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Are *Pinus halepensis* plantations useful as a restoration tool in semiarid Mediterranean areas?

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Abstract

In the semiarid areas of the Mediterranean basin, restoration activities during the XXth century have mainly relied on extensive plantations of *Pinus halepensis*, which now cover thousands of hectares. Here we review studies that have evaluated the effects of these plantations on soils, vegetation, faunal communities, and forest fires. The effects of *P. halepensis* plantations on soil properties are highly dependent on the planting technique employed. Plantations frequently show enhanced runoff and soil losses when compared to natural shrublands, as well as limited improvement in most physio-chemical properties, which rarely reach the values shown by natural shrublands even 40 years after planting. The increase in tree cover resulting from the introduction of *P. halepensis* is commonly accompanied by an increase in water use, which may have relevant hydrological consequences at the catchment scale. Most studies performed so far have shown an overall negative effect of *P. halepensis* plantations on spontaneous vegetation. In these plantations, vegetation is dominated by early-successional species, and the establishment of late-successional sprouting shrubs—even after several decades—has been rarely reported. The effects of *P. halepensis* plantations on faunal communities may vary depending on the animal group considered. Available studies suggest that *P. halepensis* plantations can reduce bird biodiversity and promote pest outbreaks. Our review contributes to the debate on the suitability of mono-specific extensive *P. halepensis* plantations, and suggests that afforestation programmes should be revised.

Keywords: Semiarid; *Pinus halepensis*; Mediterranean; Plantation; Restoration; Evaluation

1. Introduction

Arid and semiarid areas currently cover over one-third of total Earth's land surface (Reynolds, 2001), and its extension may increase as a consequence of expected climatic changes (Schlesinger et al., 1990). These areas are particularly prone to degradation because of environmental constraints and intense and continued human pressure (Schlesinger et al., 1990; Puigdefábregas and Mendizábal, 1998). Restoration of degraded arid and semiarid lands by the reintroduction of woody species has become increasingly important worldwide as a measure to protect soils (Castillo et al., 1997), to combat desertification (Reynolds, 2001), to supply natural resources (Guevara et al., 2003), and to provide space for recreation (Schiller, 2001). Its importance may also increase in the future due to the role of forest

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plantations in carbon sequestration in arid and semiarid areas (Keller and Goldstein, 1998).

In the semiarid areas of the Mediterranean Basin, restoration activities have been mainly based on the reintroduction of conifers, primarily *Pinus halepensis* Miller. This is one of the most important tree species in the region, one of the few tree species that can thrive in semiarid areas indeed, covering more than 25,000 km^2 and dominating forest formations in semiarid and dry sub-humid areas (Quézel, 2000). The surface area covered by this species has substantially increased as a consequence of spontaneous colonization of abandoned lands, and widespread use in plantations (Vélez, 1986; Pausas et al., 2004). For instance, 2600 of the 3000 ha of forest in the semiarid sector of the province of Alicante (SE Spain) are dominated by this species (Bautista, 1999). Similar observations have been made in semiarid regions in Turkey, Algeria and Morocco (Barbéro et al., 1998; Pausas et al., 2004). The main objective behind vast afforestation programs developed during the second part of the XXth century was in many cases socio-economic (Peñuelas and Ocaña, 1996). Plantations were also implemented for controlling catchment hydrology, protecting soils and fostering forest productivity. *Pinus halepensis* was preferentially chosen because of low-technical requirements for nursery production, high-resistance to adverse climatic and soil conditions, and because it was either considered a pioneer species, favoring the establishment of late successionals, or was itself considered part of the climax community, as in extensive areas in Algeria, Tunisia and Greece (Ruiz de la Torre, 1973; Quézel, 1986; Ciancio, 1986).

Despite the extent of *P. halepensis* plantations, and the time passed since the onset of vast afforestation plans, a critical review of the ecological consequences of these plantations in the semiarid areas of the Mediterranean Basin has not been performed. The objective of this paper is to review the main results obtained, and to identify the main ecological consequences of the introduction of *P. halepensis* with extensive, mono-specific plantations, in Mediterranean semiarid areas. Understanding the ecological consequences of these plantations is a question of great importance to evaluate past and current forest policies, to develop alternative restoration strategies, and to predict long-term consequences of these plantations on ecosystem function and dynamics. Its importance goes beyond the scope of the Mediterranean Basin, since *P. halepensis* has been extensively introduced in other areas of the world, such as South Africa (Richardson, 1988), Argentina (Ares and Peinemann, 1992), Australia (Richardson and Higgins, 1998) and New Zealand (Richardson and Higgins, 1998).

The evaluation of restoration actions is not easy (Holl and Howarth, 2000). Priorities may have changed since the beginning of the intervention, and in many cases original objectives are not documented. In addition, socio-economic gains can hardly be quantified, particularly in perspective. This review is restricted to the evaluation of some prominent functional and compositional ecosystem traits. Thus, we do not intend to provide a global grade for *P. halepensis* plantations in the semiarid area, what could be a futile exercise considering the complexity of the whole system. We rather aim to collect information on the different facets of the problem, and to identify lacks of knowledge that hamper a proper management of these plantations under semiarid conditions.

2. *Pinus halepensis* establishment and growth

The first step in evaluating the degree of success of *P. halepensis* plantations in semiarid areas is to quantify the survival rate and growth of this species. The works by Alloza (2003) and Castillo et al. (2002) on 79 experimental plots from different afforestation projects performed in semiarid areas of SE Spain suggest that medium term survival rate may be close to 50%. Average density in *P. halepensis* plantations under semiarid conditions in Spain is around 200 trees ha^{-1} (V.V.A.A., 2001). Assuming that planting density is commonly close to 1000 trees ha^{-1} in these plantations, this gives an average survival of ca. 20% (J.A. Alloza, personal communication). These figures are somewhat lower than survival rates recorded under dry sub-humid Mediterranean conditions (Vilagrosa et al., 1997; Alloza et al., 1999), but similar to those found for other woody species in semiarid areas (Cortina et al., in press). Early establishment and growth data obtained from experimental plantations show that the results are highly variable (Table 1), and largely depend on soil type, soil preparation and climatic

Table 1
Early survival and growth of *Pinus halepensis* seedlings experimentally planted in semiarid areas of SE Spain

RAI	TIP	SOT	SOP	SUR	RGR[a]	Reference
278	2	Limestone	None	11	–	Valdecantos et al. (1996)
385	2	Marls	None	62	–	Valdecantos et al. (1996)
300	2	Marls	Mechanical terracing	95	0.55	Roldán et al. (1996)
300	2	Marls	Mechanical terracing	97	0.22	Querejeta et al. (1998)
300	2	Marls	Manual terracing	83	0.18	Querejeta et al. (1998)
300	4	Marls	Mechanical terracing	99	0.20	Querejeta et al. (2001)
300	4	Marls	Manual terracing	62	0.14	Querejeta et al. (2001)
182	1	–	None	89	0.05	Oliet et al. (2002)
277	6	Marls	None	48	0.24	Cortina et al. (in press)
277	6	Marls	None	20	0.26	Cortina et al. (in press)

RAI: average rainfall (mm), TIP: time since planting (years), SOT: soil parent material; SOP: soil preparation technique, SUR: seedling survival (%), RGR: relative growth rate in height ($year^{-1}$, average values). The list of surveyed studies is not exhaustive.

[a] Calculated from RGR = (log(height at TIP) − log(height at planting))/(TIP).

conditions. It must be mentioned that post-planting irrigation is uncommon in *P. halepensis* plantations in semiarid areas.

