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Floristic changes induced by fire on *Pinus sylvestris* plantations in northwest of Spain

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Abstract

The effects of wildfire on vegetation regeneration in the understory of stands dominated by *Pinus sylvestris* L. in north-west Spain were analysed. In order to study changes in the composition of this community, three study areas dominated by *Pinus sylvestris* L. and burned by a summer wildfire were selected. In each area three permanent plots of 25 × 1 m^2 was established. The cover percentage of plant species present, and the cover of life forms and richness were analysed yearly from the first to the fourth year after fire. Total cover values generally increased throughout the study period. The species that appeared during the first years were those that would dominate in the mature stage, such as *Erica australis* L. and *Pterospartum tridentatum* (L.) Willk, both species being typical resprouters. Other species that appeared from the first year are typical seeders like *Pinus sylvestris* L. and *Halimium alyssoides* (Lam.) K. Koch. Floristic richness values showed higher values during the first year after fire than in the original situation, due to the fast recovery of the herbaceous species in the open spaces created by fire. After the first year changes in richness values were not significant
Key words: germination, floristic richness, resprouting, wildfire.

Resumen

Cambios florísticos inducidos por los incendios en repoblaciones de *Pinus sylvestris* en el noroeste de España

Los efectos del fuego sobre la regeneración de las comunidades vegetales en plantaciones de *Pinus sylvestris* L. en el noroeste de España han sido analizados. Para analizar los cambios en la composición y estructura de este tipo de comunidades, se seleccionaron tres zonas de estudio en plantaciones de *Pinus sylvestris* L. y en ellas se seleccionaron áreas quemadas por un incendio de verano. En cada una de estas áreas se instalaron tres parcelas permanentes de 25 × 1 m^2 donde se midió el porcentaje de cobertura por especies cada año desde un año hasta cuatro después del incendio. Los valores de cobertura total se incrementaron de forma gradual durante el periodo estudiado. Las especies que aparecen durante los primeros años son las que dominan en las etapas maduras, como *Erica australis* L. *Pterospartum tridentatum* (L.) Wilk. Otras especies que aparecen desde el primer año se regeneran obligatoriamente de semillas como *Pinus sylvestris* L. y *Halimium alyssoides* (Lam.) K. Koch. Los valores de riqueza florística encontrados en el primer año tras el incendio son mayores que los de la situación original debido a la rápida recuperación de las herbáceas en los espacios abiertos creados por el fuego. A partir del primer año los cambios en riqueza no fueron significativo
Palabras clave: germinación, riqueza florística, rebote, incendio.

Introduction

Fire plays a decisive role in the structure and dynamics of Mediterranean ecosystems (Gill *et al.*, 1981; Trabaud, 1987). It is one of the main ecological factors that originated the current mosaic characterizing the Mediterranean landscape, and in recent years there has been an increase in the importance of forest fires, with a spectacular rise in the frequency and intensity of these episodes (Moreno *et al.*, 1998; Pausas and Vallejo, 1999). The effects of fires, whether destructive or regenerative, depend on both the characteristics of the fire itself —frequency, intensity or size— and on the

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characteristics of the community (Vélez, 2000). In the Mediterranean region, the conifer forests and especially pine communities display a high vulnerability to forest fires (Quezel, 1980). Some of these species, such as *Pinus halepensis* P. Mill and *Pinus brutia* Henry (Thanos and Marcou, 1991), are favored by fire, increasing the surface area they occupy due to dissemination of seeds in the areas surrounding the original pine communities; whereas *Pinus sylvestris* L.is not quite as favored by fires in the Mediterranean environment as it is in other regions throughout its widespread distribution. Agee (1998) indicates that communities of *Pinus sylvestris* are associated with moderate fire regimes. This asserts is true in the boreal regions but not in the Mediterranean, because in the latter there are other species which are better adapted to fires.

