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Original article

Effects of silviculture treatments on vegetation after fire in *Pinus halepensis* Mill. woodlands (SE Spain)

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Abstract – In August 1994, two great fires occurred in SE Spain burning 44 000 ha of mature *Pinus halepensis* Mill. forests. Experimental silviculture treatments were carried out on five-year-old *P. halepensis* seedlings from natural regeneration: thinning to a final density of 1 600 trees/ha, total scrubbing, thinning plus scrubbing, thinning plus pruning to half the total height, scrubbing plus pruning and thinning, scrubbing plus pruning. Treatments were carried out in 45 permanent plots located in two localities with different ombroclimates: semiarid and dry. Two years after treatments were carried out, floristic richness, diversity, life form rates and vegetation cover were measured or estimated for each plot. Results showed a high capability of post-fire colonizing vegetation to rapidly recover the ecological values recorded before carrying out silviculture treatments. Floristic richness and cover values did not vary significantly. Significant differences in the vegetation life form rate were detected after thinning and scrubbing. Therophyte cover showed a significant increase two years after these treatments.

great fire / forest management / Mediterranean ecosystem / pine seedlings

Résumé – Effets des traitements sylvicoles sur la végétation après un feu dans des forêts de *Pinus halepensis* Mill. (sud-est de l'Espagne). En août 1994, deux grands feux se sont produits dans le sud-est de l'Espagne et ont brûlé 44 000 ha de forêt de *Pinus halepensis* Mill. adultes. Après le feu, il y a eu une régénération intense de la forêt qui a formé des bosquets touffus de plantules. On a alors procédé à des études sur la régénération naturelle du pin en appliquant différents traitements sylvicoles expérimentaux sur ces bosquets : dépressage jusqu'à une densité finale de 1 600 arbres/ha ; débroussaillement total ; dépressage plus débroussaillement ; dépressage plus élagage jusqu'à la moitié de la hauteur totale ; débroussaillement plus élagage et débroussaillement plus dépressage plus élagage. Les traitements se sont effectués sur 45 parcelles permanentes situées dans deux endroits différents ayant des ombroclimats différents : semi-aride et sec. Deux ans après avoir subi les traitements, on a mesuré la richesse de la flore, la diversité, le ratio de formes de vie et la couverture de la végétation sur chaque parcelle. Les résultats ont montré une grande capacité de la végétation colonisatrice postérieure à l'incendie pour récupérer les valeurs écologiques enregistrées avant l'application des traitements sylvicoles. La richesse de la flore et la couverture de la végétation n'ont pas changé significativement. Néanmoins, on a détecté quelques différences dans les ratios de formes de vie après éclaircie et débroussaillement : la couverture de thérophytes a augmenté significativement. On peut conclure que le dépressage peut être considéré comme un traitement approprié pour des masses très denses de forêt de pins de régénération après un incendie.

grands feux de forêt / gestion forestière / écosystèmes méditerranéens / plantules de pin

1. INTRODUCTION

As is well known, *Pinus halepensis* Mill. is an obligate seeder [39] that forms extensive, dense forests in the Mediterranean Region. When fire affects *P. halepensis,* the cones rupture and numerous seeds are liberated [12, 20]. Mature trees are killed by wildfire [2] and regeneration relies exclusively on the dispersed seeds originating from the seed bank [30, 36, 38]. After seed dispersal, germination is restricted to late autumn-early winter, resulting in recruitment early in the rainy season of the Mediterranean climate [35] with no dormancy period [1, 4]. Post-fire dynamics of *P. halepensis* in the Eastern Iberian Peninsula were studied by Pausas et al. [32]. In this study, no clear relationship between seedling density and fire severity was found. However, seedling mortality was lower and growth was higher in the high severity fire class.

Serotiny is another *P. halepensis* characteristic to be considered in pine forest dynamics after fire. Individual trees of this species carry both non-serotinous and serotinous cones. Serotinous cones open mainly after fire, whereas non-serotinous cones open in absence of fire. This cone response is linked to germination response of seeds to fire, heating of seeds and soil pH [16].

When dealing with pine response after fire, stand density is one of the most important factors after site quality in determining the productivity of a site [5]. This is important because stand density is the major factor that the forester can manage in developing a stand.