Pinus halepensis cover is commonly low in semiarid plantations. Chaparro (1994) found that this species covered less than 20% of the surface area in 23-year-old plantations. According to the second Spanish Forest Inventory (V.V.A.A., 2001) tree cover in >40-year-old *P. halepensis* plantations under semiarid conditions is close to 30%. These results agree with the low productivity recorded in *P. halepensis* plantations in the province of Alicante (SE Spain; Pastor and Martín, 1989). Almost 50% of the >30-year-old plantations showed wood biomass accumulation below the lowest class defined by Abbas (1986), 1 m^3 ha^{-1} $year^{-1}$. Productivity was even lower when all 120 studied plantations were pooled, with lowest productivity level of 0.01 m^3 ha^{-1} $year^{-1}$ in a 824 trees ha^{-1} 19-year-old plantation (Pastor and Martín, 1989). Under semiarid conditions, the growth of *P. halepensis* in plantations is highly related to rootable soil depth and available water. In plantations performed in the semiarid Lower Ebro valley (NE Spain), site index at 40 years was below 5 m for rootable depths ca. 30 cm (Olarieta et al., 2000).

3. Effects of *Pinus halepensis* plantations on soils

The microsite under the canopy of *P. halepensis* individuals differs in soil properties as compared to adjacent open areas devoid of vascular plants. Maestre et al. (2003a), working in two plantations in SE Spain, reported higher soil organic carbon and total nitrogen at 0–20 cm depth under the pines, 30 years after planting. Caravaca et al. (2002) found higher aggregate stability at 0–15 cm depth under the pines, 6 years after planting in a semiarid site in SE Spain. These results suggest that, despite intrinsic low productivity, *P. halepensis* may improve soil properties in a few years to decades. This lapse is probably not enough for *P. halepensis* plantations to attain the fertility levels of relatively undisturbed shrublands. Several studies have found lower soil organic matter and total nitrogen concentration in *P. halepensis* plantations than in adjacent shrublands (Chaparro, 1994; Castillo et al., 2002), and parallel differences in aggregate stability, cation exchange capacity or available P and K (Castillo et al., 2002; Caravaca et al., 2002) (Table 2). The type of shrubland used for the comparison is also relevant, as those dominated by woody sprouters—such as *Quercus coccifera* L., *Pistacia lentiscus* L., *Rhamnus lycioides* L., etc.—commonly show higher soil organic matter contents than mature *P. halepensis* plantations (De la Torre and Alías, 1996; Cortina et al., 2001).

Pinus halepensis plantations in semiarid areas usually show lower soil moisture content when compared with other plant communities, but this soil property may be affected by the planting method employed (Querejeta et al., 2001). Bellot et al. (1999, 2004) found a negative effect of *P. halepensis* plantations on soil moisture at 0–10 cm, and at 10–

Table 2
Properties of the surface soil (0–15 cm depth) in four *Pinus halepensis* plantations and adjacent shrublands of SE Spain

Variable	Shrubland	Terrace	Bank
pH	8.32 ± 0.06 a	8.29 ± 0.07 a	8.26 ± 0.05 a
Organic matter (%)	2.27 ± 0.25 a	0.84 ± 0.13 b	1.19 ± 0.16 b
Total nitrogen (%)	0.11 ± 0.01 a	0.05 ± 0.004 b	0.07 ± 0.01 c
C:N	12.14 ± 0.28 a	9.90 ± 1.03 a	9.99 ± 0.75 a
Na (Cmol kg^{-1})	0.04 ± 0.01 a	0.03 ± 0.01 a	0.05 ± 0.01 a
K (Cmol kg^{-1})	0.14 ± 0.02 a	0.15 ± 0.01 a	0.13 ± 0.01 a
Ca (Cmol kg^{-1})	3.37 ± 0.22 a	4.02 ± 0.44 a	4.21 ± 0.38 a
Mg (Cmol kg^{-1})	1.47 ± 0.17 a	0.81 ± 0.15 b	0.71 ± 0.15 b
Sand (%)	43.77 ± 5.39[a] a	27.59 ± 4.97[a] a	31.48 ± 4.80[b] a
Silt (%)	39.84 ± 3.48[a] a	46.18 ± 2.92[a] a	45.31 ± 2.99[b] a
Clay (%)	16.39 ± 3.01[a] a	26.22 ± 3.09[a] a	23.32 ± 2.34[b] a

Within plantations, two sites were sampled: the terraces (where the trees are planted), and the banks located between terraces. Data represent pooled means ± 1 S.E. ($n = 21$, except when indicated). Different letters denote significant differences ($P < 0.05$, Tukey's-*b* post hoc test after one-way ANOVA). Post-hoc results for organic matter, total nitrogen, C:N, and Na are shown for log-transformed data. Original data from Chaparro (1994).

[a] $n = 14$.

[b] $n = 13$.

30 cm depth, as compared to adjacent shrublands and grasslands in a semiarid catchment in SE Spain. In this area, soil moisture decreased as the density of planted *P. halepensis* increased, especially after the main rainfall events (Bellot et al., 2004). Results are similar when comparing soil moisture content underneath pine canopies with that of open areas (Maestre et al., 2003a). The effect of *P. halepensis* on soil moisture may result from both rainfall interception and water uptake by pines and associated species. In semiarid plantations in Spain and Israel, *P. halepensis* canopy was found to reduce water reaching the soil surface between 15 and 35% (Schiller, 1978; Bellot et al., 1999; Maestre et al., 2003a). Planted *P. halepensis*, on the other hand, can almost completely use effective rainfall in these areas (Schiller and Cohen, 1998). This may result from higher LAI, as *P. halepensis* is considered a drought avoider species with strong control of water losses on a needle surface basis (Martínez-Ferri et al., 2000). At the catchment scale, a modeling study found that *P. halepensis* plantations may reduce aquifer recharge when compared to other land cover types such as shrublands (Bellot et al., 2001). These authors suggested that, in semiarid areas with annual rainfall below 300 mm, *P. halepensis* plantations may not be appropriate to promote aquifer recharge. On the other hand, it has been argued that high-evaporative losses could supply the critical moisture needed to trigger the condensation of water in ascending air masses, and promote rainfall (Millán et al., 1995, 1997). However, the validity of this assumption in semiarid areas still remains to be experimentally tested in the field.

The effects of *P. halepensis* plantations on runoff and sediment yield are largely dependent on soil preparation. Plantations performed with heavily mechanized techniques, such as mechanically build terraces and subsoiling, have been often preferred to manual techniques due to lower costs and better performance of planted trees (Serrada, 1990; Table 1). They are the dominant planting method in semiarid areas in Spain (García, 1990; Rojo et al., 2002). An analysis of the *P. halepensis* plantations performed in the province of Alicante (SE Spain) during the period 1940–1985 (232,435 ha), reveals that mechanical methods were employed in 62% of the plantations (Pastor, 1995). Subsoiling and terracing were common in the 70–80 s, whereas the use of planting holes has been the alternative of choice in the 90 s (Pastor, 1995). Techniques such as subsoiling and terracing completely modify the original hydrological features of the slopes (Appendix A), and their implementation in semiarid areas have often resulted in enhanced water and soil losses (Chaparro, 1994). Given the importance of site preparation techniques, it is not surprising that, even at a local scale, results of

P. halepensis plantations on runoff and erosion are contrasting. In a subsoiled semiarid area in SE Spain planted with *P. halepensis* 40 years before, Chirino et al. (2001) reported a significant decrease in runoff and sediment yield when compared with open areas, but no differences where found with areas covered by shrubs or grasses. Similar results were obtained when comparing runoff and sediment yield from natural shrublands and areas planted manually with *P. halepensis* in a long-term (1985–1993) study performed in three semiarid sites of SE Spain (Sánchez, 1997). Chaparro (1994) evaluated the erosion rates and geomorphologic features of seven terraced 23-year-old *P. halepensis* plantations and adjacent shrublands in SE Spain. Over 55% of the total area planted showed symptoms of erosion (removal of A horizon, presence of pedestals and small rills), a value higher than that observed in natural shrublands (2.5%). This author estimated erosion rates in the plantations varying between 17 and 93 Tm ha^{-1} $year^{-1}$. Soil losses between 28 and 71 Tm ha^{-1} $year^{-1}$ have been reported in other *P. halepensis* plantations in SE Spain (Mintegui, 1989). These values are substantially higher than those measured in natural shrublands in the same region (3 Tm ha^{-1} $year^{-1}$; López Bermúdez, 1990). At the catchment scale, shrublands may also be more effective than *P. halepensis* plantations in reducing runoff in semiarid areas (Bellot et al., 2001).