Pinus sylvestris is an obligated seeder that in Mediterranean region has significant difficulty regenerating after a fire (Ibáñez and Retana, 1997), because it does not have serotine pine cones (Lanner, 1998) and they display a seed phenology in which dispersion occurs between the end of winter and the beginning of spring (Skordilis and Thanos, 1997). So, in summer, period with the highest frequency of forest fires the aerial seed bank is practically empty. *Pinus* aerial seed bank are maintained for a few months (Trabaud *et al*., 1997; Izhaki and Ne'eman, 2000), and in the case of *P. sylvestris* most of the seeds germinate in spring, so fire burns the seedlings. The low numbers of seeds which remain in the ground are unable to resist the high temperatures that are reached during the fire (Habrouk *et al.*, 1999), and the result is a lack of seeds to promote later regeneration. All of this could potentially influence the regeneration of this species and could affect its area of distribution, as occurs with other species (*Pinus nigra* Arn.) in Spain (Espelta *et al*., 2002).

Nevertheless, the vegetation dynamic in the *Pinus* community after fire not only depends on the *Pinus sylvestris* behavior but also on the behavior of the understory species composition. Numerous studies which analyze the behavior of Mediterranean ecosystems after fires have determined that they have a high level of resilience (Keeley, 1986; Ojeda *et al.*, 1996; Ariatnoutsou, 1998; Calvo *et al*., 2003). Because of this, post-fire regeneration in the Mediterranean region has been described as a process of autosuccession, in which the rapid re-establishment of the pre-fire community depends on the reproductive behavior of the species which make up that community. Community dominated by resprouters species such as *Erica australis* L., presents faster regeneration than communities dominated by seeders (Calvo *et al.*, 2003). However, the obligatory reproduction strategy by seeds, on the other hand, determines the genetic variability of the population (Baskin and Baskin, 1998) and is the strategy displayed by genus such as *Cistus*, *Pinus* or *Halimium*. Many studies have verified the influence of fire on the germination of the seeds of species with obligatory sexual reproduction (Thanos and Marcou, 1991; Martínez-Sánchez *et al.*, 1995; Reyes and Casal, 1995). After it passes through, fire leaves open spaces behind in which competition has been eliminated. This reason, coupled with their condition as heliophilic species, turns the species that obligatorily reproduce by seeds into potential colonizing species of these ecosystems disturbed by fire (Ne'eman *et al.*, 1992; Martínez-Sánchez *et al.*, 1996).

According to Debano *et al.* (1998), understanding how fires affect plant life is a key to developing management plans in areas subject to fires. However, there are few global works on the regeneration of *Pinus sylvestris* communities after fires.

Therefore, given the new ecological scenario described for the Mediterranean region, with an increase in the number of fires and their recurrence, it is possible to do several questions: what will the individual response of the different species be, and how will the diversity and dynamics of Mediterranean forest communities be affected?

The principal objective of this study is to analyze the effects of wildfire on *Pinus sylvestris* understory community in northern Spain. We examine the changes along fourth years of secondary succession after wildfire of plant composition, life forms and structural parameters (S gamma) of the *Pinus pinaster* understory community in three areas of the northern of Castilla y León.

Material and Methods

In order to analyze the dynamics of the composition and the modification of the richness of *Pinus sylvestris* understory communities, three sites located in the north of Castilla and León that suffered from natural fires in the summer of 1994 were studied. In each of the study sites, vegetation samplings were performed after 3 months, and 1, 2, 3 and 4 years after fire. Similarly, an analysis of the control situation was carried out.

