Fire recurrence effects on biodiversity and community structure in Sanabria Natural Park (Spain)

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Abstract: The aim of this study was to determine the effect of fire recurrence on the structural characteristics, in particular biodiversity, of different communities in Sanabria Natural Park (Castilla y León Region, Spain). Fourteen sites, ten *Erica australis* heathlands and four *Quercus pyrenaica* stands, two mature oak forests and two oak shrublands, were chosen. All of them had different levels of fire recurrence and different ages since the last fire. Data on fires occurring in the study area since 1990 are available. Sampling was carried out in July 2005. A 10 x 10 m plot was located in the centre of each site; in each plot, ten $1m^2$ quadrats were studied and all the species present were quantified as visual cover percentage. A sampling by layers was also carried out in the same quadrats, estimating total plant cover in each layer. Plant species diversity was measured as richness (number of species). Alpha diversity (diversity/m^2), gamma diversity (diversity/plot), and beta or pattern diversity (S beta = S gamma / mean S alpha) were analysed. Structural diversity was calculated by the Shannon index, using plant cover data in the different layers. An affinity analysis was carried out considering all the species present. The dendrogram showed two groups: *Erica australis* heathlands and *Quercus pyrenaica* oak stands. The effect of fire recurrence on species composition was not observed in either case. A PCA was carried out in order to determine whether recurrence or the time elapsed since the last fire had any effect on species diversity or community structural diversity. Differentiation between the oak stands and the heathlands was also observed in this case. There was higher herbaceous species richness and more structural diversity in the oak stands. Stratification was noticeably lower in the heathlands, although they usually had higher woody species richness. No ordination depending on the time elapsed since the previous fire or recurrence was observed. Therefore, changes in community structure caused by fire recurrence in a relatively short period, such as that considered (15 years), are not noticeable in areas adapted to frequent fires. Nevertheless, repeated fire impedes the progress of succession and slows down its initial immature stages. These recover by autosuccession following repeated fire and persist as heathlands or oak shrublands. Although fires occur in mature oak forests, only the understory is affected, thus maintaining greater diversity and structural complexity.

Keywords: *Autosuccession. Diversity. Fire. Heathlands.* Quercus pyrenaica

1. Introduction

Fire with natural or anthropogenic origin has been an important ecological factor in the formation of Mediterranean plant communities and landscapes (Naveh, 1974; Le Houerou, 1981; Moreno *et al.,* 1998; Luis-Calabuig *et al.,* 2000; Baeza *et al.,* 2005). Several authors have studied fire effects on landscape and community diversity (Chuvieco, 1999; Arianoutsou *et al.,* 2002; Alvarez, 2005) and in particular, fire frequency (Trabaud and Galtié, 1996; Schwilk *et al.,* 1997; Davis, 1998; Delitti *et al.,* 2005), but results were not always concordant and they were highly scale-dependent.

Land use change has modified fire frequency and intensity in the last decades in the Iberian Peninsula. As a consequence of the decrease in livestock, many pasture zones have been abandoned and the corresponding secondary succession allowed to develop. Periodical burning was a traditional method of management by shepherds and, despite being banned, is still carried out to maintain pastures, even in areas no longer used by cattle (Luis-Calabuig *et al.,* 2000). In Sanabria Natural Park (Castilla y León Region, Spain) most of this area was previously used for pasture and at present is occupied by shrublands in different stages of secondary succession as a result of livestock decrease. Fires are a frequent occurrence mostly caused by humans, both prescribed fires lit by shepherds and accidental fires caused by the large number of tourists visiting the Natural Park.

The aim of this study was to determine the effect of fire recurrence on the structural characteristics, in particular biodiversity, of different communities in this area. It is part of a wider study on the effects of fire recurrence at landscape level. In this case, the study was carried out at the smallest spatial scale (at 100 m^2 plot or 1 m^2 sampling unit level). The aim was to establish whether fire recurrence over a relatively short period (15 years) conditioned changes in species richness and horizontal heterogeneity (estimated as beta diversity on a plot scale), as well as in vertical stratification or structural diversity. However, it must be considered that time passed since the last fire, which is not the same at all the study sites, is superimposed on the effect of recurrence.

