# IMPACT OF LARGE FIRES ON A COMMUNITY OF *PINUS PINASTER*

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## Abstract
The effect of a large fire in a *Pinus pinaster* stand in NW Spain has been analysed. Regeneration of plant community and changes in the soil was studied. Studies of natural regeneration of *Pinus pinaster* in the field and density of *Pinus* seeds in the soil seed bank were carried out. Very high natural regeneration of *Pinus pinaster* was observed, with a mean of 33.23 seedlings/m$^2$ being found in the spring following the fire and after the first rains. However, the number decreased to 9.68 seedlings/m$^2$ one year after the fire and 8.86 seedlings/m$^2$ two years after it. This number was sufficiently high to ensure natural regeneration of this species. Density of *Pinus pinaster* seeds in the soil seed bank were 150 seeds/m$^2$ in the samples collected in the control area and 200 seeds/m$^2$ in the burned areas. The great heterogeneity of the fire was reflected in its effects on soil characteristics.

## Introduction
The province of León (NW Spain) is one of the areas in the Iberian Peninsula most affected by forest fires. *Pinus* stands are, in general, areas that most frequently suffer fires. The *Pinus* surface burned in this province in the last 10 years represents 60% of the total burned forest communities. One of the *Pinus* sp. communities frequently subjected to fires are *Pinus pinaster* stands.

Maritime pine (*Pinus pinaster* Ait.) is an important species in the Mediterranean basin and is found throughout the western range, from France to Morocco and from Portugal to Tunisia. Due to its high resin content this species is one of the most pyrophytic species among the Spanish conifers (Velez 2000). Also, *P. pinaster* diverges significantly from the common origin in different races in the Iberian Peninsula. The Iberian populations belong to 7 of these geographical races (Salvador *et al.* 2000). This indicates the extremely wide variety of ecological conditions under which they can develop – soils ranging from calcareous to sandy and climates from Mediterranean to Atlantic – resulting in specific adaptations of the species in terms of growth pattern and survival (Alía *et al.* 1995). For this reason it is difficult to extrapolate the results from research in different areas.

The population studied is situated in an area (NW Spain) that suffered from frequent fires. Those occurring in 1991, 1997 and 1998, amongst others, can be mentioned. The last

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one was classed as a large fire because more than 3000 ha. was burned by human activities. However, it is estimated that lightning starts two fires per year. Because of this, the *Pinus pinaster* stand in this area has acquired a series of characteristics, such as a high yield of serotinous cones, thicker bark and a significant bringing forward of the flowering age of its pines. In addition, *Pinus pinaster* is characterised by its possession of an aerial seed bank and is capable of storing fertile seeds in the closed cones for up to 50 years (Tapias *et al.* 1998).

*Pinus pinaster* is an obligate seeder (Martínez Sánchez *et al.* 1995). The advantage of germination is that it increases the genetic variability and stability of the populations (Baskin & Baskin, 1998). However, obligate seeders are rare and at a disadvantage in comparison with species that sprout vegetatively and occupy the area more quickly (Naveh 1975, Trabaud 1987).

The aim of this study was to analyse the effect of a larger fire in the regeneration of a *Pinus pinaster* stand located in NW Spain. It is also to analyse the contribution of the soil seed bank to natural regeneration and the variation in the physical and chemical characteristics of the soil.

## Materials and methods

The study area is located in a *Pinus pinaster* stand in the Sierra del Teleno, León province (NW Spain) (M.T.U.29TQG2984), at an approximate altitude of 1100 m. This is a natural *Pinus pinaster* stand with the total size of the original wood being 11500 ha. Its anatomical and physiological characteristics distinguish it from any other natural population of the species in the Iberian Peninsula. There are two aspects to be considered in this area: the large number of fires occurring and the extraordinary capacity for recovery, with up to almost two million seedlings per hectare being found after the fire (Tapias *el al.* 1998).

