



ELSEVIER

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

Forest Ecology and Management 255 (2008) 374–382

---



---

 Forest Ecology  
and  
Management
 

---



---

[www.elsevier.com/locate/foreco](http://www.elsevier.com/locate/foreco)

Review

## Shrubland management to promote *Quercus suber* L. establishment

 Marian Pérez-Devesa<sup>b,\*</sup>, Jordi Cortina<sup>a</sup>, Alberto Vilagrosa<sup>b</sup>, Ramon Vallejo<sup>b</sup>
<sup>a</sup> *Departamento de Ecología, Universidad de Alicante, Ap. 99, 03080 Alicante, Spain*<sup>b</sup> *Fundación Centro de Estudios Ambientales del Mediterráneo (CEAM), Parque Tecnológico, C/Charles Darwin 14, 46980 Paterna, Spain*

Received 16 May 2007; received in revised form 24 September 2007; accepted 26 September 2007

---

### Abstract

Shrubs often dominate early successional stages in areas that are suitable for the establishment of forests. Under a dense shrub canopy, the density of seedlings of late successional tree species can be low, suggesting that colonisation by forest species may be hampered. In contrast, several studies have shown that positive interactions may offset the negative effects of competition when environmental conditions are limiting. We have evaluated the effect of different types of shrubland clearing and planting location on the establishment of *Quercus suber* seedlings under Mediterranean conditions. Clearing a 2-m spot around planted seedlings had a weak effect on seedling performance. Seedlings planted on highly exposed microsites showed 65% increase in survival as compared to seedlings planted in undisturbed shrubland. Seedling growth showed a similar trend. For example average stem height in seedlings planted in open sites was 39.60 cm as compared to 29.59 cm in seedlings planted on undisturbed shrubland. Increased soil water availability may be responsible for the positive effect of shrubland clearing. Seedling survival was negatively correlated with the abundance of obligate seeders such as *Cistus salviifolius*, and positively correlated with the abundance of sprouting species such as *Erica arborea* suggesting that the interaction between *Q. suber* seedlings and extant vegetation may be species dependent.

© 2007 Published by Elsevier B.V.

**Keywords:** Cork oak; Seedling establishment; Shrub management; Competition

---

### Contents

1. Introduction . . . . .	375
2. Materials and methods . . . . .	375
2.1. Study area and plot characterization . . . . .	375
2.2. Experimental setup . . . . .	375
2.3. Plant cover . . . . .	376
2.4. Microclimatic conditions . . . . .	376
2.5. Seedling performance . . . . .	376
2.6. Data analysis . . . . .	377
3. Results . . . . .	377
3.1. Site properties . . . . .	377
3.2. Seedling performance . . . . .	377
4. Discussion . . . . .	378
4.1. Seedling response to clearing . . . . .	378
4.2. Interactions with extant vegetation . . . . .	379
4.3. Management considerations . . . . .	380
Acknowledgements . . . . .	381
References . . . . .	381

---

\* Corresponding author.

E-mail address: [marian.perez@ua.es](mailto:marian.perez@ua.es) (M. Pérez-Devesa).

## 1. Introduction

Shrubs often dominate successional stages in areas that are suitable for the establishment of forests (Cabezas and Escudero, 1992; Torres, 2003). Dense shrub layers may hamper the establishment of forest species (Sans et al., 1998; Chambers et al., 1999; Castro et al., 2002). The restoration of forested ecosystems in these areas may require to reset succession (Cortina et al., 2006), by reducing shrub dominance and reintroducing forest species. In environments subjected to environmental stress, however, seedling establishment may be favoured by the microenvironment created by extant vegetation (Callaway, 1995, 1998; Gómez-Aparicio et al., 2005; but see discussion on this topic in Maestre et al., 2005).

The surface area covered by oak forest have declined in Europe and North America (Standiford, 2002; Kelly, 2002; Pulido, 2002). Concerns on the future of cork oak forest has fostered vast restoration programmes in recent years (Berrahmouni et al., 2005). In addition to the large-scale reduction in surface area, oaks frequently show poor recruitment (Torres, 2003; Serrada-Hierro, 2003), compromising the persistence of existing forests, and limiting its potential to colonize new areas. Failure to establish may result from various causes, including herbivory, and competition from grasses and shrubs (Dickie et al., 2007).

*Quercus suber* L. woodlands cover almost  $2 \times 10^4$  km<sup>2</sup> in the western Mediterranean Basin (Benzzyane, 1996). They are highly valued for economic, social and ecological reasons, including *Q. suber* capacity to resprout after fire (Campos-Palacín, 1992; Benseghir, 1995; Pausas et al., 2004). In the eastern Iberian Peninsula *Q. suber* woodlands are scarce. This is partly due to the increased recurrence of wildfires, historical preference for other species, particularly *Quercus ilex* (Serrada-Hierro, 2003), limitations on *Q. suber* establishment, and lack of suitable soils (Pons and Pausas, 2006). Climatic trends may have further reduced the surface area covered by *Q. suber* woodlands (Carrión et al., 2000). Recent studies suggest that the *Q. suber* woodland area in the Region of Valencia (E Spain) could potentially duplicate if only climatic and lithological constraints were taken into account (Pausas et al., 2004).

Dense shrublands commonly dominate early secondary succession stages after agricultural abandonment and wildfires, in areas that may be suitable for *Q. suber* (Cabezas and Escudero, 1992; Torres, 2003). The density of *Q. suber* seedlings is commonly low under a dense shrub cover (Pons and Pausas, 2006). The reasons for this may be numerous, including lower dispersion, higher rodent predation, interference with extant vegetation, and unfavourable climatic conditions for seedling establishment (Natividade, 1991; Hasnaoui, 1996; Pons and Pausas, 2006).

Whether *Q. suber* establishment may be favoured by shrubland clearing or not, has been the subject of debate. Shrubland clearing and eventually uprooting, has been recommended to foster the establishment of this species (Natividade, 1991; Lepoutre, 1965; Montero and Cañellas, 1999). However, the performance of Mediterranean *Quercus* seedlings close to *Q. suber* may be improved by shading (Rey-

Benayas, 1998; Retana et al., 1999). In Mediterranean areas, the positive effect of shading can be strong enough to compensate for the negative effects of competition with neighbouring vegetation. Shade has been identified as a major driver of positive plant–plant interactions in these areas (Castro et al., 2002; Maestre et al., 2003; Cortina and Maestre, 2005). Facilitative interactions could explain reports on negative effects of shrubland clearing on the establishment of *Q. suber* seedlings (Santilli, 1998). To our knowledge, no studies have evaluated the effect of different intensities of shrubland clearing on the establishment of *Q. suber*.

We evaluate the effect of different types of shrubland clearing and planting location on the establishment of *Q. suber* seedlings, and discuss the results on the basis of the interactions between planted *Q. suber* seedlings and extant vegetation. At a management level, results provide relevant information to generate recommendations on the best practices to favour *Q. suber* establishment in these areas.