2. Materials and Methods

The study was carried out in Sanabria Natural Park (Castilla y León Region, Spain). Fourteen sites, ten heathlands dominated by *Erica australis* and four *Quercus pyrenaica* stands, two mature oak forests and two oak shrublands, were chosen in a total surface area of 30 km^2. There were located at 42º 10' N, 6º 45' W, between 1400 and 1700 m a. s. l., in the transition between Atlantic and Mediterranean climate. All of them had different levels of fire occurrence and different ages since the last fire. Data on fires occurring in the whole study area since 1990 are available. Sampling was carried out in July 2005. A 10 x 10 m plot was located in the centre of each site so that the surface was equivalent in all the sites, as diversity is a parameter which is very dependent on the sampled surface (Magurran, 1989, 2004). In each plot, ten 1m^2 quadrats, systematically situated at an equal distance from each other, were

studied and all the species present were quantified as cover percentage. A sampling by layers was also carried out in the same quadrats, estimating total plant cover in each layer (0-0.5m, 0.5-1m, 1-2m, 2-4m, 4-8m and >8m).

Plant species diversity was measured as richness (number of species), as both herbaceous and woody species were considered, and this could alter the results if quantitative indices of diversity are used. Alpha diversity, or small scale diversity (diversity/m^2, mean of the number of species found in the 10 quadrats of each site), gamma diversity (total number of species found in all 10 quadrats of each site), and beta, spatial heterogeneity or pattern diversity (using the Whittaker formula (Whittaker, 1960, in Magurran, 1989, 2004), S beta = S gamma / mean S alpha) were analysed. Besides total S gamma, annual species number, perennial herb species number and woody species number were also considered. As well as species diversity, structural diversity was calculated by the Shannon index (Shannon and Weaver, 1949, in Magurran, 1989) using plant cover data in the different layers. H'alpha (per quadrat or m^2), H'gamma (per site, total for each community) and H'beta (H'beta = H'gamma - mean H'alpha, according to the Margalef formula, Margalef, 1972) were calculated. In the case of heathlands, there was enough available data to estimate regression curve fitting between the studied variables and time since the last fire.

An affinity analysis was carried out considering all the species present as variables and all the study sites as cases. Euclidean distance was used as similarity index and U.P.G.M.A. as cluster method (Krebs, 1989). A principal component analysis was also carried out in order to determine whether recurrence or the time elapsed since the last fire had any effect on species diversity or community structural diversity, considering in this case S alpha, S beta, woody, perennial herb and annual species number, bare soil, and H' alpha, H' beta and H' gamma as variables.

3. Results

When species composition in the studied sites was compared by the affinity analysis, the dendrogram showed two groups: one formed by the *Erica australis* heathlands, with higher cover of this species but also with other shrub species such as *Chamaespartium tridentatum* and *Halimium alyssoides,* and the other group formed by the *Quercus pyrenaica* oak stands, with great cover values of oak saplings, and species like *Cytisus multiflorus* and *Stellaria holostea*, which did not appear in the heathlands (Table 1, Figure 1). However, most of the perennial herbs were common in both community types, like *Agrostis capillaris, Avenula marginata* subsp. *sulcata, Festuca paniculata, Festuca rubra* and *Luzula lactea*. The effect of fire recurrence on species composition was not observed in either case. Neither did the time since the last fire had an obvious effect, except on the joining of the two recently burnt heathlands.

Table 1. More abundance of frequent species in the study sites ((H = Heathland, OS = Oak Shrubland, OF = Oak Forest. Numbers indicate years after fire. Example: H(13/5) = Heathland burned twice, 13 and 5 years ago).