The climate is Mediterranean with 2-3 months' dryness in summer and annual precipitations of 650 to 900 mm. (Ministerio de Agricultura 1980). An interesting feature of the local climate is the frequency of dry storms together with very low precipitation in spring and summer, which often produces crown fires (Sánchez 1999). Rainfall was extremely low in the year of the fire (354.7 mm). In the next year, 1999, there were three periods of drought, one of them during the summer (29.8 mm in June; 4.1 mm in July and 30.8 mm in August) and the other two in February (2.9 mm) and November (0 mm), which have affected the regeneration process.

The soil is classified as cambisol (Junta de Castilla y León 1987). According to the granulometric analysis the soils of this area are classified as very sandy and acid (pH=5.5) with low organic matter and nitrogen content.

The vegetation present in the area before the fire was dominated by *Pinus pinaster* with 95 % cover and the species in the underground layer were: *Erica australis* (33%), *Calluna vulgaris* (7.8%), *Genistella tridentata* (3.6%), *Halimium alyssoides* and *Genista florida* with less than 1% (Santalla *et al.* 2001).

In order to analyse the regenerative capacity of *Pinus pinaster*, three plots with different slopes and exposures were established in the area affected by the 1998 fire. Three transects measuring 20 metres by 1 metre (20 inventories of 1m$^2$) were marked in each plot. The number of pine seedlings as well as their height 7, 8, 9, 10, 11, 12, 19, 20, 21 and 24 months post-fire were recorded in each inventory. The study was started 7 months post-fire, the first month when regeneration appeared in the community.

Each plot is characterised as follows:

Plot 1: Gentle slope and N exposure; Plot 2: Situated on a gentle slope with S-W exposure; Plot 3: Situated on a marked slope with N-W exposure; Control Plot: situated in an unburned area on a gentle slope with N exposure.

In order to carry out the study of the seed bank ten 20 x 2 cm soil samples were randomly collected at a depth of 5 cm. Sampling was carried out immediately after the fire (1 month), before the first rains and one year later in order to analyse the contribution made to the seed bank by the burned trees remaining in the area throughout the study period. The direct method is used to determine the density of pine seeds in the bank (Roberts 1981, Boulet 1985).

In order to analyse the regeneration of the vegetation, the percentage cover of each species was estimated visually in each sampling unit in the burned plots in 1998 from 7 to 24 months after fire.

Changes in soil characteristics were analysed in each selected plot by collecting 5 soil samples at a depth of 5 cm, as this is the part most affected by fire and where the main changes occur. The samplings were carried out in all the plots 7 months post-fire and 12 months post-fire. A sampling was also carried out in the control area. The soil samples were air-dried and passed through a 2 mm mesh sieve. The following elements were determined: pH in water (1: 2.5), organic matter, total nitrogen, assimilable phosphorus and Ca, Mg, K, and Na.

**Data analyses**

An analysis of variance of repeated measures was carried out to compare the results obtained in the number of plants/$m^2$ in time in each plot and between plots in time. Likewise an ANOVA of repeated measures was carried out to compare the results obtained in the maximum and medium height of *Pinus* seedlings in time in each plot and between plots in time. The Tukey test (1949) was used to detect any significant differences (a=0.05). The David *et al.* (1954) test was used to check the normality and the Cochran (1941) test to check the homoscedasticity.

The results obtained for the different physical and chemical parameters of the soil were compared using analysis of variance (ANOVA) to determine the existence of statistically significant differences between the plots in time.

**Results**

One month (217 seeds/$m^2$) and one year (242 seeds/$m^2$) after the fire there was a significant increase in density Pinus *pinaster* pine seeds in the soil seed bank (Fig. 1) in comparison with the values found in the control plot (156 seeds/ $m^2$). However, the increase in density between one month and one year, considering the mean of the three plots, is not significant. The results obtained in each study plot demonstrate the existence of high spatial variability in bank density. Plot 1 showed the greatest increase in time whilst there was a significant