## 2. Materials and methods

### 2.1. Study area and plot characterization

The experimental sites are located in Serra d'Espadà (Chóvar, Castelló, E Spain; Table 1). The area was burnt in 1991. Climate is dry sub-humid thermo Mediterranean, average annual rainfall is 495 mm, and average temperature is 15.2 °C. The three sites are on sandy soils developed from Triassic sandstone, and are similar in previous land use, slope, altitude and other physiographic and edaphic features (Table 1). We selected three dense shrublands (>70% shrub cover) facing SE to SW with no signs of spontaneous *Q. suber* regeneration despite the proximity of *Q. suber* adult individuals. The main shrub species present are the obligate seeders *Cistus monspeliensis* L., *Cistus salvifolius* L., *Rosmarinus officinalis* L., and *Ulex parviflorus* Pourr. (average cover 35.66%), and the resprouters *Erica arborea* L., *Calycotome spinosa* L., and *Daphne gnidium* L. (average cover 29.35%). In addition to differences in reproductive strategy, obligate seeders are characterized by shallow rooting systems which can be highly competitive against planted seedlings. In contrast, sprouter species are characterized by a deep rooting system allowing water extraction from deep soil horizons during drought (Canadell and Zedler, 1995).

In July 2003 we sampled the 0–20 cm depth soil under undisturbed shrubland in four randomly selected points per plot. After sieving through a 2-mm mesh, we determined total N content (Kjeldahl method, Bremner and Mulvaney, 1982), organic C and organic matter content (Walkley–Black method, Nelson and Sommers, 1982), total carbonate content (Bernard calcimeter method, Nelson, 1982), soil particle distribution (Robinson's pipette method, SSEW, 1982), and exchangeable cations (BaCl-TEA extraction method; Page et al., 1982).

### 2.2. Experimental setup

In February 2003, we established one 50 m × 50 m experimental plot in each site (ESP1, ESP2 and ESP3,

Table 1  
Main features of the experimental plots

	Plot 1	Plot 2	Plot 3
Location (UTM)	728,700–4,416,100	727,750–4,417,100	728,150–4,415,700
Altitude (m asl)	544	660	603
Orientation	200° SW	220° SW	170° SE
Slope	20°	40°	35°
Soil depth (cm)	>50	>50	>50
Rock fragments (%)	30 ± 14a	33 ± 12a	34 ± 11a
pH (H <sub>2</sub> O)	5.87 ± 0.15a	6.26 ± 0.24a	6.38 ± 0.26a
CaCO <sub>3</sub> equivalent (%)	<0.1	<0.1	<0.1
TKN (%)	0.1 ± 0.0a	0.2 ± 0.0a	0.1 ± 0.0a
TOC (%)	2.3 ± 0.6a	2.9 ± 0.5a	1.9 ± 0.2a
C:N	16.9 ± 1.3b	12.7 ± 0.2a	13.5 ± 0.1a
Ca (cmol + kg <sup>-1</sup> )	5.28 ± 0.88a	12.36 ± 2.23b	5.82 ± 0.61a
Mg (cmol + kg <sup>-1</sup> )	1.39 ± 0.13a	1.65 ± 0.16a	1.32 ± 0.04a
Na (cmol + kg <sup>-1</sup> )	0.07 ± 0.01a	0.05 ± 0.01a	0.06 ± 0.01a
K (cmol + kg <sup>-1</sup> )	0.26 ± 0.07a	0.27 ± 0.05a	0.23 ± 0.05a
Sand (%)	51 ± 1b	37 ± 3a	40 ± 3a
Silt (%)	38 ± 1a	41 ± 2a	38 ± 3a
Clay (%)	11 ± 1a	23 ± 1b	21 ± 1b
Texture class	Loam	Loam	Loam

Rock fragments correspond to the average and standard errors of the volume of rock fragments in the 0–40 cm depth layer. Physico-chemical soil properties are averages and standard errors of four 0–20 cm depth samples per plot. TKN, TOC and Ca, Mg, Na and K, correspond to total Kjeldahl nitrogen, total organic carbon and exchangeable calcium, magnesium, sodium and potassium, respectively.

thereafter). In each plot, we cleared three 5-m wide 30-m long shrubland strips perpendicular to the main slope, leaving alternate undisturbed strips of the same width. In addition, we cleared 2-m diameter spots in undisturbed shrubland areas. In both cases slash was crushed and spread throughout the cleared area. In March 2003 we planted 1-year-old *Q. suber* seedlings in 40 cm × 40 cm × 40 cm manually dug planting holes. Seedlings were located in undisturbed shrubland (thereafter referred as CONT), in cleared spots (SPOT), and in the upslope, midslope and downslope sections of the cleared strips (USTRI, MSTR1 and LSTR1, respectively). The number of replicates per treatment was 40, 360 seedlings per plot and 1080 seedlings for the whole experiment. Seedlings were produced in a nearby public nursery (El Toro, Conselleria de Territori i Habitatge, Generalitat Valenciana) from locally collected acorns. They were grown on equal proportions of peat, coco-peat, mineral soil, vermiculite and forest litter in 330 cm<sup>3</sup> forest containers for 1 year.

### 2.3. Plant cover

We evaluated total plant cover and species cover in a 2-m diameter circle around control seedlings in plot ESP1. We divided each circle in six sectors and determined the percentage cover of each species and bare soil visually in each sector. We then averaged the values for the whole circle.

### 2.4. Microclimatic conditions

Soil moisture and temperature were measured for all treatments by using time-domain reflectometry (TDR 100, Campbell Scientific Ltd., Loughborough, UK; Topp and Davis, 1985), and diodes, respectively. We installed 0–20-cm depth

TDR probes and 5-cm depth diodes in 10 randomly selected planting holes per treatment in plot ESP1. Measurements were taken monthly during the first summer, and seasonally in winter and spring 2004. Diodes were calibrated in laboratory with a thermostatic bath to obtain the slope between voltmeter measures and temperature values.

Measurements of the photosynthetic photon flux density (PPFD) were carried out during clear days in the first and second summer after outplanting. Measurements were taken every 2 h in 10 randomly selected seedlings per treatment between 5:00 and 17:00 h solar time by using a sunfleck ceptometer (Decagon Devices Inc., Pulman, WA, USA). The probe was placed at 20 cm height representing the average stem height of planted seedlings.

### 2.5. Seedling performance

We used seedling survival and growth and chlorophyll fluorescence to evaluate seedling response to the experimental treatments. We recorded seedling survival before and after the first and second summer, and after the third summer in the field. We measured root collar diameter and stem height on the same dates. In order to evaluate the ecophysiological status of introduced seedlings, we measured maximum photochemical efficiency (Fv/Fm) at predawn and at midday in five randomly selected seedlings per treatment in plot ESP1 by using a portable fluorometer (PAM-2000, Waltz Inst., Effeltrich, Germany). Predawn and midday measurements of maximal (Fm) and minimal (F0) fluorescence were used to calculate the maximum efficiency of the photosynthetic energy conversion of PSII (Fv/Fm = [Fm – F0]/Fm), where Fv is the variable fluorescence (Genty et al., 1989). Fv/Fm measures were taken every 3 months during the first year after planting.