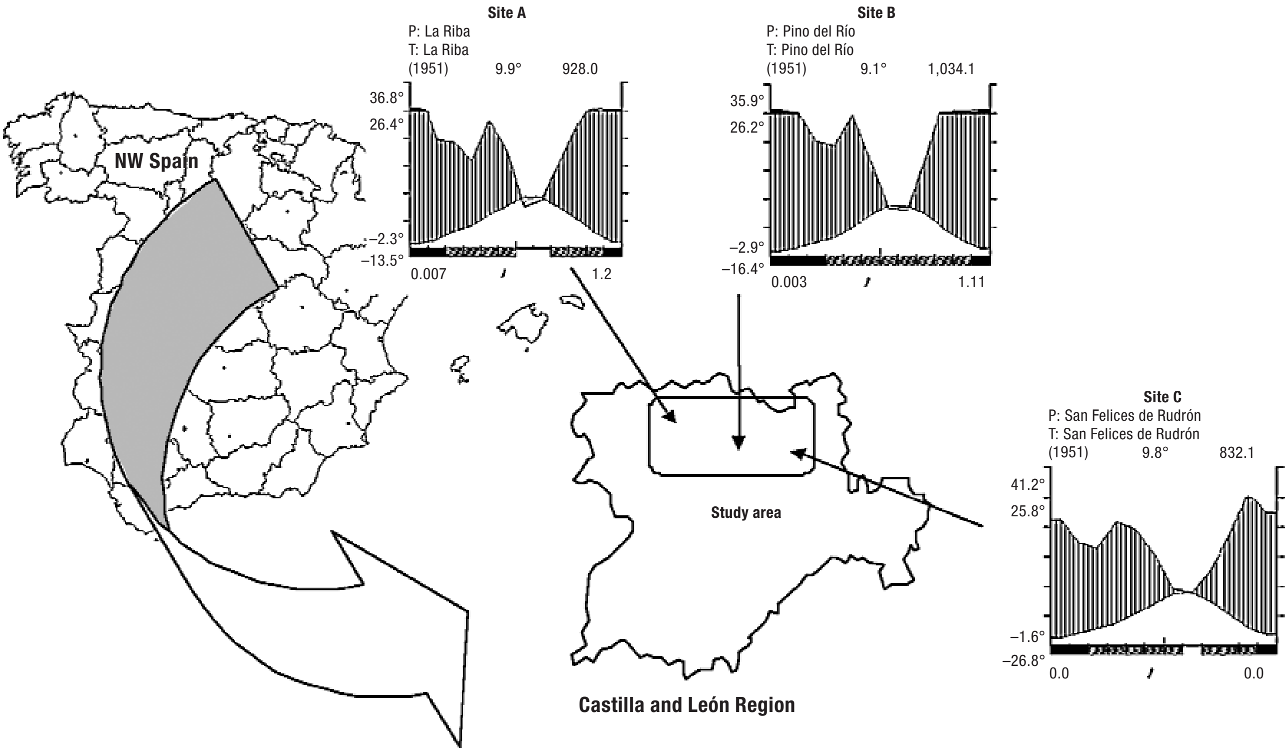

Figure 1. Location of the study sites in Norwest of Spain and climatic diagram that characterized this areas.

Description of the study areas

The study sites are located in the provinces of León (site A), Palencia (site B) and Burgos (site C) in NW of Spain (Fig. 1 and Table 1). Sites A and B were affected by a summer intense surface fire with some pines affected in its crowns while site C was affected by a summer intense surface fire while most of the pines were affected in its crowns.

The vegetation that appeared in the three sites was a stand of *Pinus sylvestris* created by afforestation. In the sites A and B the tree vegetation was dominated by *Pinus sylvestris*, whereas the understory is mostly dominated by *Erica australis* L., *Pterospartum tridentatum* L., *Calluna vulgaris* (L.) Hull and *Halimium alysoides* (Lam.) Spach. In the site C, also afforested with *Pinus sylvestris*, the shrub vegetation was dominated by *Genista scorpius* (L.), *Prunus spinosa* L. (Blackthorn),

Table 1. Main characteristics of sampling sites

	Site A	Site B	Site C
Location	León	Palencia	Burgos
Altitude (m)	1,025	1,130	1028
Coordinates	42º 43'N-5º 02' W	42º 42' N-4º46' W	42º 45' N-3º 48' W
Aspect	East	—	—
Slope (%)	12	0	0
Mean annual temperature (°C)	10.3	8.8	9.6
Mean annual precipitation (mm)	629.0	686.4	879.0
Dry seasons	July to august	July to august	August
pH	5.6	5.5	7.3
Texture	Sandy loam	Sandy loam	Sandy loam
MO (%)	1.9	1.5	6
P (ppm)	1	2	8
K (ppm)	70	55	590
Ca (meq/100 g)	2.5	1.2	36

Lavandula latifolia L. and *Arctostaphylos uva-ursi* (L.) Spreng.