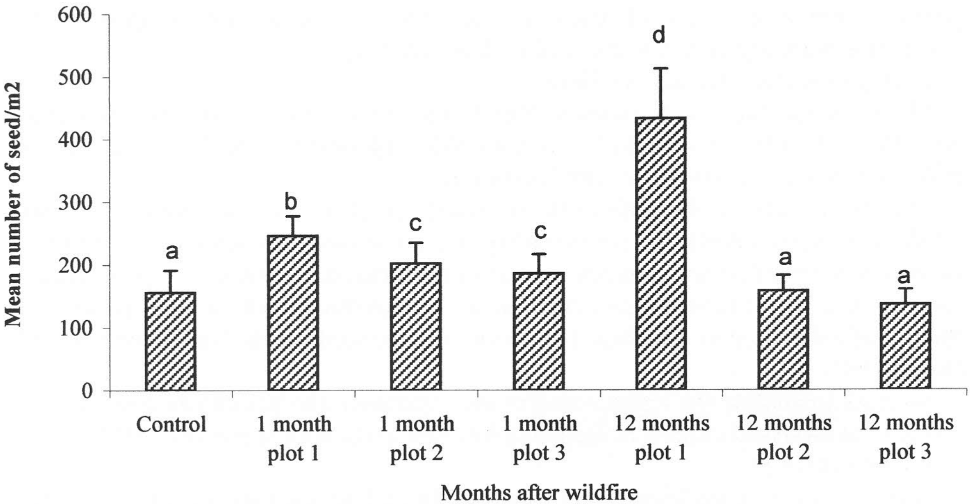


*Fig. 1.* Mean number of seeds/m$^2$ and standard errors of *Pinus pinaster* in the control and 1, 12 months after wildfire. (Different letters indicate statistically significant differences by Tukey test ($p<0.05$) for the same parameter).

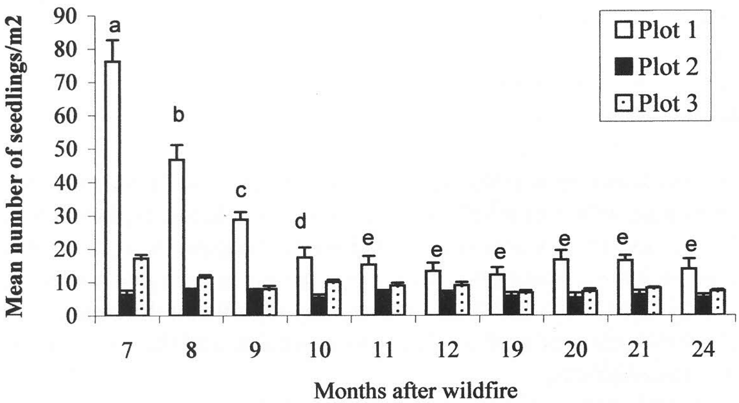


*Fig. 2.* Mean number of seedlings/m$^2$ of *Pinus pinaster* and standard errors in each plot throughout the study period. (Different letters indicate statistically significant differences by Tukey test ($p<0.05$) for the same parameter).

decrease after one year in the other two plots. Significant differences were observed throughout the study period between plot 1 and plots 2, 3.

The expression of the seed bank, that is, the number of seedlings per square metre in the field (Fig. 2) indicates great heterogeneity in the response of the three plots. For this reason they are independently analysed. Immediately after the first rains, in the spring following the fire (after 7 months), the first pine seedlings were observed. Plot 1 recorded the highest values of the mean number of seedlings/m$^2$ (76 seedlings/m$^2$) 7 months after the fire. However, this explosion in the number of seedlings is very fleeting and the number fell by over

50% the following month. Densities which remained without any significant variations throughout the study period were reached from the tenth month. Plot 2 had the lowest densities (6 seedlings/m$^2$) and this remained stable in time without presenting any significant differences. Plot 3's density 7 months post-fire was 17 seedlings/m$^2$ and, as occurred in plot 1, there was a decrease of 50% in the following month. Approximately one year after fire the mean number of seedlings, about 8 seedlings/m$^2$, was stable in the plot.

Comparing recovery in the three plots, significant differences were observed between plot 1 and plots 2 and 3 during the samplings carried out until the tenth month. From then on density was similar in the three plots.

In general, very high natural regeneration of the dominant species, *Pinus pinaster*, was observed. A mean of 33.23 seedlings/m$^2$ was recorded in the spring following the fire and after the first rains, although the number of seedlings one year post-fire fell to 9.68 and, after 2 years: 8.86 seedlings /m$^2$. This number is high enough to ensure natural regeneration of the species.