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Table I. Data from the study localities in Yeste and Calasparra.

	Yeste	Calasparra
Location	2º 20' W 38º 22' S	1º 38' W 38º 16' S
Treated pine age (years)	5	5
Annual precipitation (mm)	844.9	225.8
Annual average temperature (ºC)	16.3	17.1
Soil texture class	Sandy	Sandy loam
pH	8.6	8.7
N (%)	0.45	0.19
P (mg/kg)	3.60	3.43
K (mg/kg)	200.10	215.24

Post-fire recruitment of *Pinus halepensis* shows very different densities in SE Spain, ranging 6 months later from null regeneration [25] to almost 7 000 seedlings/ha [17] or 86 600 seedlings/ha [26]. If factors affecting natural regeneration are favourable, very high density of seedlings is usually recorded [13] and silviculture treatments such as thinning and pruning are needed [15]. The aims of these silviculture practices are two-fold: to decrease density and to disrupt vertical continuity of the canopy in order to prevent further fire propagation [42].

In addition to intraspecific competition, interspecific competition could be considered as an important factor in the regeneration of post-fire Mediterranean vegetation. In this sense, several studies carried out in the Mediterranean Basin have shown that *P. halepensis* seedlings and saplings increase growth if both intra- and interspecific competition are reduced [27, 29]. Scrubbing, which is focused on the seedlings survival [7] is another silviculture treatment carried out in early stages of pine stands (no more than 2 years old). In great fires recorded in SE Spain, a decrease in the effects of interspecific competition by partial elimination of *Cistus monspeliensis* L. individuals increased survival and growth of pine seedlings four years after fire [6].

There are several studies dealing with floristic composition and structure of post-fire vegetation in Mediterranean ecosystems [8, 18, 24, 31, 39, 40]. The vegetation patterns obtained show that the majority of the species recorded after fire were present before the disturbance, although significant differences were found when cover and abundance were measured [24]. Furthermore, Maestre et al. [23] noted that *Pinus halepensis* does not usually facilitate *Quercus coccifera* L., *Pistacia lentiscus* L., *Rhamnus lycioides* L. and *Ceratonia siliqua* L. recovery in semiarid sites; while Ferrandis et al. [10] proved that *Pinus halepensis* root systems restrain growth of *C. monspeliensis* in high density conditions after fire. Effect of fire recurrence on Mediterranean vegetation has been also studied. In this sense, changes in plant group rates that present different responses to fire were noted by Lloret et al. [22] in fires occurring in NE Spain. At last, González-Ochoa et al. [14] used mycorrhized *Pinus halepensis* seedlings in zones with null natural pine regeneration.

Despite the references mentioned, once colonizing shrubs become dense after fire and pine density reaches high values, effects on shrub canopy of silviculture treatments carried out on young trees (seedlings or saplings) such as thinning, scrubbing or/and pruning, are not well known. The main goal of the present study is to provide results obtained from two different sites that suffered great fires in 1994, dealing with the possible changes in floristic richness, diversity, life form rates and vegetation cover two years after pine seedlings were submitted to experimental silviculture treatments.

2. MATERIALS AND METHODS

Two great fires occurred in mature *P. halepensis* forests in August 1994 in SE Spain. Total burnt surface was around 44 000 ha located in two different provinces (Albacete and Murcia) and different ombroclimate [33]: dry and semiarid, respectively. In each burnt zone a representative locality was selected: Yeste (Albacete Province) and Calasparra (Murcia Province). General characteristics of the sites are shown in Table I. After fire, natural regeneration took place in both localities, reaching a very high density of seedlings: 4 722 trees/ha (2134 ± SD) with a medium height of 105.3 cm (12.4 ± SD) in Yeste, and 45 000 trees/ha (20400 ± SD) with a medium height of 51.1 cm (8.5 ± SD) in Calasparra.