4. Effects of *Pinus halepensis* plantations on vegetation dynamics

The effect of *P. halepensis* plantations on the dynamics of spontaneous vegetation is highly dependent on the type of site preparation. Several studies report a lack of recovery of spontaneous vegetation in *P. halepensis* plantations 23 years after planting in SE Spain (Chaparro, 1994; Chaparro and Esteve, 1996). These authors reported values of plant cover in seven plantations that were, on average, 20% lower than those reported in adjacent shrublands not affected by planting works. This change was accompanied by a profound modification in the relative dominance of life forms, since a significant decrease in phanerophytic and camephytic shrubs, and a significant increase in therophytes, took place after planting. Similar results were reported by Chirino et al. (2001) in a subsoiled semiarid area in SE Spain planted with *P. halepensis* 40 years before. In this study, plantation increased leaf area index and litter cover as compared to adjacent shrubland and grassland areas not affected by planting. However, it had little effect on total plant cover, and decreased species richness as compared to unplanted areas. Some qualitative observations of the dynamics of the vegetation in *P. halepensis* plantations of the Algerian Green Belt, a major plantation program in Central Algeria started in 1974 (Kadik, 1982), are given by Benabdeli (1998). This author reported that natural vegetation in *P. halepensis* plantations was characterized by the dominance of early-successional shrubs like *Globularia alypum* L. and *Helianthemum cinereum* L., with late-successional shrubs (like *Q. coccifera*, *Juniperus oxycedrus* L. and *Juniperus phoenicea* L.) showing very low cover. We may notice that decreases in overall plant cover and species richness occur despite the positive effect that *P. halepensis* individuals have on the development of herbaceous understorey under semiarid conditions (Bautista and Vallejo, 2002).

Other studies have evaluated the effect of *P. halepensis* plantations on the performance of standing plants. Bellot et al. (2004) studied the effect of *P. halepensis* on several physiological traits of adult shrubs (*Q. coccifera*, *R. lycioides* L. and *Erica multiflora* L.) that were not removed during plantation works in a semiarid catchment in SE Spain. During Spring, predawn water potential, net photosynthesis and stomatal conductance of adult shrubs were significantly reduced (up to 56%) in planted as compared to unplanted areas, a negative effect that increased with *P. halepensis* density (Bellot et al., 2004). Further insights on the role of plantations on the recovery rate of natural vegetation are provided by studies based on experimental plantings. During the last decade different experiments have evaluated the effect of *P. halepensis* plantations on the establishment of native shrubs which are part of the potential vegetation or that dominate late-successional communities. At a landscape scale, no significant differences were found in the survival rate of seedlings introduced under *P. halepensis* plantations and in ‘‘control’’ shrublands 2 years after planting (Fig. 1). At a plot scale, the response of seedlings planted underneath *P. halepensis*

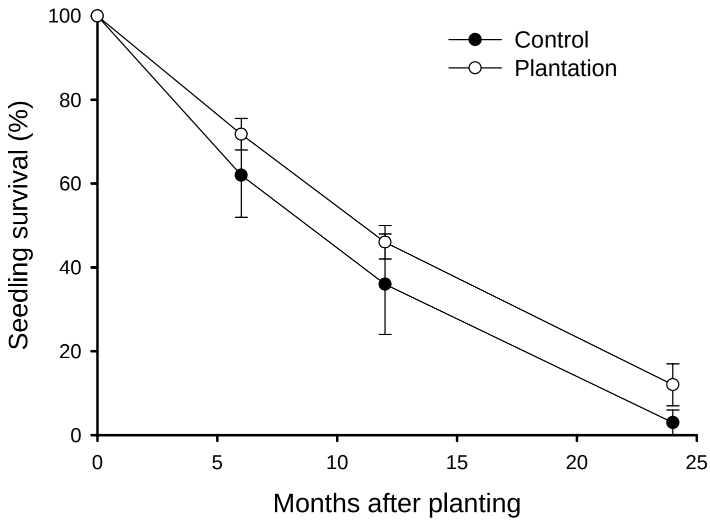

Fig. 1. Survival of kermes oak (*Q. coccifera*) seedlings introduced in *Pinus halepensis* plantations (white symbols), and in degraded areas with sparse vegetation cover (dark symbols) located in SE Spain (300 mm annual rainfall). Data represent mean $\pm$ S.E. ($n = 2$). The sites were similar in terms of climate, slope aspect, topography, and soil characteristics. Within each site, 50 one-year-old seedlings of *Q. coccifera* were planted by using 40 cm $\times$ 40 cm $\times$ 40 cm mechanically dug holes. In *P. halepensis* sites, seedlings were planted in open spaces. Original data from Vilagrosa et al. (2001).

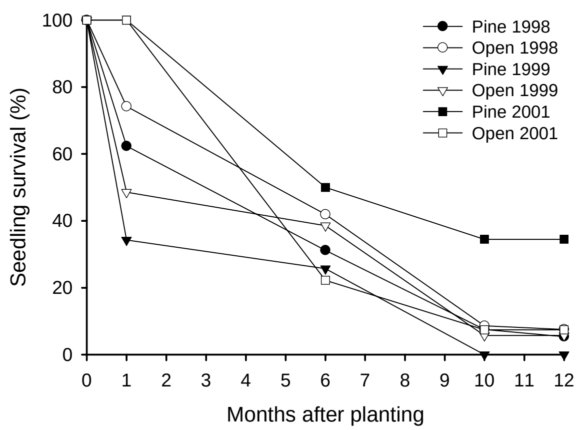

Fig. 2. Survival of *Pistacia lentiscus* seedlings planted under the canopy of *Pinus halepensis* (pine microsite) and in open areas between pines (open microsite) in a semiarid plantation in SE Spain. Results from three experimental plantations carried out in the same place but in years of contrasted rainfall (188, 240 and 381 mm for 1998, 1999 and 2001, respectively) are shown. In the 2001 plantation, the equivalent to 96 mm of water were added in Spring. The number of seedlings per microsite introduced in each plantation varied between 27 and 100. In all cases, seedlings were introduced in 25 cm $\times$ 25 cm $\times$ 25 cm manually dug planting holes. Original data from Maestre (2002) and Maestre et al. (2003a).

canopies varied with rainfall, being negative in particularly dry years (Fig. 2). Further manipulative field and greenhouse experiments showed that this negative effect was probably promoted by competition between introduced seedlings and the existing herbaceous understorey (Maestre, 2002).

