in the shrub strata (0.75-3 m height) even when the shrub/sapling density was similar to that of the closed forest. This suggests that fires in caldén forest play an important role in the physiognomy of shrub species. There was little evidence in our study for the establishment of new species as a consequence of wildfires and only one species occurred exclusively in the burned area of the Reserve.

Index terms: Argentina, Parque Luro Reserve, *Prosopis caldenia*, wildfires, woody plant structure and diversity

INTRODUCTION

Caldén (*Prosopis caldenia* [Burkart]) forests are characteristic of the landscape in the Espinal biome in the semi-arid pampas of central Argentina (Cabrera 1976; Figure 1). This 40,000-km^2 area of xerophitic vegetation, commonly called Caldenal, originally consisted of open forests dominated by caldén trees, concentrated mostly in valleys, and by grasslands on dunes and plateau (Cano et al. 1980). Since farming began in the early 20th century, caldén forests have changed in a number of ways. The most serious landscape modification has been the transition from open forest to shrubland or woodland with a high density of young caldén trees and brushes. The history of human use of caldén forests is related to wood extraction, extensive cattle raising, and non-irrigated agriculture after forest cutting. Although large-scale forest cutting has decreased during the last decades due to the high economic costs of such operations, cattle ranching and deforestation of small areas for firewood remain as important human activities.

Accidental wildfires are now the most important factor in the modification of caldén forests. An estimated 5.6 million ha of caldén forest were burned in La Pampa province between 1976 and 2002 (Sipowicz 1994, and unpubl. data from the government of La Pampa province). Recent dendrochronological studies in caldén forests (Medina et al. 2000) have shown that the fire regime in the area has changed over the last 200 years. The frequency of fire has increased from once every 14 years during the interval of Native American occupation (1787-1879) to once every 7.25 years during the European Colonization period (1911-1993). Medina et al. (2000) also found that the frequency and the extension of fires in the Caldenal have increased since 1910, which is supported by fire records on La Pampa province.

The effects of cattle grazing and natural and prescribed fires on caldén forests have been well documented. However, most studies have dealt with the effects of these disturbances on ecophysiology (Pisani et al. 1999), seed germination (De Villalobos et al. 2002), and seeds bank (Mayor et al. 1999, Mayor et al. 2003). There is also considerable information on the ecological implications of these disturbances on caldén forest related to effects on plant competition (Peláez et al. 1994) and herbivory (Bóo et al. 1993, Peinetti et al. 1993, Distel et al. 1996). Limited studies, however, have assessed the effects of wildfires on its plant composition and structure. Only Dussart et al. (1998) examined caldén densities in a comparative study of two areas where fires occurred 18 and 34 years prior to their study, and Willard (1973) and Bóo et al. (1997) evaluated plant survival and abundance in selected species after controlled and accidental fires in southern Caldenal.

In this study, we evaluated the effect of natural fires on the vertical structure and woody plant composition of caldén forests in the Parque Luro Reserve, central Argentina. We compared density, richness, and diversity of woody plant species and plant structure in three areas. Two of the areas corresponded to non-burned forests that

differed in plant structure and physiognomy as well as in their current use. The other area consisted of a caldén forest burned 15 years before the study.

MATERIAL AND METHODS

Study Site

The Parque Luro Reserve is located in eastern La Pampa province, central Argentina (Figure 1). The reserve (7604 ha.) consists mainly of xerophytic forests of *Prosopis caldenia*. Grasses such as *Stipa* spp. are the dominant herbaceous species of the lower stratum, and *Condalia microphylla* (Cav.), *Lycium chilense* (Miers), *L. gilliesianum* (Miers), and *Schinus fasciculatus* (Griseb.) are the common shrub species whenever a middle stratum is present. Areas surrounding the reserve consist of agricultural lands planted with crops and perennial and annual pastures. The climate is continental semi-arid with hot summers and cold winters with low humidity and low annual rainfall, typically concentrated in spring and summer. However, unusually high rainfalls have occurred during the last decade. The mean annual rainfall has increased from its historic value of 500-600 mm (Cano 1980) up to a mean of 791 mm for the last 11-year period.