2.6. Data analysis

Log-linear analysis was used to test the effect of plot and shrub management on seedling survival. Survival was analyzed separately for each sampling period. The relation between plant cover and seedling mortality was analyzed by using log-linear analysis, in a two-way table (survival, plant cover class). Stem height, root collar diameter and chlorophyll fluorescence were analyzed by using a general linear mixed model, with plot as a random factor, and treatment as a fixed factor. Soil moisture, soil temperature and PPFD were analyzed by using a general linear mixed model for each sampling date, with treatment as a fixed factor. Data transformations were performed when necessary to ensure the validity of the assumption of homoscedasticity. We performed Student–Newman–Keuls post-hoc test when fixed factors showed a significant effect. Statistical analyses were conducted by using the statistical package SPSS 11.0 (SPSS Inc., Chicago, Illinois, USA).

3. Results

3.1. Site properties

Soils in the three experimental plots were loamy and decarbonated. The pH values ranged from  $5.9 \pm 0.15$  to  $6.4 \pm 0.26$ , and thus they were within the highest range for this species (Serrasolses et al., in press). Shrubland clearing increased soil moisture content in plot ESP1 before (July 2003), and after (February and April 2004) summer drought (Table 2). In July 2003, the reduction in soil moisture in control seedlings versus seedlings planted in the middle of cleared strips (MSTRI) was 67%. As summer drought developed, differences in soil moisture content were reduced.

Shrub cover significantly reduced radiation, with daily reductions of 30% in control seedlings of plot ESP1 as compared to MSTRI seedlings ( $P < 0.001$ , Fig. 1). No differences were found between MSTRI and SPOT seedlings. Soil temperature at 5 cm depth showed no treatment effect, despite the differences in soil water content and incoming radiation (data not shown).

3.2. Seedling performance

Shrub clearing had a significant effect on seedling survival and growth. The highest mortality occurred during the first

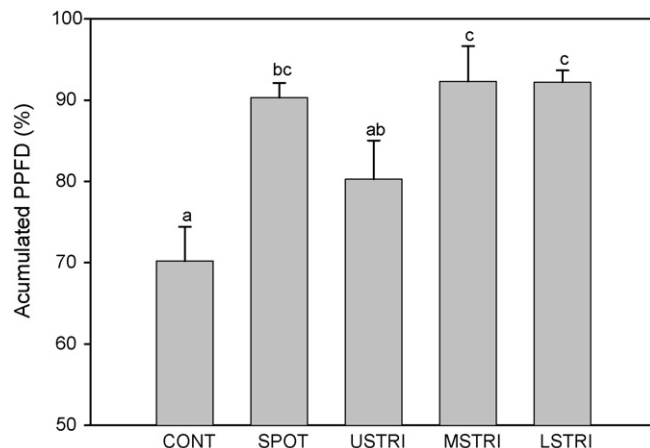


Fig. 1. Accumulated daily photosynthetic photon flux density (PPFD:  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) as a percentage of PPFD in open areas, measured in July 2003 (4 months after plantation). Each point represents the average  $\pm 1$  S.E. of 10 seedlings per treatment. Different letters indicate significant differences (SNK post-hoc test at  $P < 0.05$ ).

summer, when 59% of the control seedlings died (Fig. 2). Mortality did not change substantially afterwards. Thus, maximum and minimum recorded values of plant survival after three growing seasons were 40% and 62% in CONT and MSTRI seedlings, respectively.

Plots had a significant effect on seedling survival ( $\chi^2 = 32.495$ ,  $P = 0.0001$ ,  $\chi^2 = 88.73$ ,  $P = 0.0001$  and  $\chi^2 = 26.33$ ,  $P = 0.0001$ , for the first, second and third autumns after planting, respectively). The effect of shrubland clearing on seedling survival was evident by the end of the first summer and maintained afterwards ( $\chi^2 = 46.45$ ,  $P = 0.0001$ ,  $\chi^2 = 15.62$ ,  $P = 0.0001$  and  $\chi^2 = 23.82$ ,  $P = 0.0001$  for the first, second and third autumns after planting, respectively; Fig. 2). Seedlings planted on the cleared strip microsites (USTRI and MSTRI) showed the highest survival rates, whereas seedlings planted under the canopy of undisturbed vegetation (CONT), and in the lower part of cleared strips (LSTRI), showed the lowest. Interestingly, seedlings planted in the lower and upper part of cleared strips showed contrasted results throughout the period of study. We found no significant Plot  $\times$  Treatment effect on seedling survival.

Stem height was affected by the treatments ( $F_{4,89} = 2.088$ ,  $P = 0.037$ , power = 0.882,  $F_{4,31} = 9.137$ ,  $P = 0.001$ , power

Table 2  
Effect of shrub clearing on gravimetric 0–20 cm soil moisture content (%)

Treatment	July 2003	August 2003	September 2003	February 2004	April 2004
Soil moisture (% v/v)					
CONT	$2.28 \pm 0.32a$	$5.23 \pm 0.35a$	$10.27 \pm 0.11a$	$9.69 \pm 0.08a$	$13.48 \pm 0.57a$
SPOT	$2.68 \pm 0.27a$	$5.81 \pm 0.34a$	$11.94 \pm 0.10a$	$9.70 \pm 0.07a$	$15.88 \pm 0.32b$
USTRI	$4.50 \pm 0.75a$	$5.75 \pm 0.23a$	$11.08 \pm 0.07a$	$10.03 \pm 0.08b$	$13.50 \pm 0.27a$
MSTRI	$6.84 \pm 0.85b$	$6.21 \pm 0.15a$	$11.92 \pm 0.04a$	$10.16 \pm 0.09b$	$17.04 \pm 0.34b$
LSTRI	$4.10 \pm 0.63a$	$5.74 \pm 0.31a$	$10.68 \pm 0.09a$	$9.94 \pm 0.08ab$	$13.90 \pm 0.39ab$
F	8.62	1.22	0.85	11.36	16.58
P	<0.01	0.311	0.501	<0.01	<0.01

Values are means  $\pm$  S.E. of  $N = 10$  replicates per treatment. Different letters for each sampling date indicate significant differences at  $P < 0.05$ .

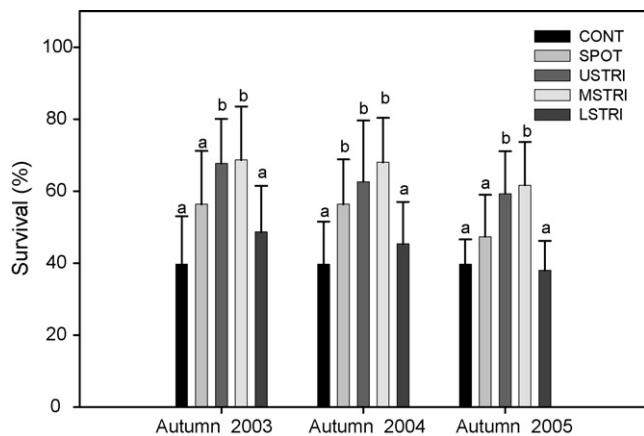


Fig. 2. Survival of *Quercus suber* seedlings after the first, second and third summer after planting. Bars correspond to average and standard errors of  $N = 3$  replicated plots. Letters indicate significant differences for a given date at  $P < 0.05$  (SNK test).