A soil pit extending down to the first 10 cm layer were used to describe forest soil condition. Soil samples were analyzed to determine percentage of sand, silt and clay (using ISSS method); percentage of carbonate and organic matter; concentrations of phosphorus using the Olsen method, potassium, calcium, magnesium and sodium following extraction with 1N ammonium acetate; cation exchange capacity (CEC), defined as the equivalent amount of cations from the first salt that are retained on the exchanges sites, in meq/100 g, pH and electrical conductivity (mmhos/cm). Soil laboratory analyses followed the standard procedures in agricultural soil research in the Itagra soil laboratory (www.itagra.com)

Sampling method

In each study site three permanent plots of 25 m × 1 m were placed and fixed perpendicularly to the slope. The first transect was placed at random and the following separated 3 metres from each other. The burned pines remained in the sites during the study period. In each plot, 25 samplings units of 1 m^2 were carried out (it is said 75 squered meters sample units in each study site) during the 1, 2, 3 and 4 years after fire. Samples were carry out in june of each year. However, three months after the fire (in September 1994) only 25 sampling unit were recorded. In the same way, a control unburnt plot (25 sampling unit in one of the three permanent plots) was set up in each zone close to the burnt area (between 25 and 50 meters from the burnt area) in September 1994. This unburnt plot is considered as control situation. In each sampling unit (quadrat), the percentage visual cover of all the species present (herbaceous and woody) was visually estimated always by the same research team (Tarrega and Luis, 1990, Calvo *et al.,* 2002). Cover percentage higher than 100% was due to the species overlapped. Plant nomenclature follows Tutin *et al*. (1964-1980) and Flora Ibérica (Castroviejo *et al*., 1986-2003).

Analysis of data

From the data of cover percentage the following parameters were analysed: percentage cover of the different life forms: annual herbaceous species, perennial herbaceous species and woody species. Structural changes in the secondary succession process after fire an analysis of diversity were carried out with the richness index (S), because we considered both woody and herbaceous species. This was calculated at a small scale Sα (per quadrat or m^2) (Whittaker, 1972; Magurran, 1989, 2004). Sα was calculated as the mean of the number of species found per quadrat in each study plot. Sampling carried out after 3 months has not been taken into consideration, because this statistical model requires that the period of time between re-measurements be homogeneous (in the case at hand, one year) We use a repeated measurements analysis of variance with one between-subjects factor (study zones) and one within-subjects factor (time) to explore the changes in time of the total cover, cover of life forms and bare soil. The mathematical formulation of the model was:

$$Y_{ijt} = \mu = \alpha_i + \pi_{i(j)} = \beta_t + \alpha\beta_{it} = + \varepsilon_{ijt},$$

where:

μ = overall mean.
α_i = fixed effect of zone *i, i* = 1,2,3
$\pi_{j(i)}$ = random effect for *j* subject in zone *i, j* = 1,2,3
β_t = fixed effect of time *t, t* = 1,2,3,4
$\alpha\beta_{it}$ = fixed effect for the interaction of the zone *i* with the time *t*
ε_{ijt} = random error term

The $\pi_{j(i)}$ are assumed to be independently normally distributed with mean zero and between-subjects variance σ^2_π. The ε_{ijt} are assumed independently distributed with mean zero and within-subjects variance σ^2.

The values of the different variables studied (richness-S and total cover percentage of woody, perennial herbs and annual herbs) were compared with the control by performing a repeated measurement variance analysis. The sphericity of the data was verified using Mauchly's test (Mauchly, 1940). In order to verify the direction of change in the variables studied over time, linear, quadratic and cubic orthogonal contrasts were carried out.

Results

Changes in total cover

The analysis of the total cover in the three study areas (Fig. 2) showed a very low cover values three months after fire and only site A reached nearly 20% of the original cover. However, from the first year, total cover followed a common behavior pattern in the three sites, with significant increases over time ($F_{3,15}$ = 15.44;