The area was declared as a Natural Reserve for the government of La Pampa province in 1965. Prior uses of the area included introduction of exotic animal species in 1907 for game and hunting (Amieba 1992). Although many species did not proliferate, others, such as the red deer (*Cervus elaphus* L.) and the wild boar (*Sus scrofa* L.), adapted well to this habitat; and at the present, they are the only large herbivores on it. Wood extraction and cattle raising occurred in the area between 1920 and 1940 (Amieba 1992), but these practices have long since been excluded. The Parque Luro Reserve is the only protected area in the Caldenal.

Study design

Sampling was conducted in three selected areas of the Reserve: (1) The "open forest" was in the visitor use area of the reserve and consisted of an open forest of caldén with a grassland stratum and a reduced shrub layer, features that are in part conditioned by soil characteristics (sandy soils); (2) The "closed forest" area in the southern portion of the reserve has had no human or natural disturbances in the last 60 years; and (3) The "burned forest" area consisted of an area of approximately 2000 ha of natural forest that was burned by a wildfire in January 1987.

Only the visitor use area was open to the public. Sampling was conducted during March and April 2002 in 30 randomly located circular plots of 25 m radius (10 plots per area).

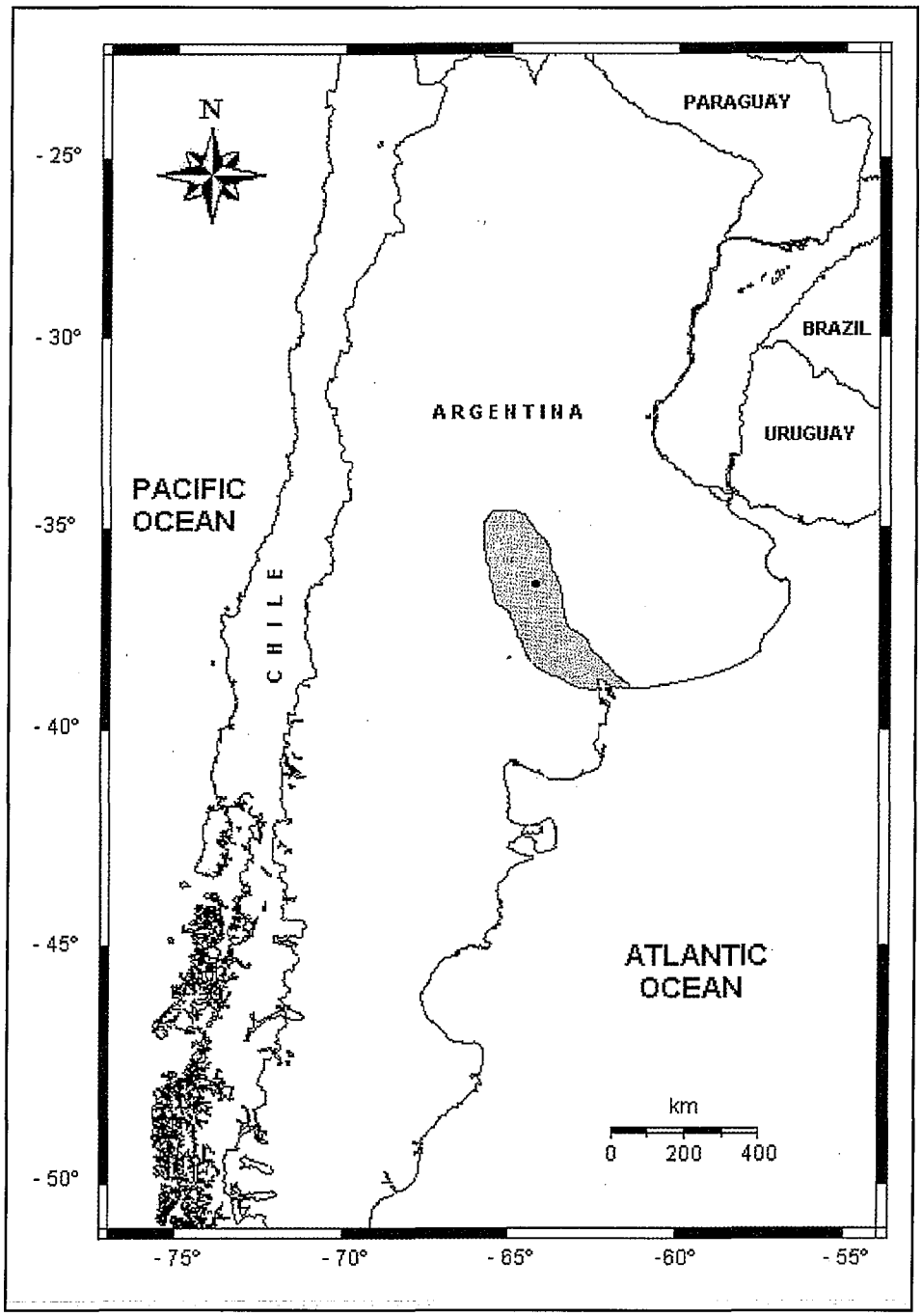

Figure 1. Distribution of caldén forests in central Argentina (shaded area) and approximate location of the Parque Luro Reserve (solid circle).

Plant structure and profile

We used a sampling method developed for Chaco forest by Lopez de Casenave et al. (1995). In the center of each randomly-located plot, we established a 25 m transect in each of the four cardinal directions. We sampled vegetation structure at 10 random points on each transect by erecting a rod marker and recording the height of each plant species that contacted the rod. For this procedure, we measured at 25 cm intervals in the first 4 m of the rod and