In each locality (Yeste and Calasparra), high density pine populations were submitted to six silvicultural treatments (experimental blocks) in August 1999: T_t (thinning to a final density of 1 600 trees/ha), T_s (total scrubbing), T_{ts} (thinning plus scrubbing), T_{tp} (thinning plus pruning to half the total height), T_{sp} (scrubbing plus pruning), T_{tsp} (thinning, scrubbing plus pruning). Furthermore, plots were set without treatments and considered as control (T_c). Residues of the treatments were removed from the plots in order to prevent fue amount increasing. There were three replicates for each treatment except the control at Yeste, which had six plots.

The experimental blocks were set in homogeneous and flat zones of both localities dominated by dense regeneration of *Pinus halepensis*. Twenty-four and 21 rectangular plots (10 m × 15 m) were set in Yeste and Calasparra respectively. To prevent a border effect, a distance of 6 m was left between plots. Treatments were randomly assigned. Thinning treatments resulted in a final density of 1 600 trees/ha. Thinning and scrubbing were carried out with a Husqvarna 254RX© clearing saw and pruning was done with shears. Forest mensuration characteristics of plots by site and just after conducting cultural treatments can be seen in González-Ochoa et al. [15].

Climatic conditions in these localities were registered at two meteorological stations. These stations recorded temperature and rainfall data every 2 h during the July 1991–April 2001 period (Tab. I). Furthermore, three soil samples were randomly taken at each site in order to characterize main soil properties.

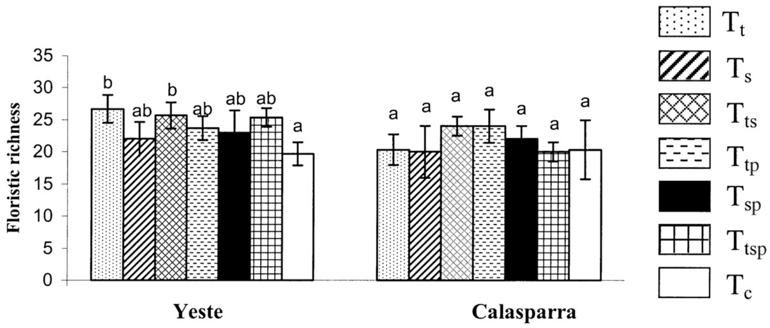

Figure 1. Average values of floristic richness two years after silviculture treatments in Yeste and Calasparra. Different letters in each column mean significant differences at $p < 0.05$.

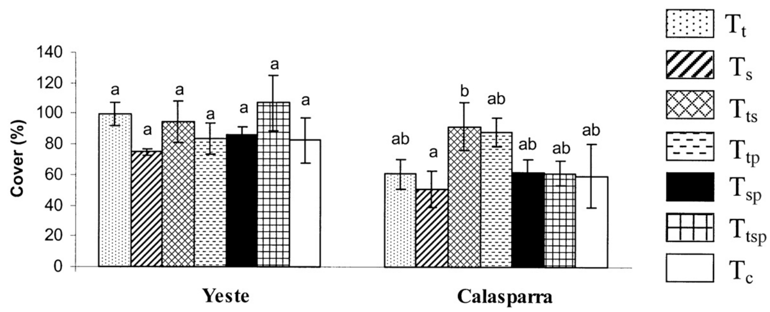

Figure 2. Average shrub cover (% ± SD) two years after silviculture treatments in Yeste and Calasparra. Different letters in each column mean significant differences at $p < 0.05$.

A sampling of shrub canopy was taken in both localities under study using the line intercept method [3, 19] in June 2001. Four lines, each 10 m long, were set in each study plot and different ecological parameters were obtained, i.e.: specific richness, total and specific average cover, average bare soil, diversity (using the Shannon-Weaver index) and life-form rates [34]. Life-forms taken into account were: phanerophytes, chamaephytes, hemicryptophytes, geophytes and therophytes. To take the field data, ropes of 10 m length, marked each 5 cm, wooden pins, needles of 1 m length (for vertical measures) and a field metre, were used.

Data was subjected to Anova treatments, in order to test significant differences by using the Duncan's test (for $p < 0.05$) in total cover, bare soil, specific richness, diversity and life forms, with silvicultural treatments constituting the main source of variance. Furthermore, a DCA (Detrented Correspondence Analysis, [11]) was used to analyse species composition in the study plots. This analysis helps to find environmental factors not included in the sampling as a source of variance. Values considered in the data matrix for each species corresponded to its cover value in the plot transformed by arcsin.