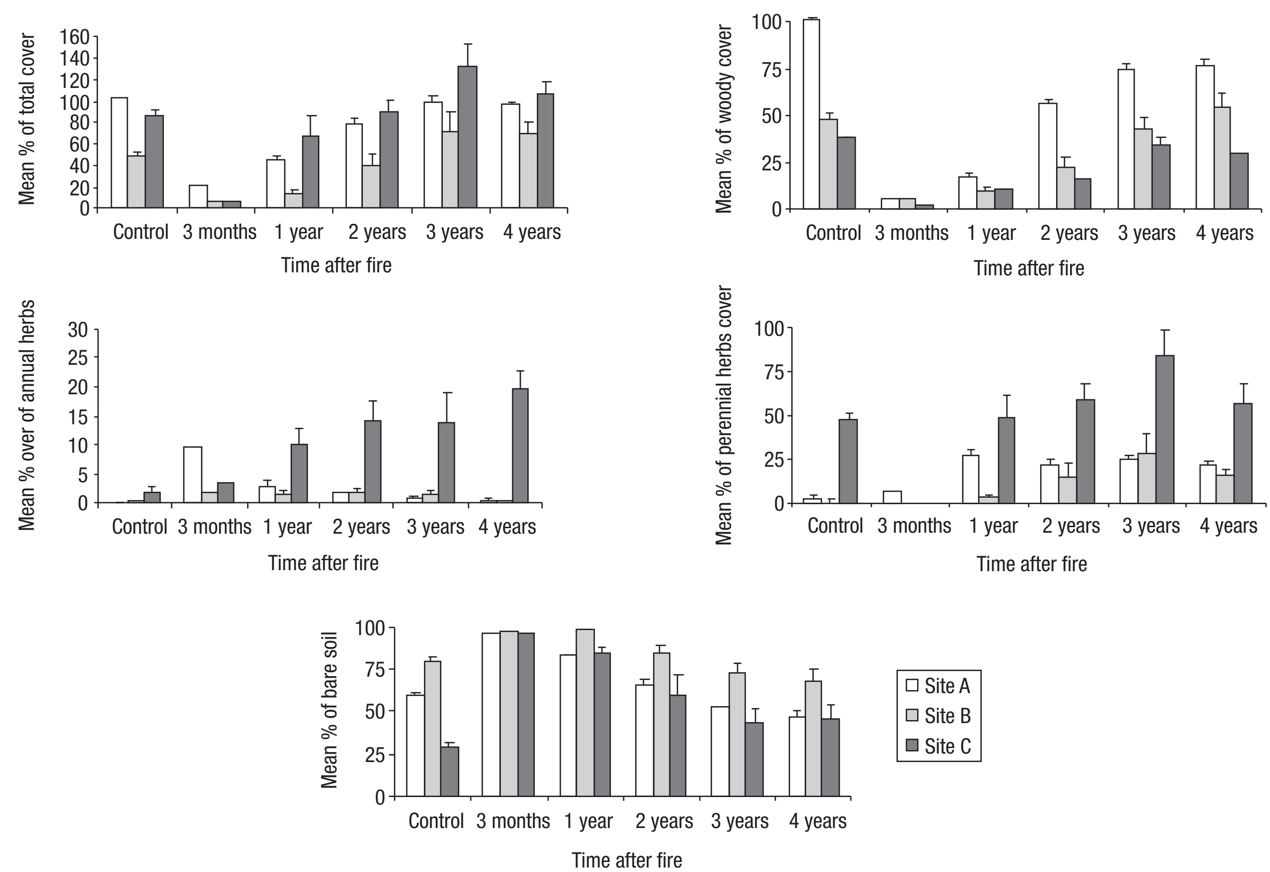

Figure 2. Mean percentage cover and standard deviation of the total cover, woody cover, cover of annual herbs, cover of perennial herbs and bare soil of the three study sites (A, B and C) in the original situation and 3 month, 1, 2, 3, 4 years after fire.

$P < 0.05$). Three years after fire, original cover values were reached in site A. In the other two study sites, B and C, during the third and fourth year after fire, there were an increase in the cover values, which surpasses the original values. There were not significant differences among sites during the fourth year after fire.

In the original situation there were a high proportion of bare soil percentages (Fig. 2), mainly in the site B, due the competition effects by light of the adult pines to understory vegetation. Similarly, during the first years after fire there were high values of bare soil. There was a decrease over time after fire and during the fourth year the site B showed higher bare soil than the other two sites.

