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Effects of different intensities of overstory thinning on tree growth and understory plant-species productivity in a semi-arid *Pinus halepensis* Mill. afforestation

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Abstract

It is becoming more and more common in the Mediterranean basin to guard against forest fires by creating wooded firebreak areas by reducing the overstory density, pruning the remaining trees and slash mulching. Nevertheless, very few attempts have been made to analyse the effect of this practice upon tree growth and the productivity of the understory plant species in semi-arid areas by following a well defined experimental design over any length of time. To remedy this lack of information, during the spring of 2005 we thinned the overstory in a semi-arid Aleppo pine (*Pinus halepensis* Mill.) afforestation in SE Spain (planted in the winter of 1993-1994) from an initial density of about 1,500 trees per ha according to three different thinning regimes. The annual growth data of each stand (diameter at breast height, canopy cover and basal area) were measured in randomly situated plots of 20 × 20 m and the above-ground biomass of understory plant species was also harvested from quadrats of 0.5 × 0.5 m during the early summers of 2005 to 2009. Our results showed a positive and significant response from trees in thinned stands compared to the controls, in spite of periods of low-rainfall and plague stress that unfortunately occurred during the study period. There were also statistical differences in understory biomass production within the different areas of overstory thinning as a response to the new conditions. Nevertheless, this biomass was only a small fraction of the total above-ground biomass of the afforestation, which was much higher in control plots. These tree responses and structural changes to the afforestation could be of great interest because of their implications for forest management in the context of global change in an area where increases in temperature and reductions and irregularity in precipitation, together with higher fire risks, are forecast.

Key words: wooded firebreak areas; DBH; understory biomass; SE Spain.

Resumen

Efectos de diferentes intensidades de clareo en el crecimiento arbóreo y en la productividad del sotobosque en una forestación semiárida de *Pinus halepensis* Mill.

En contraposición a las fajas cortafuegos tradicionales, cada vez es más frecuente en zonas mediterráneas la realización de áreas cortafuegos para prevenir los incendios forestales. Se suelen realizar disminuyendo la densidad de la masa mediante clareos, podas de los árboles restantes y astillado o triturado de los restos. Sin embargo, se han realizado pocas valoraciones de los efectos de esta práctica sobre los árboles remanentes y sobre la productividad de la flora autóctona del sotobosque, al menos en áreas semiáridas y siguiendo un diseño experimental bien definido y continuado en el tiempo. Para remediar esta falta de información, durante la primavera de 2005 se realizaron tres intensidades de clareo en una forestación de pino carrasco de un área semiárida del SE de la península Ibérica (plantados en 1993-1994), a partir de una densidad inicial de unos 1.500 pies/ha. Se tomaron datos del crecimiento anual de cada una de las densidades resultantes (diámetro normal, cobertura de copa y área basal) medidos en parcelas de 20 × 20 m distribuidas al azar y en las que la biomasa del sotobosque fue también cosechada en cuadrados de 0,5 × 0,5 m durante el principio del verano de 2005 a 2009. Los resultados mostraron diferentes patrones de crecimiento de los árboles y

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diferencias estadísticas en la producción vegetal bajo la cubierta de cada una de las zonas aclaradas en respuesta a las nuevas condiciones bióticas (menos competencia) y abióticas (más radiación, humedad del suelo,...) generadas. Estos resultados podrían ser de interés de cara a sus implicaciones en la gestión forestal dentro de un contexto de cambio global en un área donde se prevén incrementos de temperatura y reducción e irregularidad de las precipitaciones.

Palabras clave: áreas cortafuegos; diámetro normal; biomasa del sotobosque; SE España.

Introduction

Recent decades have seen the planting of millions of hectares of dense, monospecific reforestations and afforestations in the Mediterranean basin. Although artificial, many of these reconstituted woodlands have not only halted soil erosion but have also established suitable conditions for colonisation by various native plants and animals (Blondel and Aronson, 1995).