The taxa nomenclature used is based on Tutin et al. [41].

3. RESULTS

3.1. Floristic richness and specific cover

The total number of species in Yeste was 77 while in Calasparra there were 58. *Compositae* was the family with the highest number of taxa in both localities (18 and 10 respectively) such as *Atractylis humilis* L.*, Chondrilla juncea* L.*, Helichrysum stoechas* (L.) Moench.*, Leontodon taraxacoides* (Vill.) Mérat and *Phagnalon saxatile* (L.). Cass. *Leguminosae* was also well represented in both localities with *Anthyllis cytysoides* L.*, Argyrolobium zanonii* (Turra) P. Ball*, Coronilla scorpioides* (L.) Koch*, Dorycnium penthaphyllum* Scop.*, Hippocrepis ciliata* Willd.*, Ononis minutissima* (Gavó)*, Psoralea bituminosa* L. and *Scorpiurus muricatus* L. Other families with taxa present in both localities were: *Gramineae, Labiatae, Pinaceae, Liliaceae, Cruciferae, Cistaceae, Umbeliferae, Euphorbiaceae, Linaceae, Escrophulariaceae, Primulaceae, Resedaceae, Dipsacaceae* and *Santalaceae*.

In Yeste, T_t and T_{ts} plots showed significantly higher average values of floristic richness than T_c. However, silvicultural treatments did not promote significant variations in floristic richness values in Calasparra (Fig. 1). The highest average values were obtained for T_t in Yeste. In this locality, *Rosmarinus officinalis* L. and *Brachypodium retusum* (Pers.) Beauv. in T_{sp} were the species with the highest cover (19.1% and 15.2% respectively). Other species with high cover values recorded in this locality were *A. zanonii, Genista scorpius* (L.) DC.*, L. taraxacoides* and *Ononis reclinata* L. In plots with scrubbing treatments, *B. retusum* reached almost 15% average cover.

In Calasparra, *P. bituminosa* presented the highest cover values in T_{tp}, T_{sp} and T_{tsp} (12.6%, 14.8% and 14.6% respectively) and *Linum strictum* L. in T_t, T_s and T_c (12.4%, 11.3% and 12% respectively). *Stipa tenacissima* L. showed the highest cover value in T_{ts} (16.2%).

3.2. Total cover and bare soil

Average cover values did not vary significantly in Yeste plots in July 2001 (Fig. 2). The highest average value was 75%

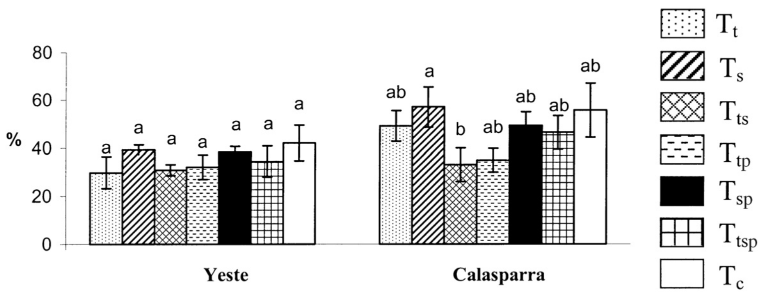

Figure 3. Average bare soil (% ± SD) two years after fire in Yeste and Calasparra. Different letters in each column mean significant differences at $p < 0.05$.

Table II. Shannon Diversity Index in plots for each treatment (average ± SE) in June 2001.

	Yeste	Calasparra
T_t	3.63 ± 0.17^{ab}	3.52 ± 0.11^{c}
T_s	3.77 ± 0.14^{a}	3.43 ± 0.19^{bc}
T_{ts}	3.70 ± 0.20^{a}	2.9 ± 0.08^{a}
T_{tp}	3.81 ± 0.08^{a}	3.38 ± 0.24^{bc}
T_{sp}	3.70 ± 0.13^{a}	3.29 ± 0.02^{abc}
T_{tsp}	3.61 ± 0.15^{ab}	2.98 ± 0.06^{ab}
T_c	3.50 ± 0.18^{ab}	3.33 ± 0.20^{abc}

in T_s and 110% in T_{tsp}. In Calasparra, only average cover value of T_{ts} was significantly higher than T_s. In this locality, average cover values were generally lower than those in Yeste. In relation to bare soil, no significant differences were recorded in Yeste, and the average value was 35% in July 2001. In Calasparra, cover value of T_{ts} was significantly lower than T_s (Fig. 3).