= 0.999 and  $F_{4,12} = 2.393$ ,  $P = 0.016$ , power = 0.0926 for the measurements performed in autumn 2003, 2004 and 2005, respectively), but only MSTRI seedlings showed a consistent difference with other seedlings (Fig. 3A). In autumn 2005, MSTRI seedlings showed the highest values (39.6 cm), and CONT seedlings showed the lowest (29.59 cm). Plot and the interaction Plot  $\times$  Treatment had no significant effect on stem height. In contrast, differences in root collar diameter were similar to those observed for seedling survival, with MSTRI seedlings showing the highest diameter, and CONT seedlings showing the lowest from the first summer on ( $F_{4,95} = 3.125$ ,  $P = 0.048$ , power = 0.882,  $F_{4,32} = 3.884$ ,  $P = 0.004$ , power = 0.862,  $F_{4,95} = 5.181$ ,  $P = 0.001$ , power = 0.998 for measurements performed in autumn 2003–2005; Fig. 3B). Root collar diameter was significantly affected by plots in 2004 and 2005 ( $F_{2,32} = 5.002$ ,  $P = 0.038$ , power = 0.931 and  $F_{2,95} = 11.460$ ,  $P = 0.04$ , power = 0.986, respectively), and the interaction Plot  $\times$  Treatment was significant in 2004 ( $F_{8,32} = 2.225$ ,  $P = 0.026$ , power = 0.911). By the end of the 3-year study, MSTRI seedlings were almost 10 cm taller, and had a root collar 3.7 mm thicker than CONT seedlings. The ratio of stem height to root collar diameter (slenderness ratio) was higher in CONT

seedlings ( $7.1 \pm 0.20$ ), and lower in MSTRI seedlings ( $6.2 \pm 0.25$ ), particularly during the first year after planting. Later, differences gradually decreased. In autumn 2005, MSTRI seedlings showed the lowest slenderness ratio ( $5.0 \pm 0.20$ ), and CONT seedlings showed the highest values ( $6.0 \pm 0.26$ ) (data not shown).

Maximum photochemical efficiency (Fv/Fm) showed higher levels of stress in CONT seedlings during both summer campaigns at predawn (0.43 and 0.67, respectively) ( $F_{4,21} = 3.6$ ,  $P = 0.020$ , power = 0.793 and  $F_{4,20} = 2.6$ ,  $P = 0.047$ , power = 0.620 for July 2003 and 2004, respectively) and at midday (0.35 and 0.58, respectively) ( $F_{4,21} = 4.3$ ,  $P = 0.011$ , power = 0.856 and  $F_{4,20} = 5.6$ ,  $P = 0.003$ , power = 0.939 for July 2003 and 2004, respectively; Fig. 4). In October 2003 and March 2004 no treatment effect was found ( $P > 0.05$ ).

Seedling survival was related to shrubland species composition (Fig. 5). We found a positive relationship between the cover of total resprouting species and seedling survival ( $\chi^2 = 9.00$ ,  $P = 0.02$ ; Fig. 5). The cover of total obligate seeder species was not significantly related to seedling survival, but we found a trend towards lower survival the higher cover of the obligate seeders ( $\chi^2 = 5.99$ ,  $P = 0.112$ ). Seedling survival was directly related to *E. arborea* cover (resprouter species;  $\chi^2 = 9.485$ ,  $P = 0.008$ ), and inversely related to *C. salviifolius* cover (an obligate seeder species;  $\chi^2 = 8.524$ ,  $P = 0.014$ ).

#### 4. Discussion

##### 4.1. Seedling response to clearing

Previous studies on optimum shrubland management to promote *Q. suber* regeneration have shown contrasted results (Natividade, 1991; Bendaanoun, 1998; Santilli, 1998; Cañellas et al., 2003). However, most of these are based on observations and not in manipulative experiments. The results of the present study show that introduction of *Q. suber* seedlings in dense shrublands can be favoured by clearing. Seedling survival and growth were higher when the effect of shrubland clearing was more intense (i.e. in MSTRI seedlings). After 3 years, MSTRI seedlings showed 65% increase in survival as compared to

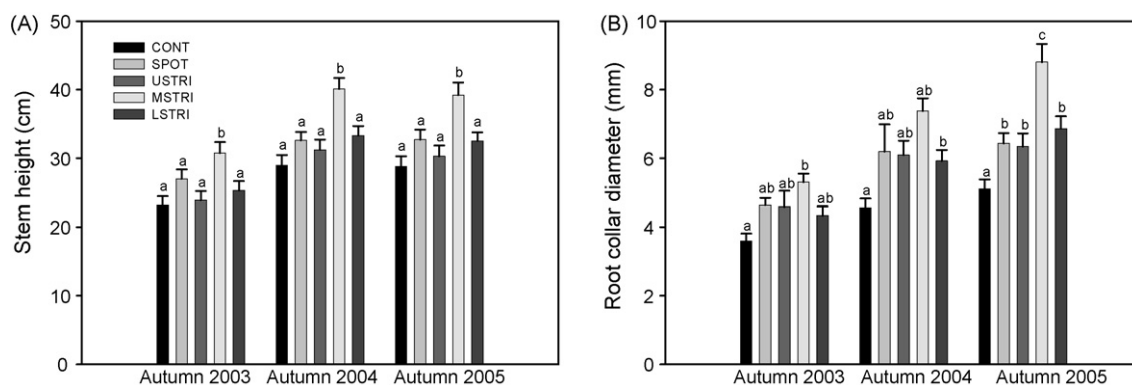


Fig. 3. Changes in stem height (A) and root collar diameter (B) of *Q. suber* seedlings throughout the 3-year experimental period after planting. Bars correspond to average and standard errors of  $N = 120$  replicated seedlings. Letters indicate significant differences for a given date at  $P < 0.05$  (SNK test).