Changes in life forms: woody, annual herbs and perennial herbs

The changes in the woody species cover (Fig. 2) followed a similar pattern to that described for total cover; in general there was a good regeneration from one year after fire. However, cover values of herbaceous species, both annual and perennial, followed a more erratic pattern due to its lesser relative importance. In the control situation, woody plants were dominant in both sites A and B, with *Pterospartum tridentatum* and *Erica australis* as dominant species in both sites (Table 1). However, in site C perennial herbaceous such as *Festuca* sp. and *Sanguisorba minor* were dominant (Table 1).

After fire in site B woody species dominated from the three months, due mainly to the presence of the same typical resprouting species and also to the presence of seeders species as *Halimium lasianthum* subsp. *alyssoides* (Table 1). In site C, one year after fire, herbaceous species such as *Festuca sp., Sanguisorba minor,* and *Campanula hispanica* became dominant, and this situation continued until the end of study period. On the contrary, in site A one year after fire, perennial herbaceous were dominant (26.17%), but from the second year woody species became dominated, reaching their maximum value during the fourth year after fire (76.38%) (Fig. 2).

The cover percentage of the annual species (Fig. 2) was relatively low in all of the study sites, both in the original situation and after fire. However, site C must be pointed out as the one with the highest values, due mainly to the presence of *Rhinanthus minor* (Table 1) that show a high variability between plots within study site.

The variations in the perennial herbaceous cover after fire made clear that they had greater importance than annual species did (Fig 2). In the sites A and B the perennial herbaceous species with higher values was *Avenula sulcata*, which had a cover of nearly 10% four years after the fire (Table 1). In site A, in addition to this species, both *Luzula lactea* and *Agrostis capillaris* presented high cover values (Table 2).

In general woody cover increase significantly in time ($F_{3,15} = 82.50$; $P < 0.05$) but perennial herbs ($F_{3,15} = 1.49$; $P < 0.05$) and annual herbs ($F_{3,15} = 4.48$; $P > 0.05$) do not change significantly in time after fire.

Changes in richness values (Sα)

In the control plots, the highest species richness value was found in site C (30 species), whereas site B is the one which shows the least richness (6 species).

Table 2. Cover of main plant species and number of species recorded in the three study sites

Species	Life forms	Biological characteristics	Control	3 months	1 year	2 years	3 years	4 years
Site A (León)								
Avenula sulcata (Boiss.) Dumort.	He	P	1.20	2.64	6.89	6.74	9.64	9.06
Pterospartum tridentatum (L.) Wilk	C	W	12.80	1.28	4.99	13.60	20.18	18.00
Erica australis L.	C	W	35.40	0.00	2.39	17.42	21.50	26.00
Calluna vulgaris (L.) Hull),	C	W	24.60	0.00	0.00	0.00	0.22	1.32
Halimium lasianthum subsp. *alyssoides* (Lam.) Greuter	C	W	16.12	1.00	5.57	15.64	23.42	23.26
Luzula lactea (Link) E. Mey	He	P	0.12	4.08	3.64	2.72	3.76	3.28
Agrostis capillaries L.	He	P	0.04	0.00	4.35	2.24	3.08	3.42
Lolium perenne L.	He	P	0.00	0.00	2.81	1.94	0.12	0.10
Arenaria montana L.	He	P	0.60	0.00	3.57	0.00	0.00	0.00
Site B (Palencia)								
Avenula sulcata (Boiss.) Dumort.	He	P	0.00	0.00	1.49	10.01	9.91	10.91
Calluna vulgaris (L.) Hull),	C	W	2.76	0.00	0.00	0.07	0.75	2.73
Erica australis L.	C	W	14.60	3.60	3.55	8.92	14.93	17.01
Erica cinerea L.	C	W	13.84	0.00	0.00	0.00	0.31	1.09
Pterospartum tridentatum (L.) Wilk	C	W	6.08	1.28	1.52	2.81	5.47	4.31
Halimium lasianthum subsp. *alyssoides* (Lam.) Greuter	C	W	0.00	0.00	1.60	9.23	19.67	26.89
Agrostis capillaris L.	He	H	0.00	0.00	0.00	0.36	0.00	0.49
Site C (Burgos)								
Campanuda rotundifolia subsp. *hispanica* (Wilk.) O. Bolòs & Vigo	He	H	0.08	0.00	2.09	0.00	0.63	0.31
Coronilla minima L.	C	W	5.60	0.00	0.88	0.43	0.25	0.00
Festuca sp.	He	P	17.92	0.00	5.20	0.32	0.00	0.00
Genista scorpius (L.) DC.	C	W	14.92	0.00	3.09	7.17	13.96	16.37
Lotus pedinculatus Cav.	C	W	0.00	0.00	0.00	0.00	0.03	0.00
Ononis spinosa L.	C	W	0.00	0.00	0.00	0.00	2.57	0.00
Prunas spinosa L.	P	W	5.36	0.00	0.63	2.40	0.00	0.00
Rhinanthus minor L.	T	A	0.00	1.11	0.03	0.00	6.20	0.00
Sanguisorba minor Scop.	He	P	2.36	0.00	3.39	3.75	5.89	5.05