Analysis of the maximum height values gives the maximum development the seedlings can reach. The minimum height indicates whether there are new germinations in time and the mean height gives an idea of the general tendency in the plot (Fig. 3). As in the case of the density values of seedlings, the height values reflect great heterogeneity so they are independently analysed. In the three plots the minimum height remained constant in time, which indicates that pine seeds are germinating from the seed bank throughout the two-year study period. As regards the mean and maximum height this increased significantly from the ninth month. The highest values appeared two years after the fire, reaching 50 cm in some cases.

An analysis of the changes in the plant community via the variation in time of cover of the main biotypes (Fig. 4) shows that regeneration started seven months after the fire, coinciding with the start of the vegetation activity period in this area. From the first moment the cover values of the woody species typical of the area increased significantly. The presence of typical resprouters like *Genistella tridentata, Erica australis* and of colonisers like *Halimium alyssoides,* which recovers by germination, stand out. Herbaceous species had very little importance throughout the study period, with a small increase observed after 20 months (Santalla *et al.* 2001).

The changes in the physical and chemical characteristics of the soil after the fire reflect heterogeneity of the effects of the fire when compared with the control situation (Table 1). The pH values increased slightly after the fire in all the plots on comparison with the control. This increase continued after 12 months in plots P1 and P2, probably due to the incorporation of ash to the soil. In P3 the slight decrease in pH may be caused by the loss of ash due to water erosion, given the pronounced slope of this plot. These variations produce significant differences in time (Table 1).

Seven months after the fire a decrease in organic material content was observed in all the plots on comparison with the control except for P3, which had a slightly higher content. One year after the fire a clear decrease occurred in all the plots. The changes in total N content showed the same tendency in time, as did organic material, with a decrease in its content in all the plots after one year.

It should be pointed out that a great increase in assimilable phosphorus is detected in all the plots seven months after the fire, although there was a great loss in its content in P3, probably due to the loss of ash by water erosion. After one year the assimilable phosphorus