	OF(7)	**OF(4)**	**OS(>15)**	**OS(0.3)**	**H(10)**	**H(9)**	**H(7)**	**H(5)**	**H(13/5)**	**H(10/5)**	**H(7/5)**	**H(3)**	**H(3/0.3)**	**H(0.3)**
Agrostis capillaris	18,5	14,5	1,3	1,0			5,8	0,8	0,8	4,6	6,5	15,0		
Asphodelus albus	0,5	5,5							8,0				1,6	
Avenula marginata ssp. *sulcata*	3,5	7,5	6,0	5,1			0,5	1,0	11,0	9,0	7,8	10,8	1,7	0,3
Chamaespartium tridentatum				6,0	52,0	33,5	57,5	41,0	36,5	56,0	57,0	28,0	43,5	41,5
Cytisus multiflorus	16,0		12,4											
Deschampsia flexuosa		3,6		4,8			3,5		2,5	0,2	2,3			
Erica australis					51,5	53,5	31,0	45,0	53,5	54,5	33,0	29,5	26,5	24,5
Festuca paniculata		1,0	34,0	13,0			2,9	1,7	2,0		1,7		0,7	
Festuca rubra		1,3	8,0	0,6			1,5		1,5	1,0	3,8	5,8		0,7
Halimium alyssoides				1,2	18,0		14,5	36,5	43,0		38,5	44,1	22,0	8,0
Luzula lactea			14,0	29,5	2,7	1,0	13,3	6,1	13,3	19,0	4,9	11,1	1,3	1,9
Quercus pyrenaica (sapling)	92,0	23,0	37,0	61,0										
Stellaria holostea	6,5	3,6												
Total plant cover	**195**	**110**	**121**	**125**	**124**	**128**	**141**	**134**	**176**	**147**	**157**	**157**	**97**	**77**
Total species Nº (S gamma)	**19**	**16**	**11**	**12**	**4**	**6**	**15**	**10**	**14**	**11**	**12**	**14**	**7**	**7**

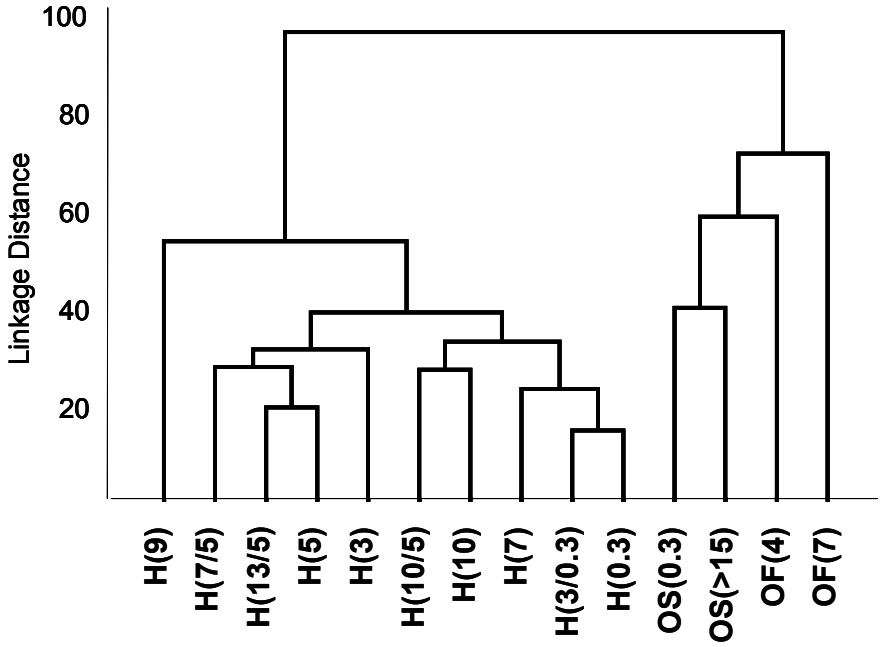

Figure 1. Affinity analysis dendrogram (H = Heathland, OS = Oak Shrubland, OF = Oak Forest. Numbers indicate years after fire. Example: H(7/5) = Heathland burned twice, 7 and 5 years ago)

Differentiation between the oak stands and the heathlands was also observed in the principal component analysis (Fig. 2). There was higher herbaceous species richness and more structural diversity in the oak stands. Obviously, stratification was noticeably lower in the heathlands, although they usually had higher woody species richness. No ordination depending on the time elapsed since the previous fire or recurrence was observed, except for a higher percentage of bare soil in the most recently burnt areas. Structural complexity was maintained in the mature oak forests as most of the trees had survived the fire. Stratification was intermediate in oak shrublands, and higher in the not recently burned one (>15 years since the last fire), but there was not a clear difference with the recently burned one, as some oak saplings measuring over 2 m were found in the former and in the latter the canopy did not exceed 3 m.