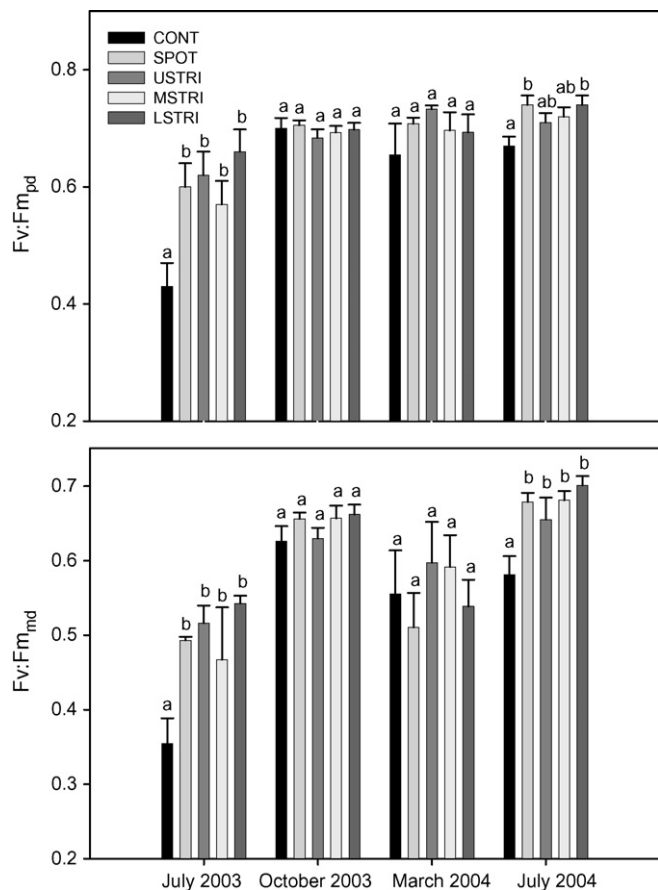


Fig. 4. Maximal photochemical efficiency (Fv:Fm) at predawn (upper) and midday (lower) in leaves of *Q. suber* seedlings as affected by different shrubland management techniques. Bars are averages and standard errors of  $N = 5$  seedlings per treatment. Different letters indicate significant differences for each sampling date (SNK test at  $P < 0.05$ ).

CONT seedlings. Seedling growth followed a similar trend in height and stem diameter with the highest values for MSTR and the lowest for CONT seedlings. Maximal photochemical efficiency also showed higher doses of stress in control seedlings than other treatments during summer months. Our results are in agreement with studies showing that seedling establishment in Mediterranean areas can be favoured by shrubland clearing, as shrubs may compete with introduced seedlings for resources, particularly water and light (Löf et al., 2006; Pemán and Navarro, 1998; Montero and Cañellas, 1999).

Increased water availability may be responsible for the positive effect of shrubland clearing. Indeed, soil water content was higher in the MSTR microsites of plot ESP1 during key periods. Runoff concentration in the planting holes of cleared areas, and control of evaporation rates by clearing slash may have contributed to the observed increase in water availability. However, substantial differences in the performance of seedlings planted on the upper part of the cleared strip and those planted on undisturbed shrubland were not matched by differences in microclimate, suggesting that other factors, probably belowground competition, may be major drivers of seedling survival and growth. Valdecantos (2001) has shown that native shrubs may quickly colonize plantation holes under

Mediterranean dry sub-humid conditions. Competition for water may be more intense in dense shrublands than in degraded shrublands, where shrubs are sparse and the amount of soil volume available for each plant is higher (Vilà and Sardans, 1999). In addition, root systems of shrubs and trees growing on slopes tend to develop upslope to improve resource capture, and ensure plant anchorage (Kummerow, 1981; Di Lorio et al., 2005; Mattia et al., 2005). Seedlings in the lower part of the strip (LSTRI) may experience more intense competition than those planted on the upper and middle parts. This may explain why the survival of LSTR seedlings was lower than that of USTR seedlings. Uprooting extant vegetation has been recommended to avoid belowground competition, and improve *Q. suber* plantation success (Natividade, 1991). In contrast with this affirmation, Gómez-Aparicio et al. (2005) showed that shrubs facilitate early recruitment of *Q. ilex* seedlings in the Mediterranean mountains. Our results show that the control of aboveground competition, and resulting decrease in belowground competition as resource demands of cleared vegetation decrease, substantially improve seedling performance while avoiding the intense disturbance associated with complete shrub removal.

Shading has proven beneficial for the establishment of several oak species (Rey-Benayas, 1998; Gómez-Aparicio et al., 2005; Puerta-Piñero et al., 2007). However, drought under shade may be more stressful than in open areas (Valladares and Pearcy, 2002; Valladares et al., 2004a; Sánchez-Gómez et al., 2006). Experiments with treeshelters suggest that shade does not improve the short-term survival of *Q. suber* seedlings under gentle conditions (Oliet et al., 2003). Thus, shade probably played a minor, or even negative role, in the balance between positive and negative interactions between *Q. suber* seedlings and neighbouring vegetation in the undisturbed shrubland. Shade may be, however, responsible for the high slenderness ratio in control seedlings, a response that has been observed in *Q. suber* seedlings protected with treeshelters (Oliet et al., 2003). Low red to far-red ratios in environments created by neighbouring vegetation promote stem elongation, and reduce biomass allocation belowground (Ballare et al., 1990; Murphy and Dudley, 2007). It is worth to mention that clearing a 2-m diameter spot around planted seedlings increased incoming radiation, but had almost no effect on soil moisture. The effects of spot clearing on seedling performance were weak, and thus, they do not justify the use of this relatively affordable and conservative practice.

#### 4.2. Interactions with extant vegetation

The three plots studied were relatively uniform in soil properties, orientation, and previous land use. But still, we found substantial differences in seedling performance. Small differences in topography and, particularly, dominant shrub species may be responsible for the differences observed. Thus, despite that the three plots shared a common vegetation composition, including the widespread presence of *C. salviifolius* and *U. parviflorus*, the presence of *E. arborea* and *R. officinalis* in plot ESP1 was higher than in the other plots