Life forms: P, phanerophyte; He, hemicryptophyte; C, chamaephyte; t¿ therophyte. Biological characteristics: P, perennial herbs; W, woody species; A, annual herbs.

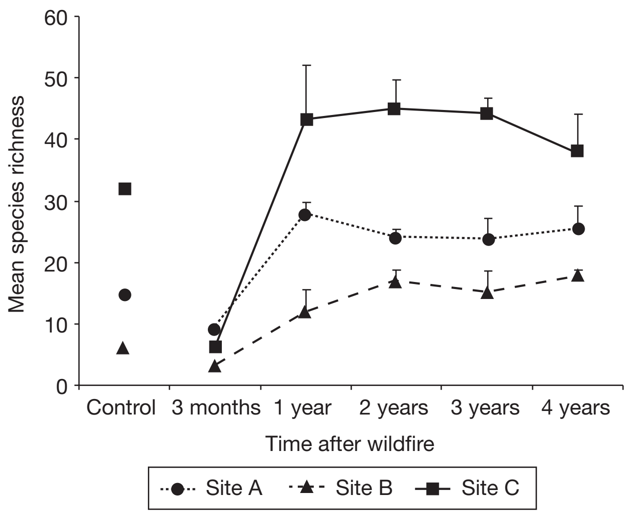

Figure 3. Mean number of richness and standard deviation of the three study sites (A, B and C) in the original situation and 3 month, 1, 2, 3, 4 years after fire.

Site A showed an intermediate richness level (12 species). These differences copuld related with soil and forest structure characteristics in each stand. However, all studied zones show a common low richness values (Fig. 3). Though, one year after fire the richness values were higher than original situation in the three study areas, this was due to greater presence of herbaceous species. From the first year changes in richness values were not significant ($F_{3, 15} = 6.63$; $P < 0.05$). It should be mentioned that the site with the greatest richness in the original situation (site C) was that which displays the greatest richness in the post-fire situation.

Discussion

The response to fire of the communities studied dominated by *Pinus sylvestris*, showed a good regeneration immediately after fire of the pioneering species mainly the resprouters. This response is modulated by forest fire characteristic (intensity, severity, date...) Resprouters species took advantage of the post-fire conditions, because they maintain their root system intact and regenerate rapidly with the first rains and had an advantage over those which use the germination system such *Erica umbellata*, *Calluna vulgaris* and *Erica cinerea* (López Soria and Castell, 1992).

Similarly, a good regeneration of perennial herbaceous species was observed, and there was only a small proportion of annual species. These results coincide with those reported by other authors (Calvo *et al.*, 1998). This means that perennial species survive fire so either in the form of seeds or through the survival of their underground organs, because in general they have dispersion mechanisms that are not very fast compared to those of annual species (Tárrega *et al.*, 1990). The annual herbaceous are not usually well represented in the original situations of these communities, because the competitive effects of woody species and also by the allelopathic effect produced by other species like ericaceous species (Carballeira and Cuervo, 1980). Another of the possible explanations may be related with the fact that these communities have been subject to frequent perturbations which produce a decrease in seeds from the soil seed bank (Keeley, 1986; Zammit and Zedler, 1988), because the fire promote the germination of many seeds, acting on their coverings, etc. (Christensen and Muller, 1975) and also influences the mortality of a high number of them (Hassan and West, 1986). This means that, with the passage of time, there is a clear decrease in the number of seeds present in the soil bank (Thompson, 1978).