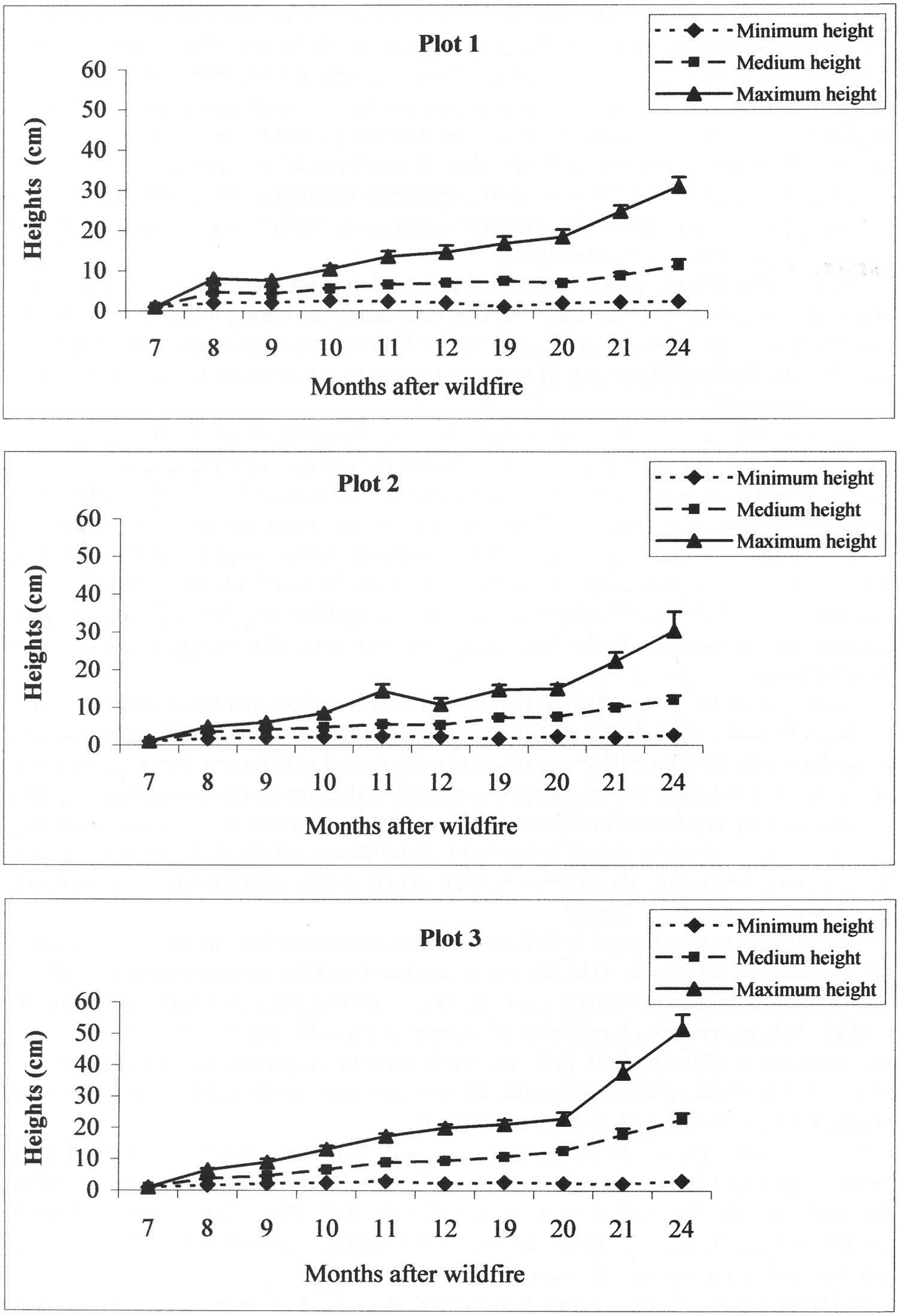


*Fig. 3*. Mean values of maximum, medium and minimum heights of *Pinus pinaster* seedlings in each plot throughout the study period.

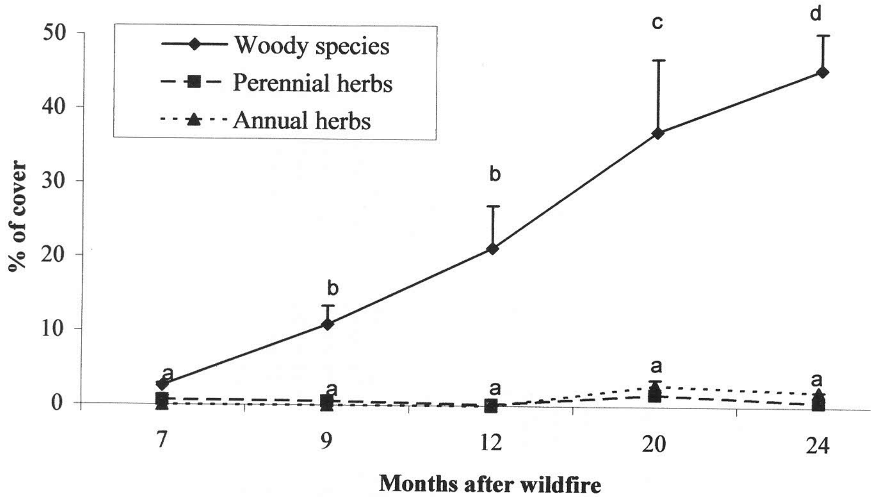


*Fig. 4*. Mean values and standard errors of cover of different biotypes (woody, perennial herbs and annual herbs) in the study area throughout the study period.

content was much higher than that found in the control. The high temperatures reached in the fire can explain this increase in phosphorus. Marcos (1997) found that heating the soil to at least 200°C for 60 minutes increased the phosphorus content to values similar to those detected. It is also necessary to bear in mind the high deviation recorded among the samples, meaning that the high phosphorus content may be due to the fact that they were collected at points with a greater accumulation of ashes which were later incorporated into the soil. It must also be taken into account that both plots are characterised by a high proportion of mother rock dispersed over the surface which, together with the pronounced slope, can retain soil and ash in certain stretches. As regards cation content, in general P3 was observed to have the highest cation content seven months after the fire (Mg, Ca and K) in comparison with the control, although all the values decreased after one year to contents similar to those of the control and did not had significant differences. No important changes occurred in the other the plots.