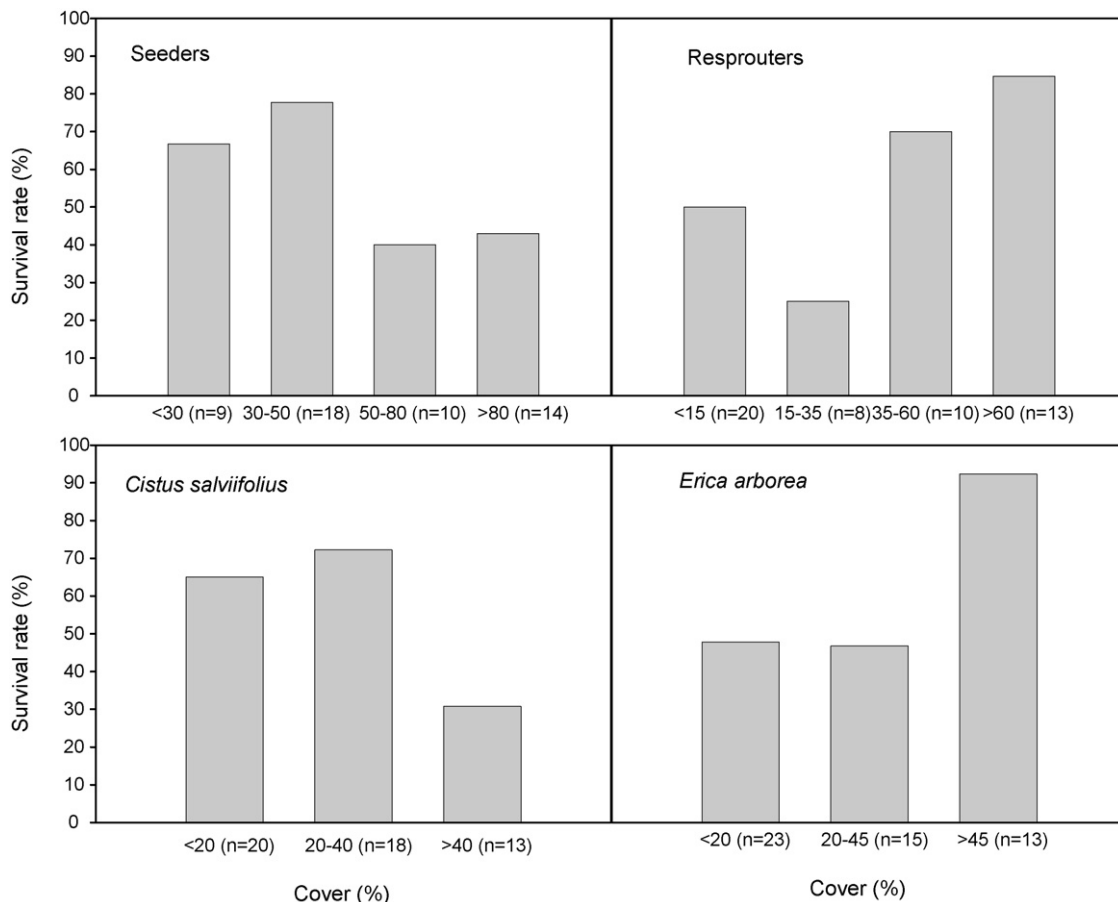


Fig. 5. Effect of the cover of neighbouring resprouting shrubs (upper left), obligate seeders (upper right), *Erica arborea* (lower left), and *Cistus salviifolius* (lower right) on the survival of *Q. suber* seedlings 1 growing season after planting in Serra d'Espadà (E Spain). The numbers of seedlings corresponding to each shrub cover class are shown in parenthesis.

(data not shown). Plot ESP2 was dominated by *C. spinosa*. And the presence of sprouting shrubs was lower in plot ESP3 than in the previous plots. Our results show that *Q. suber* survival was negatively correlated with the abundance of obligate seeders such as *C. salviifolius*, and positively correlated with the abundance of sprouting species such as *E. arborea*. The positive effect of *E. arborea* on *Q. suber* recruitment has been observed in other environments (Santilli, 1998). In contrast, Natividade (1991) observed that spontaneous *Q. suber* regeneration was higher under shrublands dominated by rockroses (*Cistus* spp.) than under other vegetation types. *Q. suber* regeneration may be fostered by species such as *Phyllirea* spp., *Pistacia lentiscus*, *Arbutus unedo*, *Crataegus monogyna*, *Viburnum* spp., *Ruscus aculeatus*, *Prunus* spp. and *Chamaerops humilis* (Beaucorps et al., 1956; Natividade, 1991). Obligate seeders display physiological characteristics that have been associated with high tolerance to water stress (Kolb and Davis, 1994; Davis et al., 1999). The opposite has been suggested for sprouters (Kolb and Davis, 1994; Davis et al., 1999), although exceptions exist (Vilagrosa et al., 2003; Valladares et al., 2004b). Species of the genus *Cistus* may be particularly well fitted to extract water from drying soils (Torrecillas et al., 2003), and their litter may contain allelopathic substances (Chaves and Escudero, 1997; Robles et al., 1999) Thus, differences in rooting habit and

physiological characteristics could explain the lower intensity of competition between sprouters, with a deep rooting systems, and planted *Q. suber* seedlings. Rooting habit may affect the strength of competition, but generalizations appear elusive (Vilà and Sardans, 1999).

#### 4.3. Management considerations

According to our results, the success of *Q. suber* plantations in dense shrublands can be greatly improved by strip clearing. Considering that the costs of clearing may range between 900 and 1250 €/ha (Mulet, 2003), and an estimated cost of planting (including seedlings) of 2500€, clearing may increase planting costs by 26–33%. These are conservative estimates, as clearing facilitates access to planting spots, and may thus reduce the costs of soil preparation and planting. In addition, the disturbance caused by strip clearing is relative low as compared to other site preparation techniques such as clearing of whole planting areas, complete shrub removal, tillage and subsoiling. Finally, the spatial heterogeneity generated by discontinuous clearing may promote biodiversity (WWF, 2006).

By clearing the shrubland we were able to increase the survival of *Q. suber* seedlings after 3 years in the field by 65%, and root collar diameter by 80%. Our results suggest that using

properly designed site preparation techniques, plantation success can be greatly improved. According to our results, clearing can be recommended to foster the establishment of *Q. suber* seedlings in dense shrublands. Cleared strips 3–5 m wide may be used, with seedlings preferentially planted in open areas. Our results would support the hypothesis that below-ground competition affects seedling performance more than light competition.

### Acknowledgements

This study has been funded by the Government of the Region of Valencia (*Generalitat Valenciana*), *Fundación Bancaixa*, CREOAK European project (QLRT-2001-01594) and the SUROS Spanish project (REN2002-11326-E). CEAM Foundation is funded by Generalitat Valenciana and Fundació Bancaixa. We are grateful to Roman Trubat, Amina Gobbi, Tadas Bitinas, Pep Pons, Adolfo Miravet and Oret Subericultura S.A. for their help. JC acknowledges support from Secretaría de Estado de Universidades e Investigación, Ministerio de Educación y Ciencia (Programa Nacional de Ayudas para la Movilidad), and thanks the Ecological Restoration Institute and the School of Forestry at Northern Arizona University for their kind hospitality.