The results reported in the literature contrast with those obtained in more mesic areas, where significant association of oak (*Quercus ilex* L.) seedlings and adult *P. halepensis* individuals have been reported (Lookingbill and Zavala, 2000), and with ecological theories and models predicting plant interactions in stressful environments (Bertness and Callaway, 1994). These models predict that the balance between competition and facilitation shifts towards facilitation in stressed environments, in such a way that competition may be counterbalanced by facilitation. Implicit in these models is the assumption that environmental harshness is ameliorated by the facilitator species, the introduced pines in our case. The observed negative effects of *P. halepensis* plantations on vegetation may be caused by a reduction of soil water availability, which may not be counterbalanced by improvements in microclimate and soil fertility. Consequently, the harshness of environmental conditions, in terms of water availability, would be intensified rather than ameliorated by the introduction of *P. halepensis*.

5. Effects of *Pinus halepensis* plantations on faunal communities

Few studies have evaluated so far the effect of *P. halepensis* plantations on faunal communities in semiarid areas, and all of them focus on birds. López and Moro (1997) found that understorey composition, rather than attributes of planted pines, was the determinant of the presence and abundance of many bird species in SE Spain. Among understorey species, sprouting shrubs such as *Q. coccifera* were most strongly associated with bird species richness and abundance. Rarity, however, is know to decrease with the development of a forest cover under Mediterranean conditions (Prodon, 2000). Sánchez-Zapata and Calvo (1999) showed that the breeding density of four raptor species (*Hieraetus pennatus*, *Circaetus gallicus*, *Buteo bubo*, *Accipiter gentilis*) increased with the area covered by *P. halepensis*. Diaz et al. (1998) suggest that pine plantations (including *P. halepensis*) in dry and semiarid cereal croplands can not be recommended to protect bird biodiversity in the Spanish Plateau. They argue that these plantations have detrimental effects on dry grassland bird communities—which are of high-conservation value (Suárez et al., 1997)—and have a limited utility to support forest bird communities given the size of most plantations (below 2 ha in the Spanish Plateau).

In the Negev Desert, Israel, the replacement of open shrublands by *P. halepensis* plantations has promoted dramatic changes in bird community composition. One conspicuous phenomenon of this landscape change has been the immigration of bird species from Northern and central Israel to the Negev, and the establishment of these species in pine plantations (Shirihai, 1996). In a recent study, Shochat et al. (2001) showed that afforestation with *P. halepensis* and other conifers (*Pinus pinea* L., *Pinus canariensis* Smith and *Cupresus sempervirens* L.) in this desert slightly increased bird species diversity in the whole landscape. However, plantations decreased the density of threatened species that were shrubland specialists because of the lack of suitable microhabitats for these species. The negative effect of *P. halepensis* on bird diversity may be partly due to the lower richness of bird species in Mediterranean forests as compared to shrublands (Blondel and Aronson, 1999).

Pinus halepensis is the host of a large number of insects that can become pests (e.g., Mendel et al., 1985; Liphschitz and Mendel, 1989; Mendel, 1990). The most common pest species in Mediterranean semiarid areas are bark beetles (*Carphoborus minimus*, *Hylurgus ligniperda*, *Hylurgus micklitzi*, *Hylastes linearis*, *Pityogenes calcaratus*, *Orthotomicus erosus*, *Tomicus destruens*), caterpillars (*Thaumetopoea pityocampa*, *Thaumetopoea wilkinsoni*) and other insects (*Neodiprion sertifer*, *Matsucoccus josephi*, *Palaeococcus fuscipennis*). Few studies have compared the sensitivity of *P. halepensis* plantations to pests with that of other forests and woodlands in the same area. Questienne (1979) noted that bark beetles affected pine plantations more heavily than natural stands in semiarid areas of Morocco. Outbreaks of *T. destruens* have been documented in semiarid plantations in Israel (Mendel et al., 1985). The latter authors reported an exponential increase in the area affected by the insect *Palaeococus forcipensis* in plantations of several pines (*P. halepensis*, *P. pinea*, *P. brutia* and *P. canariensis*) in Israel since its introduction in the late 1980s (Mendel et al., 1998). Important damages to *P. halepensis* plantations promoted by the caterpillar *T. pityocampa* are also commonly reported in semiarid areas of SE Spain (Anonymous, 2003).

Some management measures usually carried out in the plantations may also increase their sensitivity to pest attacks. Halperin et al. (1982) linked the increase of bark beetle outbreaks in *P. halepensis* to maturation of planted trees and to the increase in thinning in semiarid areas of Israel. Also in Israel, Mendel and Halperin (1982) reported that the agents predisposing *P. halepensis* plantations to attacks of *O. erosus* were thinning followed by winters of low rainfall or fires in adjacent areas. The selection of the provenances of the seedlings to be planted may also influence the *P. halepensis* sensitivity to pest attacks. Mendel (1984) evaluated the relationship between seed origin and the sensitivity to *M. josephi* in Israel, and showed that povenances from Greece and Israel were less affected by the pest than North African and Spanish provenances.

6. Effects of *Pinus halepensis* plantations on forest fires

The role of *P. halepensis* plantations as vectors of wildfires in semiarid areas is a matter of controversy. Despite being less relevant than in more mesic areas, due to lower fuel accumulation (Vázquez et al., 2002), forest fires are a first order environmental problem in semiarid Mediterranean areas in countries like Israel and Spain (Vélez, 1986; European Commission, 1996). As a result of extensive plantations, large areas are covered with highly flammable even-aged pines. They represent a high-fire hazard and may facilitate the spread of large forest fires (Moreno, 1999; Herranz, 2000). Some authors argue that *P. halepensis* plantations do not increase the frequency of forest fires as compared with shrublands and other natural formations (Ortuño, 1990), but there is no agreement on this. Vélez (1986) analyzed data from wildfires in Spain between 1969 and 1983, and found that *P. halepensis* stands represent between the 10 and 20% of the total area burned in the country each year. In the same line of argument, Herranz (2000) suggested that *P. halepensis* forests were more affected by wildfire than other land use types. *Pinus halepensis* forests represented up to 47% of the total area burned. Moreno (1999) estimated that 26% of the total area burned in Spain between 1974 and 1999, over 4.6 million hectares, correspond to *P. halepensis* plantations.

The increased recurrence of forest fires in *P. halepensis* plantations may have undesirable effects on the development of spontaneous vegetation. Forest fires generate new establishment opportunities for *P. halepensis* seedlings by reducing inter-specific competition and creating suitable microsites for seed germination and seedling establishment (Ne'eman, 2000). In semiarid stands in Spain and Israel, it has been shown that regeneration and growth of *P. halepensis* seedlings is higher near dead logs (Ne'eman, 2000; Bautista and Vallejo, 2002). These results have been attributed to the presence of fertility islands around nurse trees, which may help *P. halepensis* seedlings to overcome competition with other species existing in these microsites (mainly perennial grasses; Pausas et al., 2003). Auto-successional dynamics, which have been reported in semiarid *P. halepensis* stands (Moravec, 1990; Herranz et al., 1997), may delay the recovery of natural vegetation, and especially the recruitment of late-successional species.