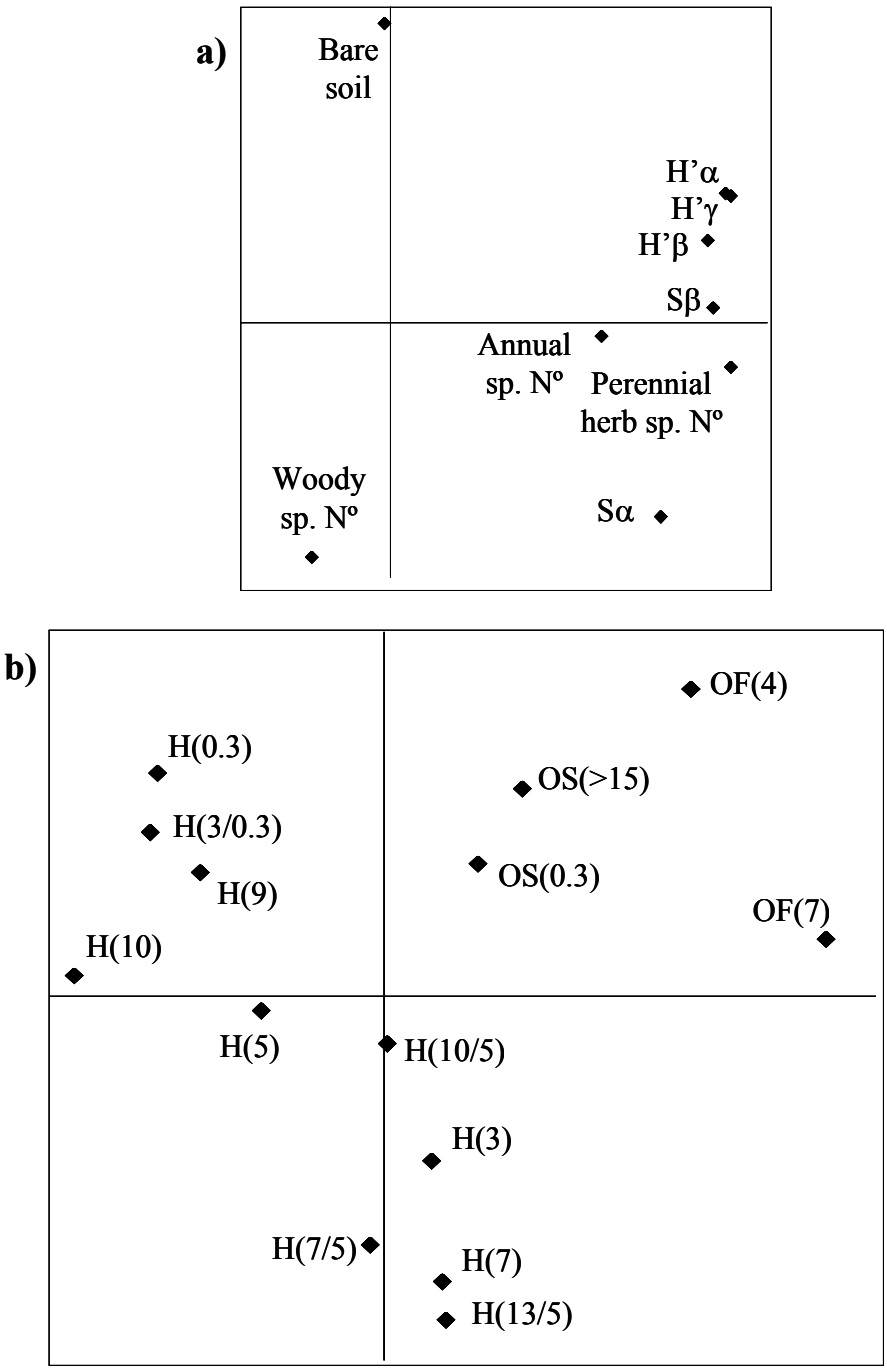

Figure 2. Location of variables (a) and samples (b) in the plane defined by the first two axes of the PCA (Explained variance axis I = 50%, axis II = 20%). (H = Heathland, OS = Oak Shrubland, OF = Oak Forest. Numbers indicate years after fire)

There were enough data on the heathlands to analyse the trend of the studied variables in terms of time since the last fire (without considering fire recurrence), therefore polynomial regression curve fitting were estimated. Only significant fitting was observed for alpha, gamma and beta species richness, plant cover and bare soil (Fig. 3). Except for the last case (bare soil), where the trend was the opposite, the highest values in all the others were observed in the intermediate period 3-7 years after fire.