at 1 m intervals from 4 to 8 m. We depicted profiles of foliage cover as the percentage of points with contacts at each interval and averaged values over the 10 plots in each area. We also included grasses and herbaceous plant species in our analysis by estimating plant cover at each of the four principal strata present in the forests: (1) ground, 0-0.5 m, (2) shrub, 0.75-3.00, (3) sub-canopy 3.25-6 m, and (4) canopy from 6 to >8 m.

Woody plant density and floristic composition

We counted every tree and shrub in each circular plot. When shrub density made access difficult, we only surveyed two randomly selected quadrants. Total density was calculated for each species as the rate between the number of individuals counted and the surface of the area of the circular plot effectively surveyed. We also measured species richness and diversity for each of the forests. Species richness was determined as the total number of woody species per sampled plot. Woody plant diversity was also calculated separately for each plot as:

$$D = 1/\Sigma p_i^2$$

where p_i is the proportion of each plant species in the sample (Magurran 1989). Mean values of richness and diversity for each area were obtained by averaging values for the 10 sample plots. Individuals of tree species with diameter at breast height (dbh) <10 cm were considered as saplings. Scorched caldén trees found in the burned area were also considered for density estimation, and the parameter calculated both with and without these specimens. Trees were considered dead when adult trees were scorched and there was no evidence of sprouting.

Statistical analysis

We evaluated differences in horizontal plant cover and vegetation profiles between the three areas by using one-way ANOVA with Tukey "a posteriori" test for paired comparison of means (Zar 1996). Logarithm transformation was used when assumption of normality was not achieved. When assumptions were not met even before logarithm transformation, data were analyzed using the non-parametric Kruskal-Wallis and Mann-Whitney U tests (Zar 1996).