Fires caused by human activity are one of the most important problems encountered in the maintenance and conservation of these forests (Vélez, 2003). Traditional fire-breaks are narrow strips of land totally devoid of vegetation, but lately these are being replaced to some extent by wooded areas that serve the same function though more efficiently and at the same time in a more ecologically acceptable way (Ruiz-Mirazo *et al.,* 2007). Such firebreaks are also more aesthetically acceptable to the general public than clear-cut strips. They are created by reducing the overstory tree density, pruning the remaining trees and using the branches for slash mulching. This sort of forest management may also increase understory productivity as a side effect. In fact, it is known that thinning reduces forest transpiration (Bréda *et al.,* 1995) and increases the availability of water and nutrients to the soil, and sunlight (Aussenac and Granier, 1987; Aussenac, 2000; Misson *et al.,* 2003). Many studies have also demonstrated that a reduction in forest overstory by means of thinning or partial cutting stimulates ground-flora development because the removal of trees allows more light to reach the understory and also results in a higher availability of water and mineral nutrients for plant species (Kleintjes *et al.,* 2004; Deal, 2007; French *et al.,* 2008). Nevertheless, these activities can change the species composition of ground vegetation, at least in temperate forests (Hannertz and Hånell, 1993; Bergstedt and Milberg, 2001), although on occasions some authors have found that there was no such response whatsoever (Götmark *et al.,* 2005; Wilson and Puettmann, 2007). Thus, some researchers (Pabst and Spies, 1998; French *et al.,* 2008) indicate that site-specific factors such as pre-treatment of the vegetation cover and composition, stand heterogeneity, site quality and other geographical and edaphic factors may dictate post-treatment response patterns, and therefore silvicultural practices need to be understood in the context of site environment. Within this context, the former land-use of afforestations is also of crucial importance to the subsequent species composition (Halpern and Spies, 1995; Eycott *et al.,* 2006).

Apart from this, as far as tree-response is concerned, it is known that thinning reduces individual competition and thus should have a positive effect on tree growth. Nevertheless, this aspect of forest management has scarcely been studied in dry and semi-arid Mediterranean environments, where water availability is the major stress factor affecting tree growth (Salguero *et al.,* 2008; Vázquez-Piqué *et al.,* 2009; Martín *et al.,* 2009; Lado *et al.,* 2009).

Therefore, more information is needed concerning the effectiveness of different treatments upon the enhancement of forest productivity and the conservation of biodiversity as a basis for sound investment in silviculture, especially in Mediterranean environments. To this end, we have studied the short-term effects caused by overstory thinning upon ground vegetation and tree growth in an Aleppo-pine afforestation in south-east Spain. Within this context we approached the question as to whether these forest treatments could change the allocation pattern of above-ground biomass production of plant species and forest productivity.

Materials and methods

Study site

The experiment was conducted in the «Altiplano del Conejo» (Guadix-Baza basin, Granada), in south-east Spain (37°26’ N and 3°5’ W, at 1,100 m.a.s.l.). Mean annual precipitation is 302 mm, although it can be very irregular (see Table 1). In winter the temperature may drop to as low as –15°C and in summer it may be higher than 40°C. According to Rivas-Martínez and Loidi

Table 1. Annual precipitation (Pp) in the assay area during the study period. Data from October 1 to September 31 of the following year (agricultural period)

	2004/05	2005/06	2006/07	2007/08	2008/09
Pp, mm	167.7	267.9	331.9	204.0	369.8

(1999), the area is in the Mediterranean macroclimate, xeric-oceanic bioclimate and meso-Mediterranean semi-arid bioclimatic belt. It is flat and the topography fairly homogeneous. The soil is a petric calcisol (FAO-ISRIC, 1998) and also very homogeneous throughout the assay area, having a petrocalcic horizon with a high $CaCO_3$ content (40-60%) of between 35 and 40 cm in depth. Prolonged cultivation in the area has developed a very homogeneous soil profile with little difference between the Ap (0-25 cm) and Bw horizons (Ripoll, 2004).

Agriculture and stockbreeding have been commonly practised in the area for at least 250 years (Gámez, 1995). In 1993, however, the land was bought by the Andalucian regional government and ceased to be ploughed. In 1994-1995 an area of 1,200 ha of this degraded agrarian land was planted with Aleppo pines (*Pinus halepensis* Mill.) to a density of about 1,500 trees per ha.