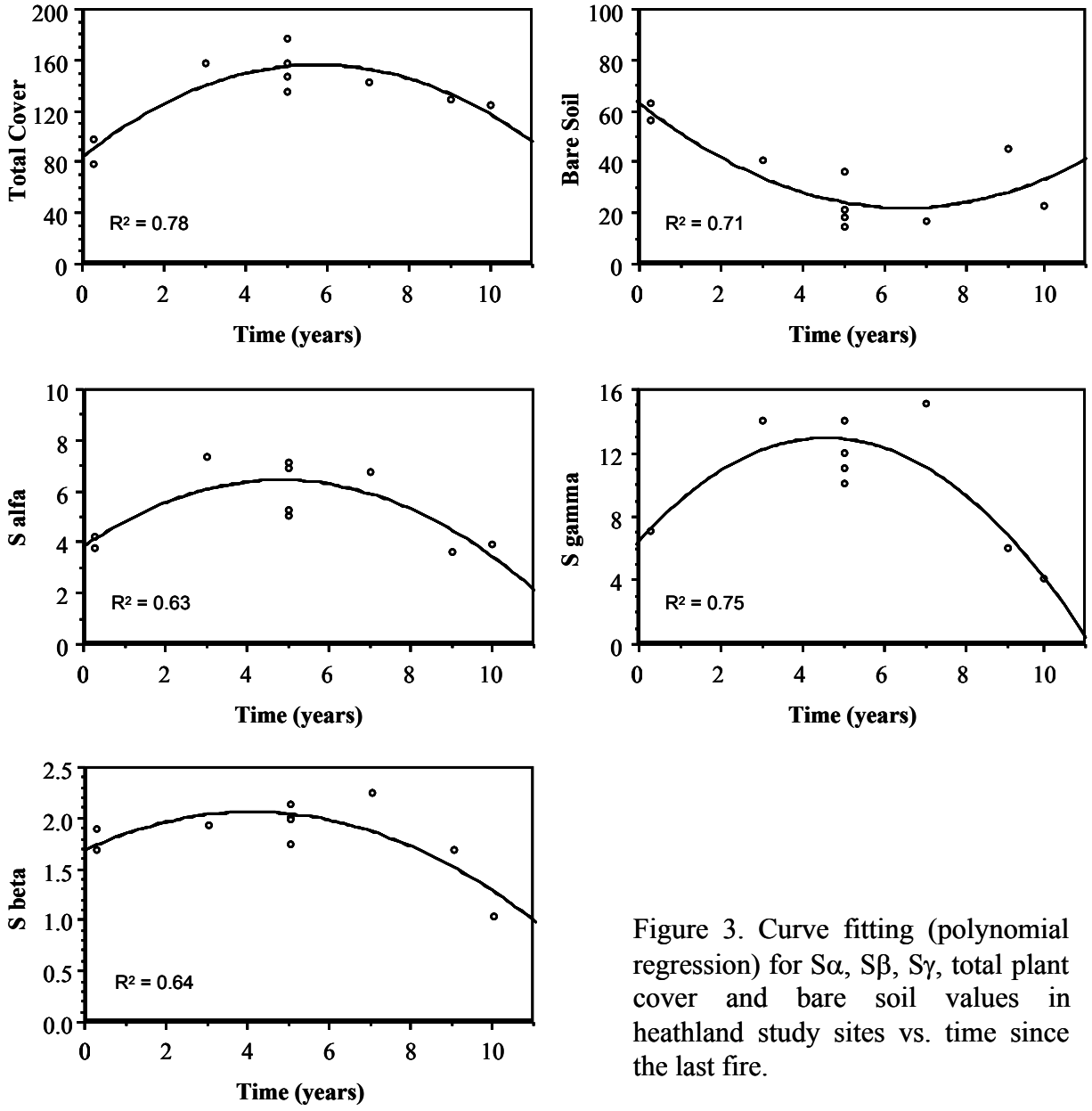

Figure 3. Curve fitting (polynomial regression) for Sα, Sβ, Sγ, total plant cover and bare soil values in heathland study sites vs. time since the last fire.