RESULTS

Plant profile and horizontal cover

There was a distinct vertical stratification of vegetation in the three areas with high foliage cover in the ground layer (i.e., grasses), decreasing in the shrub and sub-canopy strata (Figure 2). In open and closed forests, there was also a peak in sub-canopy cover at 4 m and a subsequent decrease in cover in the canopy layer. Ground layer in open and closed forests consisted mainly of grasses (*Stipa* spp.) and herbaceous plants. In the burned forest, there was a high percentage of shrub species in the ground layer that caused highest ground cover to occur at 0.5 m instead of the first 0.25 m height as in the other two areas. The major difference in foliage cover among forests was observed in the shrub stratum (Table 1, Figure 3). The percentages of foliage cover decreased as stratum height increased for the burned and the natural forests while, in the open forest, this trend was not seen due to low coverage values in the shrub layer and high coverage values in the sub-canopy stratum. Mean coverage for the canopy layer did not vary among forests, even when this stratum was almost absent in the burned area. Lack of statistical significance at this stratum could be related to physiognomic features of the dominant tree species (only few and very old specimens of caldén tree concentrate foliage at such heights) rather than to disturbance effects. In terms of relative foliage cover, *P. caldenia*, *Schinus fasciculatus*, *Condalia microphylla,* and *Lycium gilliesianum* dominated the ground and shrub strata. Only in the burned forest did *S. fasciculatus* show lower relative values than *P. caldenia,* the dominant species in the other two areas for the ground-shrub strata. The caldén also showed the largest values of foliage coverage for the sub-canopy and canopy strata.

Plant density, species richness, and diversity

Density of woody plant, differed among sites (ANOVA: $F_{2,27} = 22.32$, $P < 0.01$), with the burned forest showing the highest density followed by the natural forest and the open forest, respectively (Tukey test: $P < 0.05$). Tree density was the same for all areas (Kruskal-Wallis test: $H = 1.11$, $n = 30$, $P = 0.57$), with significant differences only in the shrubs/sapling densities among the three forest types (ANOVA: $F_{2,27} = 16.22$, $P < 0.01$) (Figure 4). However, tree density varied significantly among forests when only live trees were considered (Kruskal-Wallis test: $H = 6.54$, $n = 30$, $P < 0.05$), mainly due to the low values of live tree density that we obtained for the burned forest sample (Mann-Whitney U test: $P < 0.05$). Burned and closed forests did not differ in terms of shrub/sapling densities; however, the open forest had values of shrub/sapling density four and two times lower than the burned and closed forest, respectively (Tukey test: $P < 0.05$).

We found significant differences in plant diversity among forests (Kruskal-Wallis test: $H = 9.45$, $n = 30$, $P < 0.01$). Burned and natural forests had similar diversity indexes (Mann-Whitney test: $U = 42$, $P = 0.54$), but these areas had greater plant diversity than open forest (Mann-Whitney test: $U = 14$, $P < 0.01$, and $U = 17$, $P < 0.05$, respectively). Species richness also differed significantly among sites (ANOVA: $F_{2,27} = 11.21$, $P < 0.01$), with both burned and natural forests having greater numbers of species than open forest (Tukey test: $P < 0.05$).