3.3. Diversity

No significant differences were obtained in the Shannon diversity index values, in Yeste (Tab. II). The highest value was 3.8 ± 0.08 bits in T_{tp} and the lowest 3.5 ± 0.18 bits in T_{tsp}. In Calasparra, diversity index values were lower that those in Yeste (Tab. II). In this locality, T_t showed values significantly higher than T_{ts}.

3.4. Life forms

In Yeste, T_t presented the highest average cover value of therophytes (almost 40%) whereas T_s and T_c showed their lowest values (Tab. III). Hemicryptophytes showed lower average cover values in those plots with no scrubbing treatments (T_t, T_{tp} and T_c). Phanerophytes presented the highest cover values in T_{tsp} (35.2%).

Figure 4 shows group distribution of the plots using a DCA. Plots with low values of SD (13, 17 and 22) corresponded to plots where thinning, scrubbing and pruning treatments were carried out whereas control plots (1, 5, 19, 21, 25 and 27) presented higher SD values. The DCA axes length has an ecological meaning [11] because it represents *Beta* diversity. The 18 plots with high SD values presented a very high cover value of *G. scorpius*. In general, plots with no thinning treatment had the highest cover values of phanerophytes.

In Calasparra, no significant differences in the average cover values of the life forms were recorded (Tab. III). Therophytes had the highest cover value and hemicryptophyte and geophyte covers were the lowest in all cases (less than 3%).

The DCA carried out for Calasparra, when considering plots (Fig. 5), showed a mixed distribution with a no significant tendency. In this sense, thining, scrubbing and pruning plots (16, 9) presented high SD values with that of one of the control plots (14). *B. retusum* presented a high cover value in 14 plots (14%) and both (plot and species) showed the highest SD values.

4. DISCUSSION

Floristic richness in Yeste was higher in plots submitted to a thinning treatment than in control plots. When environmental parameters change due to a thinning operation, the response of the released plants is partly dependent on whether their photosynthetic tissues can accommodate the increases in light intensity [5]. Intolerant plants released from a relatively shaded position to one that is suddenly fully-exposed may show a decrease in growth (cover) or may actually die. However, in Mediterranean forests, plant communities are well adapted to sunny exposures and the effect produced by a thinning operation can be the opposite. In sites where prescribed fires are used on clear-cuts, diversity value increases during the early stages after silviculture operations, and after a few years, it decreases to the values before perturbation [21].

Two years after treatments, average cover values of the vegetation were higher in Yeste (> 90%) than in Calasparra (> 50%). It seems that recovery of the shrub canopy has been more effective in the dry ombroclimate locality than in the semi-arid locality. Results showed that two years after scrubbing, cover in the dry ombroclimate locality was the same as that recorded in control plots.

In Yeste, scrubbed plots (T_s) showed lower cover values than plots submitted to scrubbing plus thinning. Furthermore, vegetation cover in T_s showed a significantly lower value than