### References

- Ballare, C.L., Scopel, A.L., Sanchez, R.A., 1990. Far-red radiation reflected from adjacent leaves: an early signal of competition in plant canopies. *Science* 247, 329–332.
- Beaucorps, G., Marion, J., Sauvage, Ch., 1956. Essai monographique sur une parcelle d'expériences dans la forêt de chêne-liège de la Mamora (Maroc). *Annales Recherches Forestières au Maroc* 4, 273.
- Bendaanoun, M., 1998. Contribution à l'étude des facteurs écologiques de l'impact de la dégradation et des aménagements sur la régénération des subéraies du Rif, du Moyen Atlas Oriental et de la Mamora (Maroc Septentrional). Actes du séminaire Méditerranéen sur la régénération des forêts de chêne-liège. *Annales de l'INGREF, Tabarka*, pp. 176–197.
- Benseghir, L., 1995. Amélioration des techniques de production hors-sol de Chêne-Liège: conteneurs, substrats, nutrition minérale. *Mastère en Sciences Forestières. Ecole National du Genie Rural, des Eaux et des Forêts.*
- Benzyane, M., 1996. La suberaie marocaine produit économique et social a developper. Actes du Séminaire Méditerranéen sur la Régénération des Forêts de Chêne-Liège. *Annales de l'INRGRF, Tabarka*, pp. 12–21.
- Berrahmouni, N., Gómez, R., Escuté, X., Regato, P., 2005. WWF-Programa para la Conservación de Alcornocales. *Ecosistemas*. 2005/3. [http://www.revistaecosistemas.net/articulo.asp?Id=181andId\\_Categoria=2andtipo=portada](http://www.revistaecosistemas.net/articulo.asp?Id=181andId_Categoria=2andtipo=portada).
- Bremner, J.M., Mulvaney, C.S., 1982. Nitrogen-total. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA, pp. 595–624.
- Cabezas, J., Escudero, J.C., 1992. Variaciones en la biomasa de las especies leñosas que intervienen en la sucesión secundaria de alcornocales incendiados. *Simposio Mediterráneo sobre Regeneración del Monte Alcornocal*. Instituto de Promoción del Corcho, Junta de Extremadura, pp. 184–187.
- Callaway, R.M., 1995. Positive interactions among plants. *Bot. Rev.* 61, 306–349.
- Callaway, R.M., 1998. Competition and facilitation on elevation gradients in subalpine forests of the Northern Rocky Mountains, USA. *Oikos* 82, 561–573.
- Campos-Palacín, P., 1992. Economía del alcornocal. *Simposio Mediterráneo sobre Regeneración del Monte Alcornocal*. Instituto de Promoción del Corcho, Junta de Extremadura, pp. 15–22.
- Canadell, J., Zedler, P.H., 1995. Underground structures of woody plants in Mediterranean ecosystems of Australia, California, and Chile. In: Fox, M., Kalin, M., Zedler, P.H. (Eds.), *Ecology and Biogeography of Mediterranean Ecosystems in Chile, California and Australia*. Springer-Verlag, Berlin, pp. 177–210.
- Cañellas, I., Pardos, M., Montero, G., 2003. Efecto de la sombra en la regeneración natural del alcornoque (*Quercus suber* L.). *Actas de la III Reunión sobre Regeneración Natural y IV Reunión sobre Ordenación de Montes*. Sociedad Española de Ciencias Forestales 15, 107–112.
- Carrión, J.S., Parra, I., Navarro, C., Munuera, M., 2000. Past distribution and ecology of the cork oak (*Quercus suber*) in the Iberian Peninsula: a pollen-analytical approach. *Biodiv. Distrib.* 6, 29–44.
- Castro, J., Zamora, R., Hódar, J.A., Gómez, J.M., 2002. Use of shrubs as nurse plants: a new technique for reforestation in Mediterranean mountains. *Restor. Ecol.* 10, 297–305.
- Chambers, J.C., Van der Wall, S.B., Schupp, E.W., 1999. Seed and seedling ecology of piñon and juniper species in the pygmy woodlands of western North America. *Bot. Rev.* 65, 1–38.
- Chaves, N., Escudero, J.C., 1997. Allelopathic effect of *Cistus ladanifer* on seed germination. *Funct. Ecol.* 11, 432–440.
- Cortina, J., Maestre, F.T., 2005. Plant effects on soils in drylands. Implications for community dynamics and dryland restoration. In: Binkley, D., Menyailo, O. (Eds.), *Tree Species Effects on Soils: Implications for Global Change*, vol. 6. NATO Science Series Kluwer Academic Publishers, Dordrecht, pp. 85–118.
- Cortina, J., Maestre, F.T., Vallejo, R., Baeza, J.M., Valdecantos, A., Pérez-Devesa, M., 2006. Ecosystem structure, function, and restoration success: are they related? *J. Nat. Conserv.* 14, 152–160.
- Davis, S.D., Ewers, F.W., Wood, J., Reeves, J.J., Kolb, K.J., 1999. Differential susceptibility to xylem cavitation among three pairs of *Ceanothus* species in the Transverse Mountain Ranges of southern California. *Ecoscience* 6, 180–186.
- Dickie, I.A., Schnitzer, P.B., Reich, P.B., Hobbie, S.E., 2007. Is oak establishment in old-fields and Savanna openings context dependent? *J. Ecol.* 95, 309–320.
- Di Lorio, A., Lasserre, B., Scippa, G.S., Chiatante, D., 2005. Root system architecture of *Quercus pubescens* trees growing on different sloping conditions. *Ann. Bot.* 95, 351–361.
- Genty, B., Briantais, J.M., Baker, N.R., 1989. The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. *Acta Biochem. Biophys.* 990, 87–92.
- Gómez-Aparicio, L., Gómez, J.M., Zamora, R., Boettinger, J.L., 2005. Canopy vs. soil effects of shrub facilitating tree seedlings in Mediterranean montane ecosystems. *J. Veg. Sci.* 16, 191–198.
- Hasnaoui, B., 1996. Régénération naturelle du chêne-liège en Tunisie: difficultés et propositions de solutions. Actes du Séminaire Méditerranéen sur la Régénération des Forêts de Chêne-Liège. *Annales de l'INRGRF, Tabarka*, pp. 126–147.
- Kelly, D.L., 2002. The regeneration of *Quercus petraea* (sessile oak) in southwest Ireland: a 25-years experimental study. *For. Ecol. Manage.* 166, 207–226.
- Kolb, K.J., Davis, S.D., 1994. Drought tolerance and xylem embolism in co-occurring species of coastal sage and chaparral. *Ecology* 75, 648–659.
- Kummerow, J., 1981. Structure of roots and root systems. In: Di Castri, F., Goodall, D.W., Specht, R.L. (Eds.), *Ecosystems of the World 11. Mediterranean-Type Shrublands*. Elsevier Sci. Publ. Com., pp. 269–288.
- Lepoutre, B., 1965. Régénération artificielle du chêne-liège et équilibre climatique de la subéraie en forêt de la Mamora. *Annales de la Recherche Forestière au Maroc* 9, 1–188.
- Löf, M., Rydberg, D., Bolte, A., 2006. Mounding site preparation for forest restoration: survival and short term growth response in *Quercus robur* L. seedlings. *Forest Ecol. Manage.* 232, 19–25.
- Maestre, F.T., Cortina, J., Bautista, S., Bellot, J., 2003. Does *Pinus halepensis* facilitate the establishment of shrubs in Mediterranean semi-arid afforestations? *Forest Ecol. Manage.* 176, 147–160.
- Maestre, F.T., Valladares, F., Reynolds, J.F., 2005. Is the change of plant–plant interactions with abiotic stress predictable? A meta-analysis of field results in arid environments. *J. Ecol.* 93, 748–757.