Experimental design and statistical analyses

In the spring of 2005 a firebreak area about 200 m wide was cleared through about 5 ha of the afforestation by regular overstory thinning and pruning the remaining trees to form strips of land with different tree densities (treatments 1, 2 and 3). The trunks were taken away whilst the branches and leaf litter were spread out in rows (about 1 m wide) between every other rank of trees for slash mulching with a brushcutter. In the rest of the area (1,500 trees per ha) only pruning and slash mulching were carried out, using the same procedure, which we have taken as control treatment. The slash mainly consisted of needles and, to a lesser extent, fragments of branches 10-20 cm long.

After these treatments were undertaken, sixteen 20 × 20 m plots were randomly established (4 per treatment) to measure the resulting afforestation characteristics (see Table 2) and the evolution of each stand over time. Tree density (trees · ha^{-1}) was calculated by a direct count; tree canopy cover (m^2) was estimated from crown diameter, and the diameter at breast height (DBH, in cm) was measured at 1.30 m from ground level with a calliper. Basal area was calculated as a combination of the total tree cross-sectional areas [$CSA = (\pi/4) \cdot DBH^2$), in cm^2] per plot and converted into $m^2 \cdot ha^{-1}$. Above-ground biomass of the trees ($kg \cdot ha^{-1}$) was estimated from a model previously established from DBHs [dry tree biomass = $0.5981 \cdot (DBH^{1.6989})$, $R^2 = 0.9611$, $n = 32$ (unpublished data)].

We also included in each stand 27 quadrats of 0.5 × 0.5 m, using a random criterion that involved harvesting the above-ground biomass of plant species with the aid of scissors (destructive samples) without taking into account individual species. Samples were also harvested from an area devoid of trees (treatment 0). These fractions were numbered and taken to the laboratory, where they were dried for 48 h at 80°C in a forced-air oven and subsequently weighed.

Data were measured during the early summers from 2005 to 2009. Univariant analyses were carried out using STATISTIX 8 (Analytical Software®, Tallahassee, Florida, USA) (one-way ANOVA or the non-parametric Kruskal-Wallis test if homocedasticity was violated). LSD post-hoc comparison tests were carried out in the first case, and Kruskal-Wallis all-pairwise comparison tests in the second. Spearman correlation analyses were also run in the case of aboveground-biomass production of understory plant species. Graphic outputs were designed with STATISTICA 6 (StatSoft®, Tulsa, Oklahoma, USA). The α level for statistical significance was 0.05 in all cases.

Results

The overstory-thinning treatments practised during this study resulted in a significant increase in the DBH

Table 2. Characteristics of the forest stands just after the application of overstory-thinning treatments (mean ± SE). Data were measured in 20 × 20 m plots ($n = 4$) at the end of spring 2005

	Treatment 1	Treatment 2	Treatment 3	Control
No. stems per plot	13.5 ± 1.5	20.2 ± 1.8	27.2 ± 1.4	58.2 ± 5.1
No. stems per ha	337.5 ± 37.5	506.2 ± 44.9	681.2 ± 34.4	1456.2 ± 128.4

of the remaining trees compared to controls from the first year after the treatments were applied (Fig. 1). Tree growth showed a clear increase in DBH after the first vegetative period after treatment (2006) and a lesser general growth in subsequent years, probably due to lower rainfall from Oct. 2007 to Sept. 2008 (see Table 1), which coincided with a plague of pine processionary moths (*Thaumetopoea pityocampa* Den. & Schiff.) from 2007 to the end of the study. Despite these drawbacks, however, the increase in DBH in all the three treatments compared to control trees was significant in all the sampling years and remained so during the fourth year after treatment (Fig. 2).

There was also an overall increase in tree canopy cover during the first two years after treatment but with notable differences between the different treatments (Fig. 3). This increase slowed down considerably during the final two sampling years however, probably due to the drop in rainfall and the plague of processionary moths that occurred at this time. This decrease was not so evident in the basal area, however, which tended to increase linearly, at least in the first years (Fig. 4).

The above-ground biomass of plant species harvested in the afforestation understory increased significantly in all the treatments compared to the control zone throughout the four experimental years, but to different extents, depending above all upon annual rainfall (Fig. 5), especially in 2008. In spite of this, the understory plant species biomass accounted for only a small fraction of the total above-ground biomass of the afforestation (Fig. 6), which practically doubled in all treatments during the study period (including the controls).