According with the specific plants response to fire, three groups can be distinguished. First of all, some species that are favored by fire, increasing their cover. Examples of this behavior can be found in the annual and perennial herbaceous such as *Avenula sulcata* and also the seeders woody species as *Halimium lasianthum subsp. alyssoides*. The species in the genus *Halimium* regenerate exclusively by seeds that have a hard coats and fire favours its breakage by stimulating their germination, as is the case with other *Cistaceae* (Thanos and Georghiou, 1988; Valbuena *et al.*, 1992; Herranz *et al.*, 1999). A similar effect has been observed in some leguminous (*Lotus corniculatus* and *Trifolium* sp), which appear after fires in pine stands in the southwestern part of the Iberian Peninsula (Martínez Sánchez, 1994). However, more important than the direct effect of temperature on the germination of a specific species (Nuñez *et al.*, 2003) is the differential effect of fire in the competition ability of each species (González-Martínez and Bravo, 2001).

Another group of species is made up of colonizers whose establishment is favored by the creation of open spaces after fire and great availability of nutrients. These species, which are not present in original composition of these communities, represent the majority of specie during the first year after fire. Species of the families which include *Arnoseris minima, Hieracium castellanum* and *Senecio vulgaris* or the family of the

Caryophyllaceae, such as the genus *Stellaria,* are examples of this group.

The last group is made up of species that are dominant in the control plots and recover fastly that dominant position after fire. Examples of this group include the woody species such as *Calluna vulgaris*, *Erica australis*, *Erica umbellata, Pterospartum tridentatum*. If the time of recurrence is very short, the reappearance of these species is more difficult and may lead to a replacement of these dominant species.

We must emphasize the behavior of the dominant tree species, *Pinus sylvestris*, which displays a very low or no recruitment in the field in the study sites (unpublished data), similar to what was found by other authors (Ibáñez and Retana, 1997). Additionally, weather conditions the year after the fire, distance to seed sources or masting can affect recruitment rate. Analyzed stands were originated by plantation but now they are naturalized and fully integrated in the surrounding landscape.

The changes in species composition and the importance values of the species determine changes in the community's structure. In the first years of regeneration, there is an increase in the richness, which is reduced over time when the effects of competition begin to arise by the dominant species (O'Leary, 1990). In all of the study sites, it was observed that, one year after the fire, there was an important increase in the richness parameter. This may be explained by the contribution of pioneering species to the colonization of these sites throughout this period. The main source of these species comes from the soil seed bank (Moore and Wein, 1977). However, Valbuena *et al.* (2001) observed that this type of pioneering species (r strategies) lose their dominant position one year after fire. This may explain the decrease in richness observed two years after fire. However, fourth years after fire the richness values do not reach the original situation. In studies carried out on heaths, where afforestation of *Pinus sylvestris* are established, it has been observed that the maximum diversity values appear, as in the study sites, just a few years after the fire (Calvo *et al.,* 1998). In order to restore the original situation, they require a period of more than four years, such that stabilization of the community has been described at approximately nine years (Calvo *et al*., 2002).

The results of this study demonstrate that, four years after fire, the main attributes studied are close to the values in the control situation. The knowledge of time necessary for the community to recover is essential in order to be able to define possible methods for managing these communities. For instance, by concentrating silvicultural activities to enhance natural regeneration in site with low (and slow) natural recruitment rate managers could improve its management practices. The results of this study back up the proposal of using fire as a silvicultural tool which must be considered within the broader framework of changes in nutrients after a fire and the influence of the fire on the possible accompanying endemic vegetation.

The main conclusions are that immediately after the fire, the vegetation cover is strongly altered, but the vegetation rapidly recovers. Herbaceous species present high cover values during the first year after fire in these communities of *Pinus sylvestris*. Afterwards, woody species recover their dominance and fourth years after fire the main characteristics of the communities studied are similar to their initial values. An initial increase in the richness of these communities has been observed, which may be associated with the increase in herbaceous during the first year after fire. These herbaceous species, which have little cover in the control situation, could be originate from either the seeds existing in the soil seed bank or from nearest unburned sites and were favored by fire.

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