## Discussion

A certain fraction of *Pinus pinaster* seeds can survive the fire, protected by the scales of the closed serotinous cones. This has been observed in other pine species such as *Pinus halepensis* (Tapias *et al.* 2001) and *Pinus brutia* (Spanos *et al.* 2000). The presence of serotinous cones in these *Pinus pinaster* populations indicate that this species mainly has an aerial seed bank, whose density usually oscillates at around 2.25 million viable seeds per hectare (Tapias 1998). As a result of the thermal increase due to fire the cones open and disperse their seeds immediately after a fire. Different studies (Tapias 1998; Velez 2000) demonstrate that the temperature, which allows the serotinous cones of *Pinus pinaster* in this area to open, is 42-50°C. In spite of high temperatures that can be reached during fires

*Table 1*. Mean values and standard deviation of the soil characteristics of the control plot and the burned plots 7 and 12 months after the fire (* = $p<0.05$ and NS = not significant)

| | 7 Months | | | 12 Months | | | Control | |
|---|---|---|---|---|---|---|---|---|
| | P1 | P2 | P3 | P1 | P2 | P3 | | |
| pH | 4.28 (0.26) | 4.41 (0.25) | 4.74 (0.37) | 4.53 (0.17) | 4.95 (0.27) | 4.60 (0.05) | 4.08 (0.34) | * |
| O.M. (%) | 7.79 (2.30) | 7.69 (2.48) | 10.80(0.50) | 7.46 (0.62) | 5.31 (0.99) | 9.31 (1.10) | 9.36 (1.65) | * |
| N (%) | 0.18 (0.05) | 0.12 (0.03) | 0.25 (0.03) | 0.15 (0.02) | 0.09 (0.01) | 0.20 (0.04) | 0.18 (0.03) | * |
| P (mg $kg^{-1}$) | 14.15(3.45) | 9.35 (5.89) | 33.20(9.87) | 16.50(8.84) | 37.50(17.27) | 14.40(9.92) | 2.85 (0.49) | * |
| $Mg^{2+}$ ($cmol_c kg^{-1}$) | 0.35 (0.09) | 0.23 (0.09) | 0.61 (0.15) | 0.22 (0.07) | 0.29 (0.14) | 0.28 (0.07) | 0.26 (0.04) | NS |
| $Ca^{2+}$ ($cmol_c kg^{-1}$) | 0.78 (0.21) | 0.55 (0.14) | 1.62 (0.49) | 0.47 (0.13) | 0.79 (0.39) | 0.64 (0.26) | 1.07 (0.66) | NS |
| $Na^{+}$ ($cmol_c kg^{-1}$) | 0.18 (0.02) | 0.19 (0.02) | 0.16 (0.01) | 0.22 (0.06) | 0.16 (0.03) | 0.17 (0.02) | 0.16 (0.02) | * |
| $K^{+}$ ($cmol_c kg^{-1}$) | 0.20 (0.05) | 0.13 (0.04) | 0.37 (0.08) | 0.20 (0.04) | 0.13 (0.04) | 0.21 (0.03) | 0.18 (0.05) | NS |

**O.M.** = Organic Matter (%)

the pine seeds do not suffer any damage as long as the cones do not ignite. Thus, if the fire passes fast enough, the stored seeds can be released with barely any damage.

In areas that are repeatedly subjected to fires the *Pinus pinaster* populations usually have very abundant cone production as well as the presence of serotinous cones (Daskalakou & Thanos 1996). This characteristic determines that the number of seeds found in the soil bank is very high, mainly after fires, with values above those recorded by other authors in other populations of the same species (Tapias 1998) or in other species which behave in a similar way (Ne′eman *et al.* 1992). However, the density of the bank was found to be variable in all the areas studied. This heterogeneity in seed density in the bank is possibly due to the fact that the fire reached different intensities according to the exposure of each slope and the accumulation of fuel. In plot 1 there were fewer damaged trees since the whole crown of some was not completely consumed so the seeds stored in the cones were probably less drastically affected, thus allowing higher survival rates. Another possible source of seeds is the unburned area beside this plot.