Increasing the number and extension of forest fires may also compromise the persistence of *P. halepensis* plantations. As forest fires become more recurrent, the probability of affecting young plantations increases. *Pinus halepensis* achieves sexual maturity at ages below 10 years old, but, even under favorable conditions, formations of this species are not able to promote a significant canopy seedbank before they are 10–15 years old (Thanos and Daskalakou, 2000). Thus, inter-fire periods shorter than 10–15 years are likely to results in local extinctions (Pausas, 1999). *Pinus halepensis* is well-adapted to wildfire, and fires may actually promote the dominance and extension of this species (Trabaud, 1991; Barbéro et al., 1998). But post-fire pine regeneration may be impaired under semiarid conditions (Ferrandis et al., 2001), probably due to climate adversity and seed predation (Pausas et al., 2004). It is important to note that *P. halepensis* seed bank is transient, and thus, a drought spell lasting one to two years can compromise the establishment of this species after fire. The lack of post-fire regeneration in *P. halepensis* stands has been associated with altitude, competition and grazing (Chakroun, 1986; De las Heras et al., 2002; Pausas et al., 2003).

7. Concluding remarks: implications for the management of *Pinus halepensis* plantations and the restoration of semiarid degraded areas

In the last years there has been an increasing concern among land managers, scientists, restoration practitioners and non-governmental organizations on the impacts of extensive coniferous plantations in Mediterranean countries (e.g., Castroviejo et al., 1985; Esteve et al., 1990; Ortuño, 1990; Andrés and Ojeda, 2002). Our review contributes to the debate on the suitability of using *P. halepensis* plantations in semiarid Mediterranean areas and, despite being based on a limited number of studies, suggests that these plantations do not fulfill some of the objectives of restoration. This assumption is based on three key results:

(i) Plantations promote regression in plant communities

The introduction of *P. halepensis* has promoted an increase in tree cover in semiarid areas. But, in general, this has not triggered the establishment of late-successional species, especially sprouting shrubs. In fact, plantations are frequently characterized by earlier successional plant communities, and lower plant cover than the shrublands that were replaced. It is important to emphasize that these effects may result from site preparation and spontaneous succession, rather than by a direct influence of *P. halepensis*. This complicates the analysis, as soil preparation techniques are diverse and so are their effects. Heavily mechanized operations may bring the ecosystem back to early stages of succession, with limited effect of pre-existing vegetation on post-planting successional trajectories. Considering this, and the substantial amount of time needed for successional changes under semiarid conditions, it is not surprising that *P. halepensis* plantations differ from relatively undisturbed shrublands in terms of community composition and structure.

(ii) Plantations do not improve soil conditions

Comparisons on an individual tree basis indicate that some ecosystem features, as those related to soil fertility and hydrology, may improve under the canopy of *P. halepensis* at relatively fast rates. This effect is, however, spatially limited, and plantations rarely reach the values achieved in natural mature shrublands 40 years after planting. This limited improvement in most physio-chemical soil properties has been often accompanied by an increase in runoff and sediment yield, as a consequence of drastic topographical modifications during planting, and by an increase in the use of water that may have relevant hydrological consequences at the catchment scale.

(iii) There are evidences of negative effects of plantations on faunal communities

The effects of *P. halepensis* plantations on faunal communities are likely to vary depending on the animal group considered. But they often homogenize the landscape and reduce habitat diversity, two key factors that negatively affect several groups of animals (Lindenmayer and Hobbs, 2004). Despite the number of studies on the topic is very reduced, available studies suggest that *P. halepensis* plantations can reduce bird biodiversity and promote pest outbreaks in Mediterranean semiarid areas.

Socio-cultural, economic and aesthetic value of *P. halepensis* plantations in semiarid areas must be acknowledged (Dahmane, 1986; Schiller, 2001). However, policies based on the extensive use of these plantations to restore degraded semiarid Mediterranean ecosystems should be revised. Many of the negative impacts of *P. halepensis* plantations are associated with the use of single species and intense site preparation, and not with the species itself. As in other climatic areas, multi-species plantations should replace large single-specific plantations of this conifer. Whenever possible, these plantations should be performed using shrub seedlings from local provenances, to ensure appropriate adaptation to harsh environmental conditions, and with low-impact planting techniques that do not alter existing vegetation and remaining ecosystem functions. This is particularly relevant due to the negative and long-lasting impacts of the techniques employed in semiarid areas in the last decades (Chaparro, 1994). There are evidences that restoration practices are gradually changing in this direction (Pausas et al., 2004), although monospecific *P. halepensis* plantations performed with mechanized methods are still recommended and used by land managers as the main option to restore degraded ecosystems in semiarid Mediterranean areas (Rojo et al., 2002). When introducing shrubs, special attention must be paid to small-scale heterogeneity in the distribution of abiotic and biotic factors. In these areas, small changes in exposition, slope, soil surface properties and plant cover can strongly affect plant establishment and performance (Maestre et al., 2001, 2003b). This includes *P. halepensis*, whose introduction under semiarid conditions should be restricted to relatively favorable microsites (we must take into account that this species has its optimum at average precipitation higher than 350 mm; Quézel, 1986). Under these conditions, integrating small-scale spatial heterogeneity into restoration practices is a must. This represents a real challenge because of the need to understand vegetation-environment interactions at this scale, and to translate them into straightforward indicators for managers.

In addition to the proposed shift in the composition of the species used in new plantations, other management measures could be taken to improve the resilience of existing *P. halepensis* plantations, and to increase their biodiversity, measures that are frequently common to other climatic areas or vegetation types (Pausas et al., 2004). The introduction of late-successional sprouting shrubs seems to be one of the most appropriate (Vallejo et al., 1999). Communities dominated by these shrubs have the capacity to resprout quickly after disturbances (Lloret and Vilà, 1997), provide suitable habitats for wild and game animals (López and Moro, 1997), and accumulate carbon and nutrients in the soil (De la Torre and Alías, 1996). Thus, the introduction of shrubs in these plantations could stimulate successional processes, increase diversity, improve ecosystem resilience against disturbances, and have a positive effect on faunal communities. The studies performed so far suggest that this task is still challenging due to a limited success of shrub establishment in *P. halepensis* plantations (Maestre et al., 2003a). It could also be unfeasible to perform in large areas due to high-financial costs. However, the introduction of shrubs in semiarid *P. halepensis* plantations could be a suitable management measure for those slow-growing plantations having a poor reproductive capacity, and thus with limited possibilities to regenerate themselves after disturbances.

The answer to the question posed in the title of this review is not straightforward, and the topic covered will continue generating debate in the future. According to our review, we suggest that extensive, single-specific plantations of *P. halepensis* are not useful to restore semiarid Mediterranean areas, especially when they replace native shrublands and are performed with heavy machinery. Despite increased efforts to improve our understanding on the ecosystem effects of *P. halepensis* plantations under semiarid Mediterranean conditions, crucial questions remain unanswered. This is particularly surprising considering the magnitude of this practice and the risk of desertification that characterizes these areas. We hope that our review will be helpful in identifying relevant questions and fostering research on important topics. Among them, the following deserve special research attention in the future:

(i) Long-term natural vegetation dynamics in *P. halepensis* plantations

Recent studies have emphasized the slowness of successional processes in these plantations, which may not reach to pre-planting vegetation cover even 50 years after planting (Chaparro, 1994; Chirino et al., 2001; Castillo et al., 2002). However, there is a lack of information on *P. halepensis* regeneration capacity and on the spontaneous colonization of pine plantations by shrubs. These are key questions for the restoration of degraded ecosystems and the management of *P. halepensis* plantations in semiarid areas. Field observations suggest that both processes are limited: spontaneously established seedlings are rare, despite the presence of isolated old *P. halepensis* individuals and clusters of shrubs. This may be a false perception resulting form a limited record that does not integrate long-term ecosystem dynamics.