Discussion

Our results are in accordance with the results reported by other authors (Vázquez-Piqué *et al.,* 2009; Martín *et al.,* 2009), who have found similar effects in the growth of *Pinus nigra* Arn. and *Quercus suber* L. up to five-to-six years after the thinning process.

The DBH increases we found were tending in general to reduce over time but the differences between treatments and controls persisted (Fig. 2) even with low rainfall and periods of plague.

On the other hand, during the driest period (Oct. 2007-Sept. 2008) there was a drastic decrease in biomass production of understory plant species, but in the Oct. 2008-Sept. 2009 period, when rainfall was higher than average, it increased considerably, particularly in treatments 1 and 2. This trend may be put down not only to the increase in rainfall but also to the greater

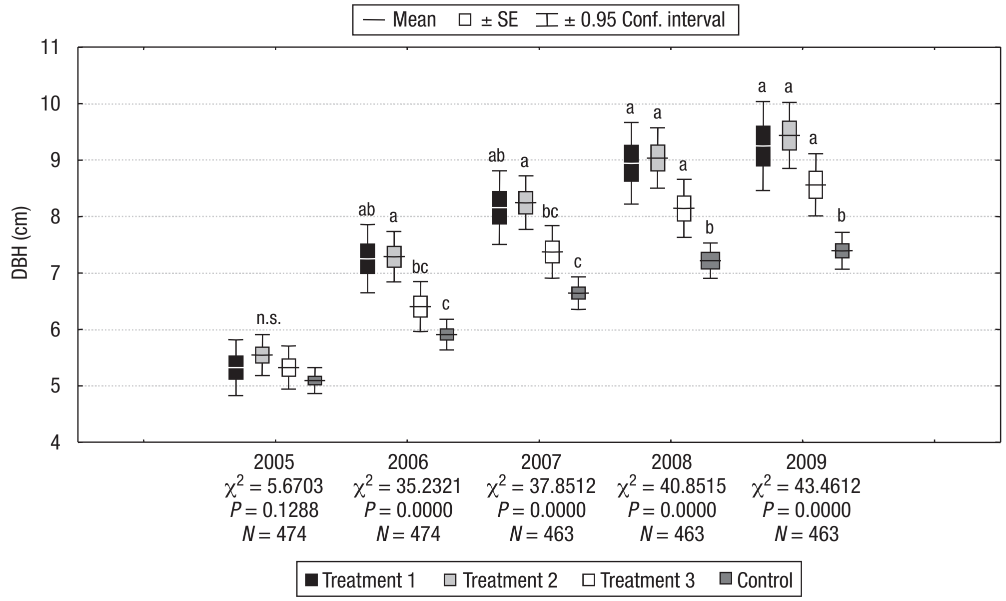

Figure 1. Development of diameter measured at breast height (DBH) during the study period taking into account different intensities of overstory-thinning treatments (see Table 2 for more details of resulting forest stands after treatment application). The different letters indicate statistical differences between treatments (n.s: not significant). The results of non-parametric Kruskal-Wallis tests are indicated below. The outliers have been left out for clarity.