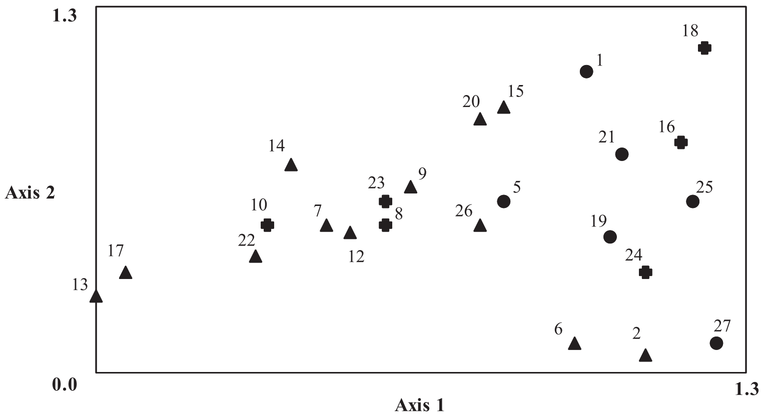

Figure 4. DCA analysis considering species cover in the permanent plots of Yeste. T_t: 2, 9,14; T_s: 8, 16, 24; T_{ts}: 7, 15, 20; T_{tp}: 6, 12, 26; T_{sp}: 10, 18, 23; T_{tsp}: 13, 17, 22; T_c: 1, 5, 19, 21, 25, 27. Triangle: plots submitted to a thinning treatment; cross: plots submitted to a scrubbing treatment but not thinning; circle: control plots.

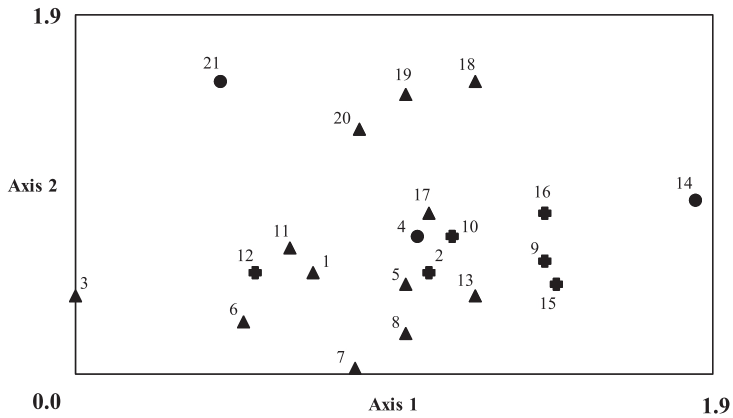

Figure 5. DCA analysis considering species cover in the permanent plots of Calasparra. T_t: 1, 7, 18; T_s: 2, 10, 15; T_{ts}: 6, 11, 19; T_{tp}: 3, 5, 17; T_{sp}: 9, 12, 16; T_{tsp}: 8, 13, 20; T_c: 4, 14, 21. Triangle: plots submitted to a thinning treatment; cross: plots submitted to a scrubbing treatment but not thinning; circle: control plots.

Table III. Life form cover in the plots for each silviculture treatment (% average ± SE) in June 2001.

		Chamaephytes	Phanerophytes	Hemicryptophytes	Therophytes	Geophytes
Yeste	T_t	6.6 ± 3.7^a	15.0 ± 3.8^{ab}	23.4 ± 4.5^{ab}	40.3 ± 4.4^b	0
	T_s	4.4 ± 0.9^a	20.2 ± 7.1^{ab}	27.8 ± 2.7^{ab}	15.1 ± 3.8^a	0
	T_{ts}	4.7 ± 0.6^a	13.5 ± 2.2^{ab}	31.8 ± 9.2^{ab}	22 ± 10.4^{ab}	0
	T_{tp}	10.1 ± 4.0^a	23.3 ± 5.1^{ab}	16.2 ± 4.8^a	22.5 ± 8.4^{ab}	0
	T_{sp}	6.5 ± 2.4^a	9.5 ± 3.0^a	25.8 ± 5.0^{ab}	26.2 ± 11.5^{ab}	0
	T_{tsp}	5.2 ± 1.8^a	35.2 ± 24.4^b	29.3 ± 14.5^{ab}	27.6 ± 7.3^{ab}	0
	T_c	6.2 ± 2.1^a	20.4 ± 3.0^{ab}	17.8 ± 4.1^a	15.7 ± 4.1^a	0
Calasparra	T_t	11.1 ± 0.1^a	20.1 ± 9.8^a	3.25 ± 0.62^a	25.2 ± 0.7^a	0.6 ± 0.3^a
	T_s	11.6 ± 2.4^a	11.6 ± 7.0^a	2.4 ± 1.5^a	24.5 ± 8.3^a	0.6 ± 0.4^a
	T_{ts}	14.1 ± 4.6^a	27.0 ± 7.3^a	2.4 ± 0.8^a	46.5 ± 11.3^a	1.3 ± 0.4^a
	T_{tp}	20.4 ± 7.0^a	21.25 ± 5.7^a	3 ± 1.1^a	41.9 ± 11.5^a	1.1 ± 0.6^a
	T_{sp}	17 ± 6.9^a	13.8 ± 6.5^a	2.1 ± 0.3^a	27.2 ± 3.4^a	1.4 ± 0.9^a
	T_{tsp}	19.2 ± 6.0^a	13.7 ± 7.5^a	0.8 ± 0.6^a	26.5 ± 5.6^a	0.7 ± 0.4^a
	T_c	12.8 ± 2.4^a	8.3 ± 1.2^a	4.1 ± 2.6^a	33.5 ± 19.6^a	0.4 ± 0.2^a