(ii) Conducting manipulative studies in *P. halepensis* plantations

Most information on the effects of *P. halepensis* plantations under semiarid conditions comes from observational studies. These are excellent explorative tools, but may lead to erroneous conclusions for several reasons, including the presence of hidden factors and spurious relationships (Quinn and Keough, 2002). Manipulative experiments are likely to provide new insights and unexpected results on the effects of planted *P. halepensis* individuals on the structure and dynamics of natural plant and faunal communities, and of ecosystem processes, and should be promoted in the future.

(iii) Effects of *P. halepensis* plantations on faunal communities

There is a clear lack on information on the impacts of these plantations on animal groups other than birds. Biodiversity criteria are expected to play an increasingly important role in the land-use policies of many countries, especially in Europe (Robson, 1997), and extensive plantations of single species are often preferred over other land uses in rural and marginal areas (Suárez et al., 1997). Thus, increasing our knowledge on the impacts of *P. halepensis* plantations on biodiversity is of capital importance from a management point of view.

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Appendix A

View of a *Pinus halepensis* plantation performed with mechanical terrazing in SE Spain, in an area of 300 mm mean annual rainfall. Note the poor colonization of the banks and the magnitude of the erosive processes, denoted by rill abundance and size.

References

Abbas, H., 1986. Les forests de pin d'Alep dans le sud-est Méditerranéen français. Analyses écodendrométriques. Options Méditerranéennes 1986-I, 127–158.

Alloza, J.A., 2003. Análisis de repoblaciones forestales en la Comunidad Valenciana. Desarrollo de criterios y procedimientos de evaluación. Ph.D. Thesis, Universitat Politècnica de València, Spain.

Alloza, J.A., Fernández, B., Fuentes, D., Boix, M., 1999. Seguimiento de repoblaciones forestales en la Comunidad Valenciana. Fundación CEAM. Unpublished Report.

Andrés, C., Ojeda, F., 2002. Effects of afforestation with pines on woody plant diversity of Mediterranean heathlands in southern Spain. Biodivers. Conserv. 11, 1511–1520.

Anonymous, 2003. La salud de nuestros bosques. Resultados de la prospección año 2002. CIDAM. Conselleria de Territori i Habitatge. Valencia.

Ares, A., Peinemann, N., 1992. Provisional site quality evaluation for coniferous plantations in Sierra de la Ventana, Argentina. For. Ecol. Manage. 54, 89–94.

Barbéro, M., Loisel, R., Quézel, P., Richardson, D.M., Romane, F., 1998. Pines of the Mediterranean Basin. In: Richardson, D.M. (Ed.), Ecology and Biogeography of Pinus. Cambridge University Press, Cambridge, pp. 153–170.

Bautista, S., 1999. Regeneración post-incendio de un pinar (*Pinus halepensis*, Miller) en ambiente semiárido. Erosión del suelo y medidas de conservación a corto plazo. Ph.D. Thesis, University of Alicante, Spain.

Bautista, S., Vallejo, R., 2002. Spatial variation of post-fire plant recovery in Aleppo pine forests. In: Trabaud, L., Prodon, R. (Eds.), Fire and Biological Processes. Backhuys Publishers, Leiden, pp. 13–24.

Bellot, J., Sánchez, J.R., Chirino, E., Hernández, N., Abdelli, F., Martínez, J.M., 1999. Effect of different vegetation type cover on the soil water balance in semi-arid areas of south eastern Spain. Phys. Chem. Earth (B) 24, 353–357.

Bellot, J., Bonet, A., Sánchez, J.R., Chirino, E., 2001. Likely effects of land use changes on the runoff and aquifer recharge in a semiarid landscape using a hydrological model. Landscape Urban Plann. 55, 41–53.

Bellot, J., Maestre, F.T., Chirino, E., Hernández, N., Ortiz de Urbina, J.M., 2004. Afforestation with *Pinus halepensis* reduces native shrub performance in a Mediterranean semiarid area. Acta Oecol. 25, 7–15.

Benabdeli, K., 1998. First dendrometrical results of Aleppo pine plantation (*Pinus halepensis* Mill.) in the Green Barrage (Aflou Algeria). Ecol. Mediterranea 24, 43–51.

Bertness, M.D., Callaway, R.M., 1994. Positive interactions in communities. Trends Ecol. Evol. 9, 191–193.

Blondel, J., Aronson, J., 1999. Biology and Wildlife of the Mediterranean Region. Oxford University Press, Oxford.

Caravaca, F., García, C., Hernández, M.T., Roldán, A., 2002. Aggregate stability changes after organic amendment and mycorrhizal inoculation in the afforestation of a semiarid site with *Pinus halepensis*. Appl. Soil Ecol. 19, 199–208.

Castillo, V., González-Barberá, G., Mosch, W., Navarro-Cano, J.A., Conesa, C., López-Bermúdez, F., 2002. Seguimiento y Evaluación de los trabajos de restauración hidrológico-forestal, III. In: López Bermudez (Ed.), Seguimiento y evaluación de los efectos sobre el medio natural de la sequía y los procesos erosivos en la Región de Murcia. Consejería de Agricultura, Agua y Medio Ambiente de la Región de Murcia, Murcia, pp. 166–233.

Castillo, V.M., Martínez-Mena, M., Albaladejo, J., 1997. Runoff and soil loss response to vegetation removal in a semiarid environment. Soil Sci. Soc. Am. J. 61, 1116–1121.

Castroviejo, S., García Dory, M.A., Martínez, S., Prieto, F., 1985. Política forestal en España (1940–1985). Quercus 19, 1–51.

Chakroun, M.L., 1986. Le pin d'Alep en Tunisie. Options Méditerranéennes 1986-I, 25–27.

Chaparro, J., 1994. Consecuencias ambientales de repoblaciones forestales mediante aterrazamientos en ambientes semiáridos. M.Sc. Thesis, University of Murcia, Spain.

Chaparro, J., Esteve, M.A., 1996. Criterios para restaurar la vegetación en ambientes mediterráneos semiáridos. Quercus 121, 14–17.

Chirino, E., Sánchez, J.R., Bonet, A., Bellot, J., 2001. Effects of afforestation and vegetation dynamics on soil erosion in a semi-arid environemnt (SE Spain). In: Villacampa Y., Brebbia, C.A., Usó, J.L. (Eds.), Ecosystems and Sustainable Development III. WIT Press, Southampton, pp. 239–248.

Ciancio, O., 1986. Sylviculture du pin d'Alep. Options Méditerranéennes 1986-I, 47–54.

Cortina, J., Bellot, J., Vilagrosa, A., Caturla, R., Maestre, F.T., Rubio, E., Martínez, J.M., Bonet, A., in press. Restauración en semiárido. In: Vallejo, R., Alloza, J.A. (Eds.), Avances en la Gestión del Monte Mediterráneo. CEAM- Conselleria de Medio Ambiente, Valencia.

Cortina, J., Valdecantos, A., Fuentes, D., Casanova, G., Vallejo, V.R., Díaz Bertrana, J.M., Llavador, F., Ruano, R., 2001. El uso de biosólidos en el sector forestal valenciano. Foresta 13, 64–69.

Dahmane, M., 1986. Les produits du Pin d'Alep en Tunisie. Options Méditerranéennes 1986-I, 157–161.

De las Heras, J., Martínez-Sánchez, J.J., González-Ochoa, A.I., Ferrandis, P., Herranz, J.M., 2002. Establishment of *Pinus halepensis* Mill. saplings following fire: effects of competition with shrub species. Acta Oecol. 23, 91–97.

De la Torre, A., Alías, L.J., 1996. Suelos y vegetación en el Alto Vinalopó. Universidad de Alicante, Alicante.