In contrast to what was observed by other authors (Cowling & Lamont 1987, Thompson *et al.* 1997) regarding the seed bank of other species of the *Pinus* genus, in *Pinus pinaster* the bank can be classified as persistent in the short term (Thompson & Grime 1979), as germinations have been obtained in laboratory seed bank studies using samples of soil more than two years old (Unpublished data).

The expression of the seed bank, represented by the number of seedlings that germinated shortly after the fire is sufficiently high to ensure natural regeneration of these *P. pinaster* masses. As occurs in the population dynamic of other species this high density decreases in a very marked manner in the first summer, due to the great stress produced by drought. But it has to be pointed out that the seeds present in the soil continue to germinate throughout the study period (two years). This species produces seeds with a wide range of dormancy tendencies as an adaptation mechanism for regeneration in areas with irregular meteorological conditions. Therefore the existence of different dormancy intensities allows germination to be prolonged over time in order to prevent adverse meteorological conditions causing failure in community regeneration (Tapias 1998).

The different seedling densities found in the studied plots are due to the fact that each plot has a different exposure. Thus the plots with a north exposure have greater soil humidity and this is one of the required conditions not only for germination but also for seedling viability. Likewise pine leaf content contributes to maintaining plot humidity, an aspect that differentiates plot 1 from the rest as greater density is recorded here. Similar results have been found by Sánchez *et al* (1996) for *Pinus pinaster* though the opposite was recorded for *Pinus halepensis*. However, Fernández Rebollo *et al.* (2001) recorded greater regeneration of *Pinus pinaster* populations in Andalusia according to the amount of light reaching the area. Independent of the initial significant differences in seedling density in the different study areas, more or less stable densities of 8 seedlings per square metre were observed in time. These densities are much higher than those recorded by other authors in *P. halepensis* stands in the south of Spain (3.3 seedlings/m$^2$) (Martínez-Sanchéz *et al.* 1999, Simarro *et al.* 2001) or in *P. brutia* populations in Greece (2-6 seedlings/m$^2$) (Spanos *et al.* 2000).

The density of pine seeds in the soil and the recruitment of new seedlings from these communities benefit from the presence of burned trees in the area, as they maintain cones which continue to contribute to the incorporation of seeds to the bank. Therefore, the typical management practice of extracting burned trees shortly after fire is not good, especially in *Pinus pinaster* communities, as they contribute to the natural regeneration of the whole area.

Another aspect which influences the appearance of seedlings in the burned areas is the changes in the physical and chemical characteristics of the soil. The results obtained on studying the short-term soil changes clearly show the precise effect of the fire on the soil (Marcos 1997). Seven months after the fire greatly increased organic material, nitrogen and other nutrients similar to those found in other burned areas are detected (Marcos *et al.* 1998, Ludwig *et al.* 1998, Iglesias *et al.* 1997). This increase tends to diminish one year after the fire (Iglesias *et al.* 1998), either due to nutrient losses or changes in plant establishment (De las Heras 1992). On comparing different post-fire regeneration age zones in this area, Marcos *et al.* (2001) found that the soil characteristics 8 years after the fire were very similar to those of the control and the changes produced by the effect of a fire remain for a year, after which a recovery stage begins that leads to pre-fire characteristics being attained over time.

These initial changes in pH values, slightly increasing it, and above all the increased organic material, nitrogen and phosphorus content favour natural regeneration of this *Pinus pinaster* population as recorded by many authors (Naveh 1974, Tsitsoni 1997). This increase in nutrient content also favours increased seedling viability.

Thus, the communities of *Pinus pinaster* situated in the Northwest of the Iberian Peninsula are specially adapted to fire due to their being repeatedly subjected to forest fires. The density of seeds present in the soil is sufficient to ensure natural regeneration in this area without the need to introduce new pine seedlings. Germination of these seedlings clearly benefits from the variations in soil conditions, mainly the pH modifications, the increased organic material content and the increased phosphorus. The heterogeneity in regeneration observed during the first year tends to become minimal over time.

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