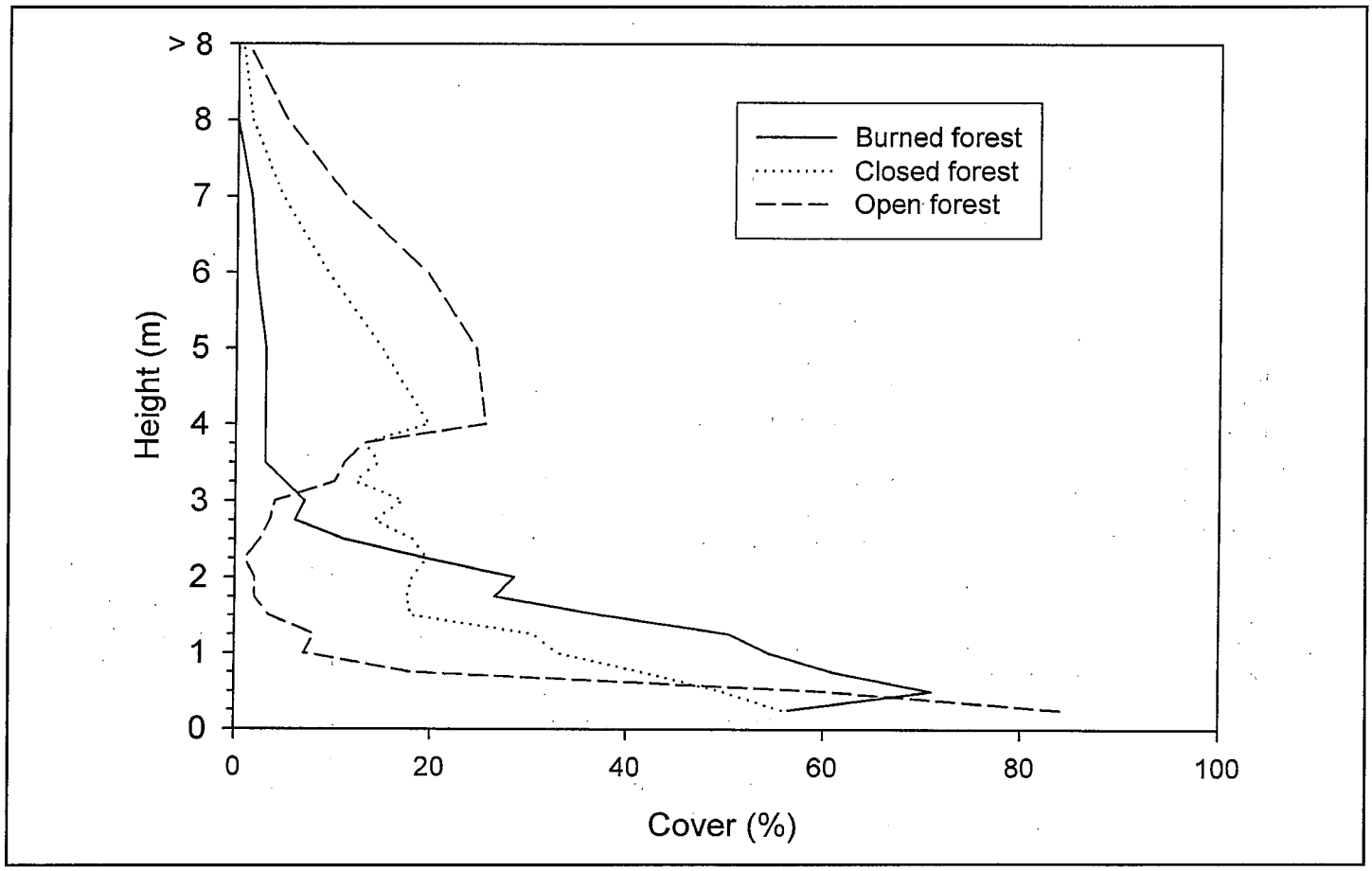

Figure 2. Vertical structure expressed as average profile of foliage cover at different heights in the burned, closed, and open caldén forests of the Parque Luro Reserve, La Pampa, Argentina.

DISCUSSION

This study provides an initial assessment of the changes in vegetal structure and composition in a burned caldén forest. Our results should be considered as preliminary since only an adequate replication of burned and unburned sites would allow a broad generalization of the effects of wildfires in the Caldenal.

Prior to the fire, the burned area of the reserve was similar in appearance to the closed forest area we analyzed in our study in that it had well-developed sub-canopy and canopy strata with a conspicuous but not extremely dense shrub layer (Amieba 1992). For example, the density of caldén trees in burned and closed areas is almost the same when considering the scorched specimens. Now, however, the plant structure and physiognomy of the burned forest is characterized by a dense cover of shrubs up to 3 m followed by a decrease in cover in the sub-canopy and canopy layers. Despite this difference, the burned and closed forests still share some floristic features. The two areas have similar plant diversity and richness and some of the shrub and trees species not observed in the open forest, such as *Chuquiraga erinacea* (D. Don), *Prosopis alpataco* (Phil.), and *Geoffroea decorticans* (Gillies ex Hook. et Arn.) were recorded in the burned and closed forests. Our results agree with those of Tálamo and Caziani (2003) that also found similar values of plant species richness among primary and burned areas of Chaco forest.