Diaz, M., Carbonell, R., Santos, T., Telleria, J.L., 1998. Breeding bird communities in pine plantations of the Spanish plateaux: biogeography, landscape and vegetation effects. J. Appl. Ecol. 35, 562–574.

Esteve, M.A., Ferrer, D., Ramírez-Díaz, L., Calvo, J.F., Suárez, M.L., Vidal-Abarca, M.R., 1990. Restauración de la vegetación en ecosistemas áridos y semiáridos: algunas reflexiones ecológicas. Ecología. Fuera de Serie 1, 497–510.

European Commission, 1996. Forest Fires in the South of the European Union, 1989–1993. Pilot Project in Preparation for the Setting Up of the Community Forest-fire Information System. Office for Official Publications of the EC, Luxembourg.

Ferrandis, P., de las Heras, J., Herranz, J.M., Martínez- Sánchez, J.J., 2001. Influence of a low-intensity fire on a *Pinus halepensis* Mill. forest seed bank and its consequences on the early stages of plant succession. Isr. J. Plant Sci. 49, 105–114.

García, J., 1990. La repoblación forestal: técnicas y repercusión en la mejora de la calidad del suelo. In: Albaladejo, J., Stocking, M.A., Díaz, E. (Eds.), Soil Degradation and Rehabilitation in Mediterranean Environmental Conditions. CSIC, Murcia, pp. 117–137.

Guevara, J.C., Silva Colomer, J.H., Estevez, O.R., Paez, J.A., 2003. Simulation of the economic feasibility of fodder shrub plantations as a supplement for goat production in the north-eastern plain of Mendoza, Argentina. J. Arid Environ. 53, 85–98.

Halperin, J., Mendel, Z., Golan, Y., 1982. On the damage caused by bark beetles to pine plantations. Preliminary report. La-Yaraan 32, 31–38.

Herranz, J.M., 2000. Aspectos botánicos y ecológicos del pino carrasco (*Pinus halepensis* Mill.). Cuad. Soc. Esp. Cien. For. 10, 13–17.

Herranz, J.M., Martínez-Sánchez, J.J., Marin, A., Ferrandis, P., 1997. Postfire regeneration of *Pinus halepensis* Miller in a semi-arid area in Albacete province (Southeastern Spain). Ecoscience 4, 86–90.

Holl, K.D., Howarth, R.B., 2000. Paying for restoration. Restor. Ecol. 8, 260–267.

Kadik, B., 1982. Le Barrage Vert: caractéristiques écologiques. Bull. Tech. For. I.N.R.F. 7, 9–14.

Keller, A.A., Goldstein, R.A., 1998. Impact of carbon storage through restoration of drylands on the global carbon cycle. Environ. Manage. 22, 757–766.

Lindenmayer, D.B., Hobbs, R.J., 2004. Fauna conservation in Australian plantation forests—a review. Biol. Conserv. 119, 151–168.

Liphschitz, N., Mendel, Z., 1989. Pathological changes in the cortex of *Pinus halepensis* (Coniferales: Pinaceae) as related to injury by *Matsucoccus josephi* (Insecta: Homoptera: Margarodidae). Can. J. Bot. 67, 2692–2703.

Lloret, F., Vilà, M., 1997. Clearing of vegetation in Mediterranean garrigue: response after a wildfire. For. Ecol. Manage. 93, 227–234.

Lookingbill, T.R., Zavala, M.A., 2000. Spatial pattern of *Quercus ilex* and *Quercus pubescens* recruitment in *Pinus halepensis* dominated woodlands. J. Veg. Sci. 11, 607–612.

López, G., Moro, M.J., 1997. Birds of Aleppo pine plantations in south-east Spain in relation to vegetation composition and structure. J. Appl. Ecol. 34, 1257–1272.

López Bermúdez, F., 1990. Soil erosion by water on the desertification of a semi-arid Mediterranean fluvial basin: the Segura Basin, Spain. Agric. Ecosys. Environ. 33, 129–145.

Maestre, F.T., 2002. La restauración de la cubierta vegetal en zonas semiáridas en función del patrón espacial de factores bióticos y abióticos. Ph.D. Thesis, University of Alicante, Spain.

Maestre, F.T., Bautista, S., Cortina, J., Bellot, J., 2001. Potential for using facilitation by grasses to establish shrubs on a semiarid degraded steppe. Ecol. Appl. 11, 1641–1655.

Maestre, F.T., Cortina, J., Bautista, S., Bellot, J., 2003a. Does *Pinus halepensis* facilitate the establishment of shrubs under semi-arid climate? For. Ecol. Manage. 176, 147–160.

Maestre, F.T., Cortina, J., Bautista, S., Bellot, J., Vallejo, R., 2003b. Small-scale environmental heterogeneity and spatio-temporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems 6, 630–646.

Martínez-Ferri, E., Balaguer, L., Valladares, F., Chico, J.M., Manrique, E., 2000. Energy dissipation in drought-avoiding and drought-tolerant tree species at midday during the Mediterranean summer. Tree Physiol. 20, 131–138.

Mendel, Z., 1984. Provenance as a factor in susceptibility of *Pinus halepensis* to *Matsucoccus josephi* (Homoptera: Margarodidae). For. Ecol. Manage. 9, 259–266.

Mendel, Z., 1990. On the origin of the pine processionary caterpillar, *Thaumetopoea wilkinsoni* Tams (Lepidoptera, Thaumetopoeidae) in Israel. J. Appl. Entomol. 109, 311–314.

Mendel, Z., Assael, F., Zeidan, S., Zehav, A., 1998. Classical biological control of *Palaeococcus fuscipennis* (Burmeister) (Homoptera: Margarodidae) in Israel. Biol. Control 12, 151–157.

Mendel, Z., Halperin, J., 1982. The biology and behavior of *Orthotomicus erosus* in Israel. Phytoparasitica 10, 169–181.

Mendel, Z., Madar, Z., Golan, Y., 1985. Comparison of the seasonal occurrence and behavior of 7 pine bark beetles (Coleoptera: Scolytidae) in Israel. Phytoparasitica 13, 21–32.

Mintegui, J.A., 1989. Evaluación de beneficios físicos derivados de la restauración hidrológico-forestal y la conservación de suelos en cuencas torrenciales. In: Degradación de zonas áridas en el entorno mediterráneo. Monografías de la Dirección General de Medio Ambiente, Madrid, pp. 37–54.

Millán, M., Estrela, M.J., Caselles, V., 1995. Torrential precipitation on the Spanish East Coast: the role of the Mediterranean sea surface temperature. Atmos. Res. 36, 1–16.

Millán, M., Estrela, M.J., Bardenas, C., 1997. Meteorological processes relevant to forest fire dynamics on the Spanish Mediterranean Coast. J. Appl. Meteorol. 37, 83–100.

Moravec, J., 1990. Regeneration of N.W. Africa *Pinus halepensis* forests following fire. Vegetatio 87, 29–36.

Moreno, J.M., 1999. Forest fires: trends and implications in desertification prone areas of Southern Europe. In: Balabanis, P., Peter, D., Ghazi, A., Tsogas, M. (Eds.), Mediterranean Desertification. Research results and policy implications. Office for Official Publications of the European Communities, Luxembourg, pp. 115–150.

Ne'eman, G., 2000. The effect of burned pine trees on post-fire regeneration. In: Ne'eman, G., Trabaud, L. (Eds.), Ecology, Biogeography and Management of *Pinus halepensis* and *P. brutia* Forest Ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, pp. 303–319.