T_{ts} plots in Calasparra. Once more, the increase in light intensity linked to a probable decrease in competition for water and nutrients promoted a rapid regeneration of cover.

Average bare soil value in T_s was high (57%) whereas that of T_{ts} was significantly lower in Calasparra. These results agree with those of vegetation cover obtained in this locality, thus indicating that elimination of tree seedlings allows for a more effective plant recovery.

In relation to diversity, Shannon Index values were similar for all treatments both in Yeste and Calasparra. Diversity values were high (> 3 bits) and very close to those obtained in mature pine forests [24]. In any case, diversity values depend on work scale and results have to be considered merely as a reference [31].

Thinning and pruning helped increase the number of therophytes that were recorded in both localities. In those treatments where initial pine density was maintained, therophyte percentage was the lowest. Once more, the increase in light intensity and decrease in competition promote the installation of short-life plants. These results agree with those obtained by Naveh and Kutiel [28] and Wilson et al. [44]. Dominancy of therophytes during the early stages of succession after fire and their scarcity in mature stages have been observed in Mediterranean forests. Trabaud [38] noted that this pattern is favoured by an increase in light, an absence of humus and a nutrient increase in the upper soil layers. Furthermore, therophyte dynamics are related to germination mechanisms. The majority of species that appear immediately after fire have seeds whose germination capability is induced by high temperatures during fire [9, 18]. Verroios et al. [43] noted that therophytes present in young *Pinus halepensis* stands can reach 50% of all species recorded during the first two years after fire. In the present study, therophytes represented this percentage during the first two years after thinning.

In this sense, the response of short life plants is opportunistic [37]. Finally, DCA confirmed the relationship between thinned plots and therophytes.

In young *P. halepensis* stands after fire in Greece, hemicryptophyte, chamaephyte and geophyte populations are stable in comparison to data obtained before fire [43]. In this study, silviculture treatments did not significantly affect either the floristic composition of each life form or their percentage, two years after they were carried out. However, it is important to note that presence (cover) of a few species was modified after treatments. In this way, *B. retusum* presented 16% cover in scrubbed plots. This species usually increases after fire in burnt *P. halepensis* forests [31, 32, 39, 43]. This can be explained by taking into consideration its high vegetative reproduction capability. It is important to note the high presence of this species after scrubbing because of its high combustibility potential [42] and competition effects on germination of therophytes described by Pausas et al. [32].

As a conclusion to this study, in spite of the intense modification of vegetation structure just after silviculture treatments, cover and floristic richness did not vary significantly two years after they were carried out (2001). Even after scrubbing of shrub and herbaceous canopies two years after fire, their cover reached 90% in Yeste and 50% in Calasparra. Nevertheless, potential improvement in young pine stands after scrubbing has been recently questioned [15]. Other silviculture treatments such as thinning and pruning could be considered for foresters dealing with pine stands after fire improvement in Mediterranean zones, even with a semiarid climate. Decrease of intra- and inter-specific competition effects must be considered for foresters in managing of early stages of succession after fire. When it's considered both vegetation responses to culture treatments carried out in the present study and consequences on *P. halepensis* growth and cone production [15], thinning to a final density of 1 600 trees/ha must be recommended. Pine forests of SE Spain are low productive but they represent a very important ecological role to preserve diversity and prevent erosion. We think that main economic efforts in managing forests have to be done in the early stages of succession after fire because it represents lesser costs than silviculture treatments on mature pine stands and, in the other hand, this culture treatments acts as a very important tool to prevent new fires.

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