Table 1. Mean horizontal coverage (%) ± S.D. for shrub species and tree saplings in ground-shrub strata and for caldén tree in the sub-canopy and canopy strata in Parque Luro Reserve, La Pampa, Argentina.

Strata	Burned forest	Closed forest	Open forest
Ground-shrub[a]	73.60 ± 22.4	64.99 ± 27.50	76.28 ± 38.53
Sub-canopy and canopy	60.37 ± 38.13	88.62 ± 11.33	98.48 ± 2.69

[a] Include *Condalia microphylla*, *Lycium chilense*, *L. gillesianum*, *Prosopis caldenia*, *Schinus fasciculatus* and *Geoffroea decorticans*.

The plant structure and physiognomy of the open forest reassembles the typical physiognomy of caldén forest in deep valleys and plateaus, which are considered

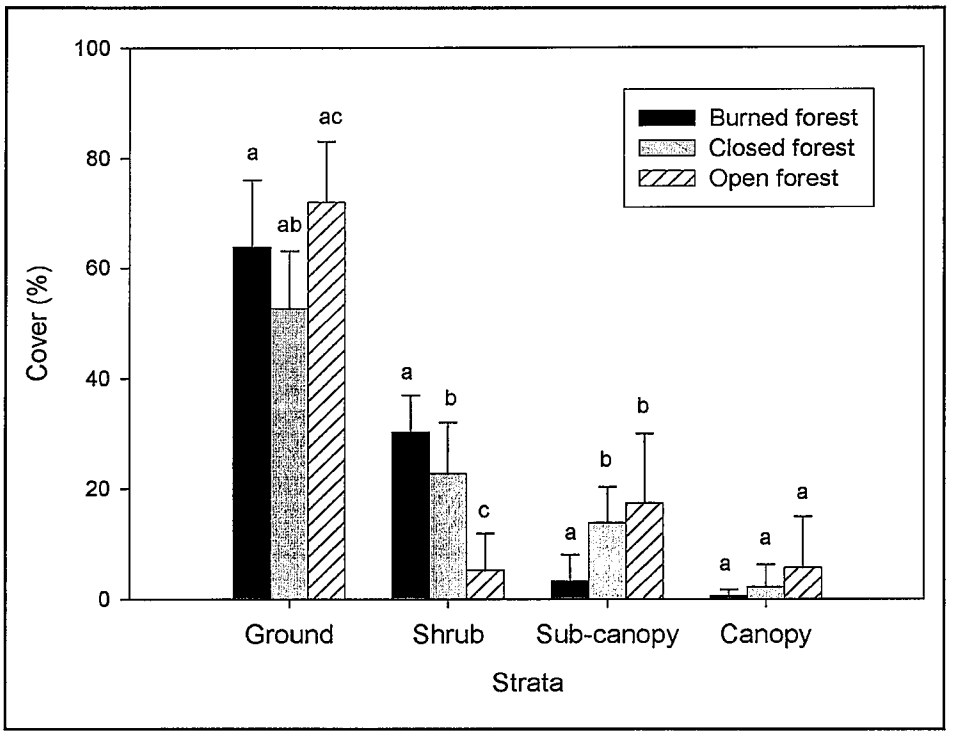

Figure 3. Mean horizontal coverage (and 1 S.D. indicated by vertical line) of the four strata in the burned, closed, and open caldén forests in Parque Luro Reserve, La Pampa, Argentina. Means with the same letter indicate non-significant differences at P = 0.05 (Mann-Whitney U tests).