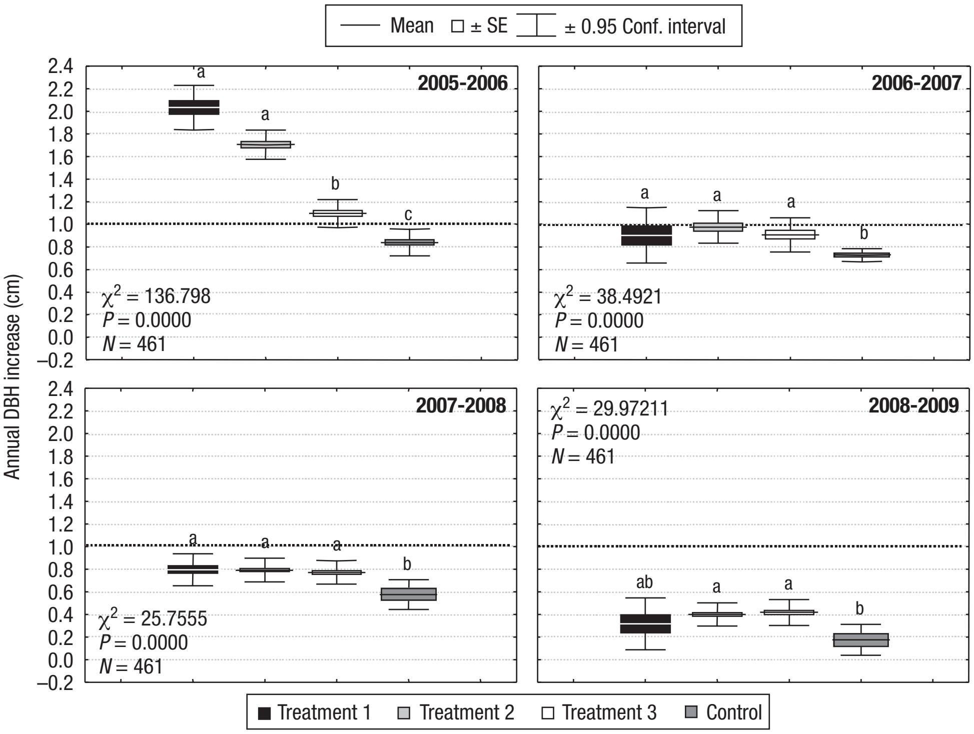

Figure 2. Evolution of the annual increase in the mean diameter at breast height (DBH) of the treatments compared to the increase in the annual mean DBH of the control treatment during the study period. The different letters indicate statistical differences between treatments. The results of non-parametric Kruskal-Wallis tests are indicated. The outliers have been left out for clarity.

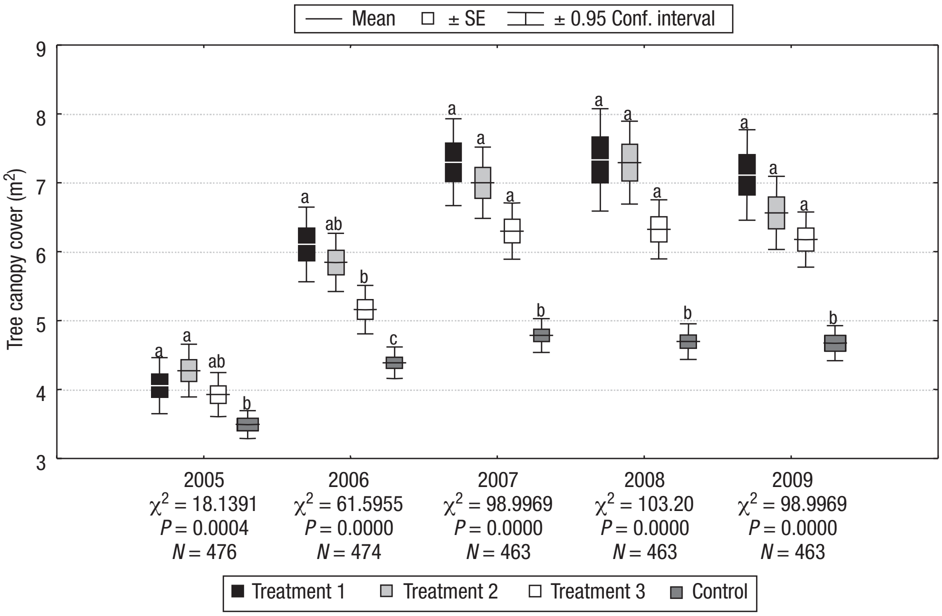

Figure 3. Evolution of the tree-canopy cover during the study period, taking into account different intensities of overstory-thinning treatments (see Table 2 for more details of resulting forest stands after treatment application). The different letters indicate statistical differences between treatments. The results of non-parametric Kruskal-Wallis tests are set out below. The outliers have been left out for clarity.