- Mattia, C., Bischetti, G.B., Gentile, F., 2005. Biotechnical characteristics of root systems of typical Mediterranean species. *Plant Soil* 278, 23–32.
- Montero, G., Cañellas, I., 1999. Manual de reforestación y cultivo del alcornoque (*Quercus suber* L.). Ministerio de Agricultura, Pesca y Alimentación. Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, Madrid, pp. 267.
- Mulet, J., 2003. Les estassades forestals. *Catalunya Forestal*, p. 61.
- Murphy, G.P., Dudley, S.A., 2007. Above- and below-ground competition cues elicit independent responses. *J. Ecol.* 95, 261–272.
- Natividade, J.V., 1991. Subercultura. Madrid: MAPA Secretaría General Técnica. MAPA. Hojas divulgadoras. 7-8/95 HD.
- Nelson, R.E., 1982. Carbonate and gypsum. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA, pp. 181–197.
- Nelson, R.E., Sommers, L.E., 1982. Total carbon, organic carbon, and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA, pp. 539–580.
- Oliet, J., Navarro, R., Contreras, O., 2003. Evaluación de la aplicación de mejoradores y tubos en repoblaciones forestales. *Consejería de Medio Ambiente de la Junta de Andalucía, Córdoba*.
- Page, A.L., Miller, R.H., Keeney, D.R., 1982. *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*, 2nd ed. Madison, Wisconsin, USA.
- Pausas, J., Bladé, C., Valdecantos, A., Seva, J.P., Fuentes, D., Alloza, J.A., Vilagrosa, A., Bautista, S., Cortina, J., Vallejo, R., 2004. Pines and oaks in the restoration of Mediterranean landscapes of Spain: new perspectives for an old practice—a review. *Plant Ecol.* 171, 209–220.
- Pemán, J., Navarro, R., 1998. *Repoblaciones Forestales*. Servei de publicacions de la Universitat de Lleida.
- Pons, J., Pausas, J.G., 2006. Oak regeneration in heterogeneous landscapes: the case of fragmented *Quercus suber* forests in the eastern Iberian Peninsula. *Forest Ecol. Manage.* 231, 196–204.
- Puerta-Piñero, C., Gómez, J.M., Valladares, F., 2007. Irradiance and oak seedling survival and growth in a heterogeneous environment. *Forest Ecol. Manage.* 242, 462–469.
- Pulido, F.J., 2002. *Biología reproductiva y conservación: el caso de la regeneración de bosques templados y subtropicales de roble (Quercus spp.)*. *Rev. Chilena Hist. Nat.* 75, 5–15.
- Retana, J., Espelta, J.M., Gracia, M., Riba, M., 1999. Seedling recruitment. In: Rodà, F., Retana, J., Gracia, C.A., Bellot, J. (Eds.), *Ecology of Mediterranean Evergreen Forests*. Springer, Berlin, pp. 89–103.
- Rey-Benayas, J.M., 1998. Growth and survival in *Quercus ilex* seedlings after irrigation and artificial shading on Mediterranean set-aside agricultural lands. *Ann. Forest Sci.* 55, 801–807.
- Robles, C., Bonin, G., Garzino, S., 1999. Potentialités autotoxiques et allélopathiques de *Cistus albidus* L. *Comptes rendus de l'Académie des sciences. Série 3, Sciences de la vie* 322, 677–685.
- Sánchez-Gómez, D., Zavala, M.A., Valladares, F., 2006. Seedling survival responses to irradiance are differentially influenced by drought in four tree species of the Iberian cool temperate-Mediterranean ecotone. *Acta Oecol.* 30, 322–332.
- Sans, F.X., Escarré, J., Gorse, V., Lepart, J., 1998. Persistence of *Picris hieracioides* populations in old fields: an example of facilitation. *Oikos* 83, 283–292.
- Santilli, J., 1998. Communication de l'Office National des Forêts sur la régénération des forêts de chêne-liège varoises. *Actes du séminaire Méditerranéen sur la régénération des forêts de chêne-liège*. *Annales de l'INGREF, Tabarka*, pp. 48–62.
- Serrada-Hierro, R., 2003. Regeneración natural: situaciones, concepto, factores y evaluación. *Actas de la III Reunión sobre Regeneración Natural y IV Reunión sobre Ordenación de Montes*. *Sociedad Española de Ciencias Forestales* 15, 11–16.
- Serrasolses, I., Pérez-Devesa, M., Vilagrosa, A., Pausas, J.G., Sauras, T., Cortina, J., Vallejo, V.R., in press. Soil conditions for Cork oak. Chapter 12 in 'Cork Oak Woodlands in Transition. In: Aronson, J., Pereira, J.S., Pausas, J.G. (Eds.), *Ecology, Management, and Restoration of an Ancient Mediterranean Ecosystem*'.
- Soil Survey of England and Wales [SSEW], 1982. *Soil Survey Laboratory methods*. *Tech. Monogr.* 6, SSEW, Harpenden, UK.
- Standiford, R.B., 2002. California's oak woodlands. In: McShea, W.J., Healy, W.M. (Eds.), *Oak Forest Ecosystems*. The John Hopkins University Press, Baltimore, pp. 280–303.
- Topp, G.C., Davis, J.L., 1985. Measurement of soil water content using time-domain reflectometry (TDR): a field evaluation. *Soil Sci. Soc. Am. J.* 49, 19–24.
- Torrecillas, A., Rodríguez, P., Sánchez-Blanco, M.J., 2003. Comparison of growth, leaf water relations and gas exchange of *Cistus albidus* and *Cistus monspeliensis* plants irrigated with water of different NaCl salinity levels. *Scientia Horticulturae* 97, 353–368.
- Torres, E., 2003. Experiencias sobre regeneración natural de alcornoque (*Quercus suber* L.). *Actas de la III Reunión sobre Regeneración Natural y IV Reunión sobre Ordenación de Montes*. *Sociedad Española de Ciencias Forestales* 15, 37–48.
- Valdecantos, A., 2001. *Aplicación de fertilizantes orgánicos e inorgánicos en la repoblación de zonas degradadas de la Comunidad Valenciana*. PhD Thesis. University of Alicante.
- Valladares, F., Pearcy, R.W., 2002. Drought can be more critical in the shade than in the sun: a field study of carbon gain and photoinhibition in a Californian shrub during a dry El Niño year. *Plant Cell Environ.* 25, 749–759.
- Valladares, F., Dobarro, I., Sánchez-Gómez, D., Pearcy, R.W., 2004a. Photoinhibition and drought in Mediterranean woody saplings: scaling effects and interactions in sun and shade phenotypes. *J. Exp. Bot.* 56, 486–494.
- Valladares, F., Vilagrosa, A., Peñuelas, J., Ogaya, R., Camarero, J.J., Corcuera, L., Sisó, S., Gil-Pelegrín, E., 2004b. Estrés hídrico: ecofisiología y escalas de sequía. In: Valladares, F. (Ed.), *Ecología del bosque mediterráneo en un mundo cambiante*. MMA, pp. 163–190.
- Vilà, M., Sardans, J., 1999. Plant competition in Mediterranean-type vegetation. *J. Veg. Sci.* 10, 281–294.
- Vilagrosa, A., Bellot, J., Vallejo, V.R., Gil-Pelegrín, E., 2003. Cavitation, stomatal conductance and leaf dieback in seedlings of two co-occurring Mediterranean shrubs during an intense drought. *J. Exp. Bot.* 54, 2015–2024.
- WWF, 2006. *Conflicting EU Funds: Pitting Conservation Against Unsustainable Development*. WWF Global Species Programme, Wien, pp. 72.