climax plant communities (Llorens 1995). The open forest had the lowest values for species richness and diversity. Species diversity is often greatest at intermediate levels of disturbance (Petraitis et al. 1989) indicating that the low values we recorded in the open forest could be related to the limited amount of disturbance that has occurred in this habitat. Modification of this area has been related to the alteration of small areas of native forest to facilitate tourist activities (i.e., the establishment of new roads and recreation areas). The effects of such practices on caldén forest could lead to some forest fragmentation and the subsequent increase of the edge area of patches, rather than to a general and broad extended modification of the plant structure. The sampling design used here was more suited to detect general spatially distributed changes on vegetal structure and composition than to record this edge effect on forest fragments (for which further and specific studies at a minor scale are needed; see, Lopez de Casenave et al. 1995).

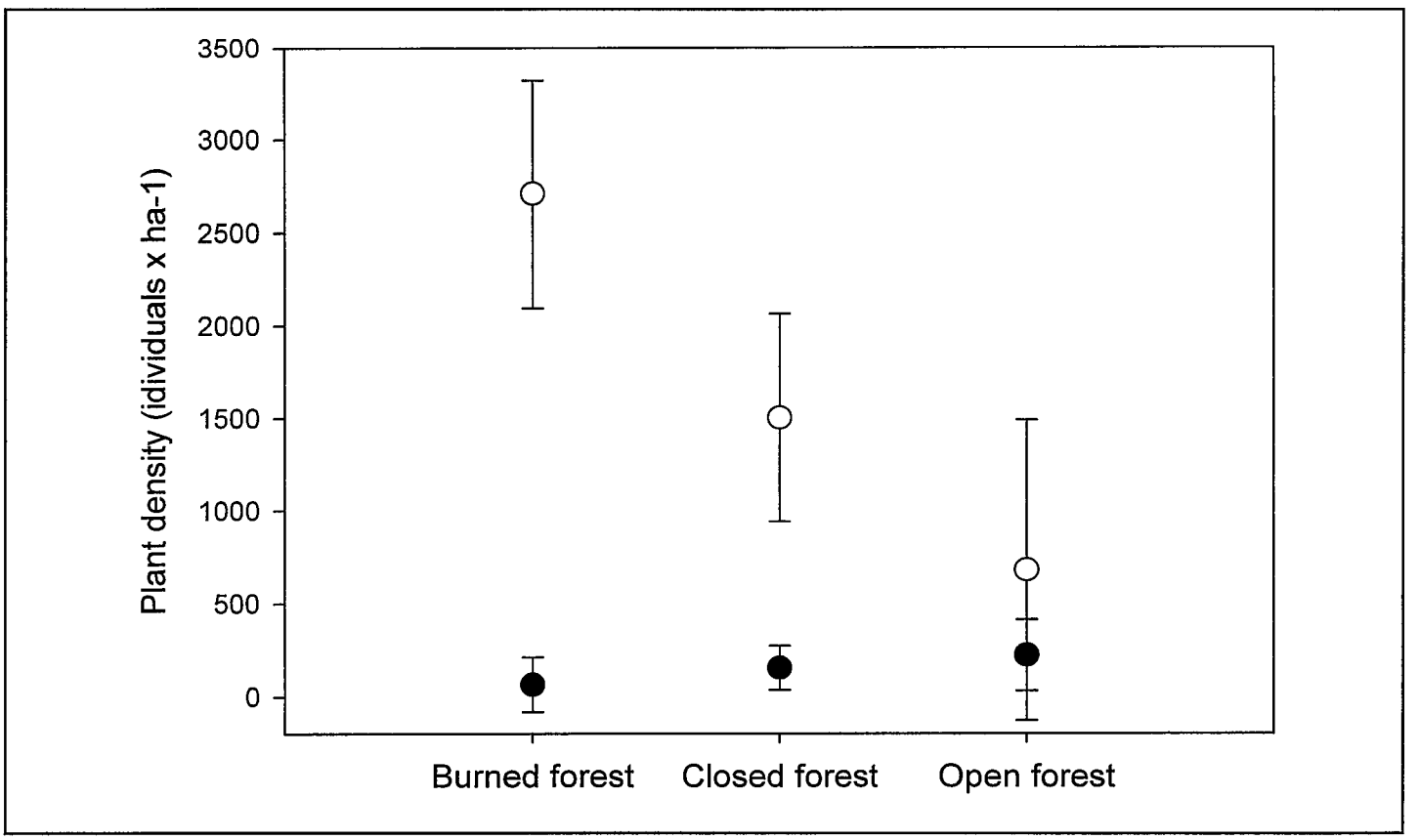

Figure 4. Mean tree and shrub densities (± S.D.) in the three areas of caldén forests in Parque Luro Reserve. Open circles are shrub/sapling densities and solid circles are tree densities.

Caldén trees dominated the forests we studied in both sub-canopy and canopy strata. The amount of foliage cover of caldén in these strata differed among areas, with highest foliage cover occurring in the open forest followed by closed and burned forests, respectively. In addition to caldén, foliage coverage also resulted from other tree species (e.g. *Geoffroea decorticans*) and shrub species (e.g. *S. fasciculatus*), which reach heights two times greater in burned and closed forests than in the open forest.

Increased light availability resulting from canopy removal and the reduction of competition within plant communities through the elimination of trees is known to stimulate germination and enhance growth of pioneer species (Keeley 1987). We found supporting evidence for this when we studied the burned vs. the closed forest. Although some particular shrub species showed densities two and three times greater in the burned area than the closed forest, the differences in the overall shrubs density between these two areas were not statistically significant. However, foliage cover for shrub strata differed between these two forests type. This suggests that the increase of foliage cover in the shrub strata in caldén forest after fire disturbance is linked to the dominance