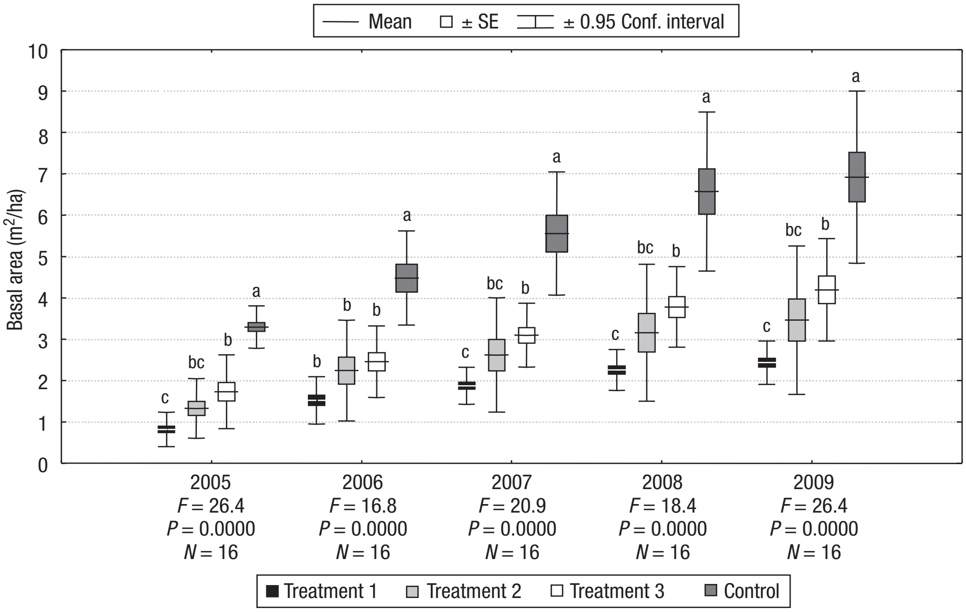

Figure 4. Evolution of the basal area during the study period, taking into account different intensities of overstory-thinning treatments (see Table 2 for more details of resulting forest stands after treatment application). The different letters indicate statistical differences between treatments. The results of one-way ANOVA tests are set out below.