A Pearson correlation analysis was carried out with all the study sites (Table 2), after checking data normality by Kolmogorov-Smirnov test. Perennial herb species were the most correlated with biodiversity, both with species richness values and structural diversity values. Woody species richness had no significant correlation with any of the studied variables. Species diversity values were positively correlated with structural diversity values.

Table 2. Pearson correlation analysis between some of the studied variables (N = 14. Marked in red colour correlation values are significant at $p < 0.05$).

	BS	**A**	**P**	**W**	**Sγ**	**Sα**	**Sβ**	**H'γ**	**H'α**
Bare Soil (BS)	1.00								
Annual sp. Nº (A)	0.02	1.00							
Perennial herb sp. Nº (P)	-0.11	0.24	1.00						
Woody sp. Nº (W)	-0.31	0.05	-0.31	1.00					
S gamma (Sγ)	-0.17	**0.55**	**0.91**	-0.01	1.00				
S alpha (Sα)	-0.38	0.22	**0.79**	0.10	**0.81**	1.00			
S beta (Sβ)	0.12	**0.65**	**0.72**	-0.07	**0.85**	0.40	1.00		
H' gamma (H'γ)	0.24	0.38	**0.70**	-0.40	**0.66**	0.44	**0.63**	1.00	
H' alpha (H'α)	0.23	0.36	**0.70**	-0.43	**0.64**	0.44	**0.60**	**1.00**	1.00
H' beta (H'β)	0.27	0.47	**0.57**	-0.03	**0.66**	0.36	**0.72**	**0.82**	**0.78**

4. Discussion

Time since the last fire, except in the case of the most recently burned sites, did not appear to have any clear effect on plant species composition. This could be because the studied communities have adapted to frequent fires and the species present were mostly resprouters, as the dominant species in the two types of community considered, *Quercus pyrenaica* and *Erica australis*, that appeared immediately after fire, determining quick recovery by autosuccession (Luis-Calabuig and Tárrega, 1993; Calvo *et al.*, 1991, 2002; Vega *et al.*, 2005). Nor was the influence of fire recurrence shown, although other authors have pointed out that fire frequencies could affect the post-fire response of species in a different way depending on their life history traits (Lloret *et al.*, 2003; Alvarez, 2005), and higher fire recurrence could determine an impoverishment of soil seed bank (Trabaud, 2000). However, it must be pointed out that our study only considered recurrence over the last 15 years. It is likely that historic fire recurrence in this area had already determined the elimination of the most sensitive species.

In the case of structural diversity or stratification, the differences were associated to the type of community existing prior to the fire, as many high trees in oak forests were able to survive, maintaining a pluristratified community, regardless of time since the last fire. Stratification was intermediate in the unburned oak shrubland, although the rapid growth of *Quercus pyrenaica* resprouts (Luis-Calabuig and Tárrega, 1993; Marcos *et al.*, 1993; Vega

et al., 2005) determined that the differences with the recently burned oak shrubland were not so clear.

The dynamic of the studied heathlands, with the greatest species richness in the intermediate period, coincided with the results of most authors, who have recorded an initial increase of diversity in arbustive communities followed by a later decrease as the dominant woody species recover their initial pre-fire cover (Trabaud and Lepart, 1990; Casal *et al.,* 1984, 1990; Bond and van Wilgen, 1996; Calvo *et al.,* 2005). The increase in woody cover displaced the herbs and determined the decreased total cover and increased bare soil in the final years (from the 6th year).

According to correlation analysis, perennial herb species were those that mainly affected total richness, both on a sampling unit (per m^2 or alpha diversity) and a plot (gamma diversity) scale, their presence being also associated with greater horizontal space heterogeneity (S beta). The higher structural diversity, determined by the greater stratification of the mature oak forests, was also correlated to the greater richness of perennial herbs and total species richness found in these communities.

It can be concluded that changes in community structure caused by fire recurrence in a relatively short period, such as that considered (15 years), are not noticeable in zones adapted to frequent fires. Only the effect of the last fire can be observed in the case of the most recently-burnt areas. Nevertheless, considering the process over a long-term period, repeated fire impedes the progress of succession and slows down its initial immature stages. These recover by autosuccession following repeated fire and persist as heathlands or oak shrublands. On the other hand, although fires occur in mature oak forests, only the understory is affected (Luis-Calabuig *et al.,* 2000), thus maintaining greater diversity and structural complexity.

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