in plant community of species having a sprouting strategy in response to fire (sensu Whelan 1995) which may determine highest cover in the shrub stratum for the burned forest without an increase in the number of shrubs per area. Our results agree with those of Bóo et al. (1997) who, in their study area on southern Caldenal, observed little variation on shrub abundance of the principal woody species following fire events. There was little evidence for the establishment of new colonizing species after fire in our study and we only found one species, *Senna aphylla*, to occur exclusively in the burned area. Other species, when we compared their densities among burned and unburned areas, seem to have a pioneer-type behavior: *Jodina rhombifolia* (Hook et Arn; occurring as trees and saplings), *Geoffroea decorticans* and *Prosopis flexuosa* (DC.; saplings), and all the shrub species with the exemption of *Ephedra ochreata* (Miers) and *Prosopis alpataco* (Phil.).

The fire that burned our study area is suspected to have been very hot and, therefore, had a more destructive impact on the caldén forest. The high number of scorched caldén trees, 55%, evidences this even when they all sprouted. Dussart et al. (1998) found 5.2 % and 1.1% of dead individuals at two sites of burned caldén forest, and Bóo et al. (1997) recorded only 2.5% of dead caldén after an accidental fire. Willard (1973) reported a 50% mortality in caldén trees one year after a fire (but this estimate may not be an accurate representation of the final mortality attributed to the fire).

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José Hernán Sarasola graduated from the Universidad Nacional de La Pampa, Argentina, in Natural Resources and is currently a PhD student at the Doñana Biological Station, Spain. He has been conducting research works on Parque Luro Reserve since 1998, studying the breeding biology, foraging ecology, and habitat selection of birds of prey in this protected area.

Laura Araceli Bragagnolo also graduated from the Universidad Nacional de La Pampa, Argentina, in Natural Resources. She is currently involved in the Master Program on Conservation Biology of the Universidad Internacional de Andalucía (Spain). Her thesis project is focused in the effect of wildfires on bird species assemblages in caldén forest.

Ramón Alberto Sosa is a Professor of Biological Diversity at Universidad Nacional de La Pampa, Argentina. His research focuses on the effects of caldén forest fragmentation on bird species assemblages.

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