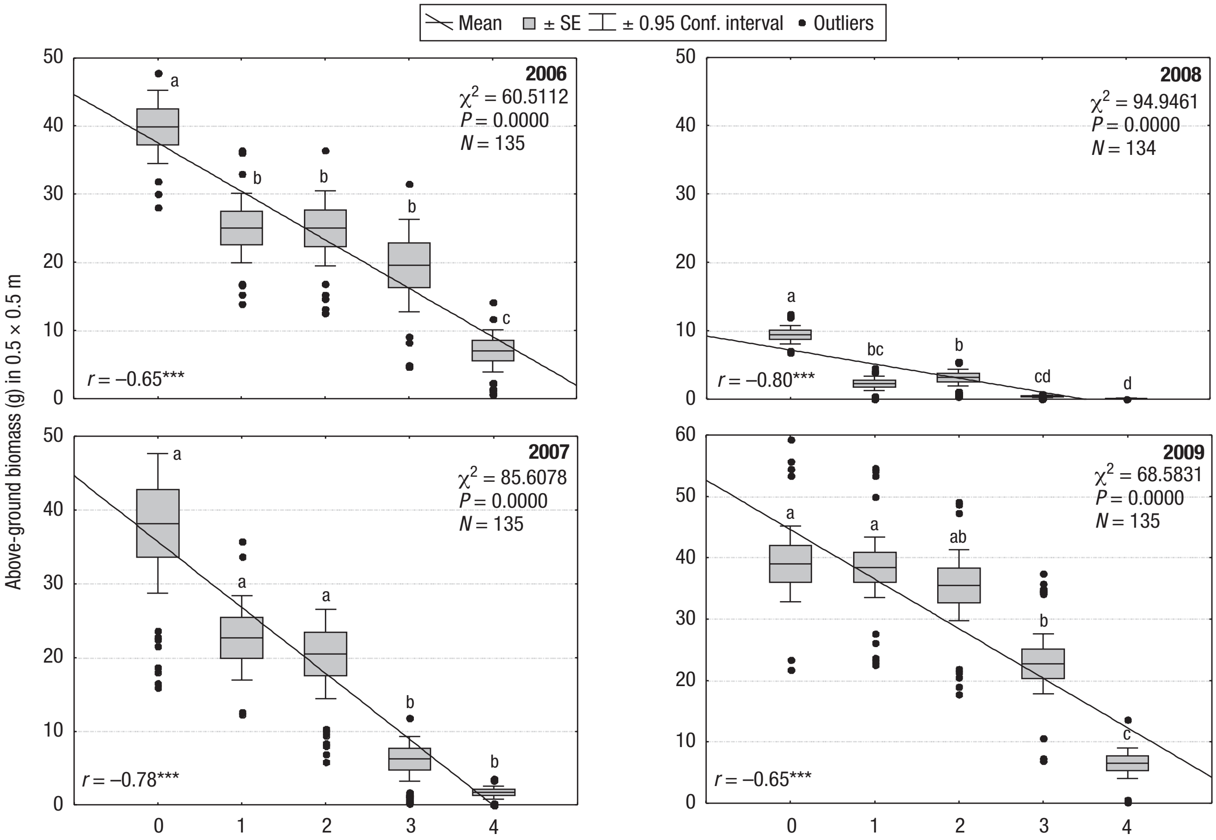

Figure 5. Above-ground biomass production of understory plant species during the study period. 4 = control treatment; 0 = area devoid of trees; 1, 2, 3 = overstory-thinning treatments (see Table 2). The different letters indicate statistical differences between treatments. The results of non-parametric Kruskal-Wallis tests are indicated. *r:* linear correlation coefficient. *** = $P < 0.001$.

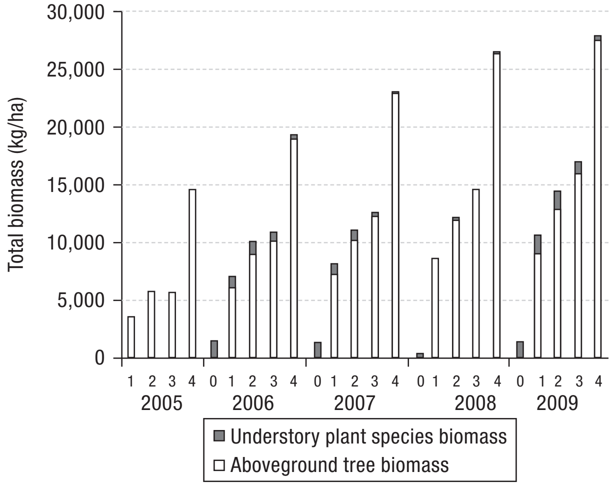

Figure 6. Evolution of the total above-ground forest biomass during the study period. 4 = control treatment; 0 = area devoid of trees; 1, 2, 3 = overstory-thinning treatments (see Table 2). Data are mean values, SE and ± 0.95 confidence intervals have been left out for clarity. Understory biomass only from 2006 ($N = 135$); aboveground tree biomass, $N = 474$ (2005, 2006) and $N = 463$ (2007, 2008, 2009).

levels of sunlight reaching the ground, the decrease in canopy interception of rainfall and/or reduction in tree transpiration losses caused by the defoliation of the trees caused by the processionary moth caterpillars,.

These results lead us to the conclusion that the overstory-thinning treatments applied had a significant effect on the development of the trees concomitantly with the intensity of the thinning (Cescatii and Piutti, 1998; Misson *et al.,* 2003). These effects were quite evident throughout the four-year sampling period, which accords with the results obtained by other researchers working with similar species and environments (Martín *et al.,* 2009). In fact, the response of the trees to the various overstory-thinning treatments applied would seem to indicate a faster and more comprehensive adaptation to stress (compared to the control treatment) caused by competition or by external factors such as low precipitation periods or plagues. This should be taken into account when planning the management of this kind of afforestation in the context of global weather changes.

The positive effects of overstory thinning on the aboveground biomass of plant species also varied according to external factors and was always a small fraction of the total above-ground biomass of the afforestation (Fig. 6).

In summary, the canopy-thinning treatments applied for the purposes of this research, especially the most intensive, resulted in an improvement in afforestation characteristics at tree-level, afforded the trees better possibilities to adapt to negative external factors such as drought and plague and favoured the productivity of understory plant species and probably plant biodiversity. Our results also suggest that thinning helps to prevent fire because we reduce the total afforestation biomass and change the structure of the control stand (in spite of an increase in understory plant species biomass, as can be seen in Fig. 6). Although this study is limited to a fire-break area, its scope could be extended to other afforestations in Mediterranean areas. These tree responses and structural changes in the afforestation could be of great interest because of their implications for forest management in the context of global change in an area where increases in temperature, reductions and irregularity in precipitation together with higher fire risk are predicted.

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