Olarieta, J.M., Usón, A., Rodríguez, R., Rosa, M., Blanco, R., Antúnez, M., 2000. Land requirements for *Pinus halepensis* Mill. growth in a plantations in Huesca, Spain. Soil Use Manage. 16, 88–92.

Oliet, J., Planelles, R., López Arias, M., Artero, F., 2002. Soil water content and water relations in planted and naturally regenerated

Pinus halepensis Mill. seedlings during the first year in semiarid conditions. New For. 23, 31–44.

Ortuño, F., 1990. El plan para la repoblación forestal de España del anõ 1939. Análisis y comentarios. Ecología 1, 373–392.

Pastor, A., 1995. Repoblaciones forestales con *Pinus halepensis* en la provincia de Alicante. Evaluación ecológica del método de revegetación habitual en la cuenca mediterránea española. In: Pastor, A., Seva, E. (Eds.), Restauración de la cubierta vegetal en ecosistemas mediterráneos. Instituto de Cultura Juan Gil-Albert, Alicante, pp. 81–120.

Pastor, A., Martín, J., 1989. Tipificación de la calidad en repoblaciones de pino carrasco (*Pinus halepensis* Mill.) en Alicante. Implicaciones con la gestión forestal. Options Méditerranéennes 1989-3, 313–317.

Pausas, J.G., 1999. The response of plant functional types to changes in the fire regime in Mediterranean ecosystems. A simulation approach. J. Veg. Sci. 10, 717–722.

Pausas, J.G., 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: new perspectives for an old practice. Plant Ecol. 171, 209–220.

Pausas, J.G., Ouadah, N., Ferran, A., Gimeno, T., Vallejo, R., 2003. Fire severity and seedling establishment in *Pinus halepensis* woodlands, eastern Iberian Peninsula. Plant Ecol. 169, 205–213.

Peñuelas, J.L., Ocaña, L., 1996. Cultivo de plantas forestales en contenedor. Ministerio de Agricultura, Pesca y Alimentación & Mundi-Prensa, Madrid.

Prodon, R., 2000. Landscape dynamics and bird diversity in the north Mediterranean basin: conservation issues. In: Trabaud, L. (Ed.), Life and Environment in the Mediterranean. WIT Press, Southampton, pp. 261–299.

Puigdefábregas, J., Mendizábal, T., 1998. Perspectives on desertification: western Mediterranean. J. Arid Environ. 39, 209–224.

Querejeta, J.I., Roldán, A., Albaladejo, J., Castillo, V., 1998. The role of mycorrhizae, site preparation, and organic amendment in the afforestation of a semi-arid mediterranean site with *Pinus halepensis*. For. Sci. 44, 203–211.

Querejeta, J.I., Roldán, A., Albaladejo, J., Castillo, V., 2001. Soil water availability improved by site preparation in a *Pinus halepensis* afforestation under semiarid climate. For. Ecol. Manage. 149, 115–128.

Questienne, P., 1979. Notes sur quelques insectes nuisibles aux pins au Maroc. Annales de Gembloux 85, 113–130.

Quézel, P., 1986. Les pins du groupe "Halepensis". Ecologie, végétation, écophysiologie. Options Méditerranéennes 1986-I, 11–23.

Quézel, P., 2000. Taxonomy and biogeography of Mediterranean pines (*Pinus halepensis* and *P. brutia*). In: Ne'eman, G., Trabaud, L. (Eds.), Ecology, Biogeography and Management of *Pinus halepensis* and *P. brutia* Forest Ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, pp. 1–12.

Quinn, G.P., Keough, M.J., 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge, UK.

Reynolds, J.F., 2001. Desertification. In: Levin, S.A. (Ed.), Encyclopedia of Biodiversity, vol. 2. Academic Press, London, pp. 61–78.

Richardson, D.M., 1988. Age structure and regeneration after fire in a self-sown *Pinus halepensis* forest in the Cape Peninsula, South Africa. S. Afr. J. Bot. 54, 140–144.

Richardson, D.M., Higgins, S.I., 1998. Pines as invaders in the Southern Hemisphere. In: Richardson, D.M. (Ed.), Ecology and Biogeography of *Pinus.* Cambridge University Press, Cambridge, pp. 450–474.

Robson, N., 1997. The evolution of Common Agricultural Policy and the incorporation of environmental considerations. In: Pain, D.J., Pienkowski, M.W. (Eds.), Farming and Birds in Europe. Academic Press, London, pp. 43–78.

Rojo, L., García, F., Martínez, J.A., Martínez, A., 2002. Management plan to combat desertification in the Guadalentín River basin. In: Geeson, N.A., Brandt, C.J., Thornes, J.B. (Eds.), Mediterranean Desertification: A Mosaic of Processes and Responses. Wiley, Chichester, pp. 303–317.

Roldán, A., Querejeta, I., Albaladejo, J., Castillo, V.M., 1996. Growth response of *Pinus halepensis* to inoculation with *Pisolithus arhizus* in a terraced rangeland amended with urban refuse. Plant Soil 179, 35–43.

Ruiz de la Torre, J., 1973. Significación de los pinares xerófilos. Vida Silvestre 6, 108–113.

Sánchez, J.R., 1997. Estimación de las pérdidas erosivas inducidas por las técnicas de preparación del suelo previa a la reforestación en el sur de la Comunidad Valenciana. Ph.D. Thesis, University of Alicante, Spain.

Sánchez-Zapata, J.A., Calvo, J.F., 1999. Raptor distribution in relation to landscape composition in semi-arid Mediterranean habitats. J. Appl. Ecol. 36, 254–262.

Schiller, G., 1978. Factors Involved in Natural Regeneration of Aleppo Pine. Ph.D. Thesis, University of Tel-Aviv, Israel (Hebrew with English summary).

Schiller, G., 2001. Biometeorology and recreation in east Mediterranean forests. Lands. Urban Plann. 57, 1–12.

Schiller, G., Cohen, Y., 1998. Water balance of *Pinus halepensis* Mill. afforestation in an arid region. For. Ecol. Manage. 105, 121–128.

Schlesinger, W.H., Reynolds, J.F., Cunningham, G.L., Huenneke, L.F., Jarrell, W.M., Virginia, R., Whitford, W.G., 1990. Biological Feedbacks in Global desertification. Science 247, 1043–1048.

Serrada, R., 1990. Consideraciones sobre el impacto de la repoblación forestal en el suelo. Ecología Fuera de Serie 1, 453–462.

Shirihai, H., 1996. The Birds of Israel. Academic Press, London.

Shochat, E., Abramsky, Z., Pinshow, B., 2001. Breeding bird species diversity in the Negev: effects of scrub fragmentation by planted forests. J. Appl. Ecol. 38, 1135–1147.

Suárez, F., Naveso, M.A., de Juana, E., 1997. Farming in the drylands of Spain: birds of the pseudosteppes. In: Pain, D.J., Pienkowski, M.W. (Eds.), Farming and Birds in Europe. Academic Press, London, pp. 297–330.

Thanos, C.A., Daskalakou, E.N., 2000. Reproduction in *Pinus halepensis* and *Pinus brutia*. In: Ne'eman, G., Trabaud, L.

(Eds.), Ecology, Biogeography and Management of *Pinus halepensis* and *P. brutia* Forest Ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, pp. 79–90.

Trabaud, L., 1991. Is fire an agent favouring plant invasions?. In: Groves, R.H., Di Castri, F. (Eds.), Biogeography of Mediterranean Invasions. Cambridge University Press, Cambridge, pp. 179–190.

Valdecantos, A., Vilagrosa, A., Seva, J.P., Cortina, J., Vallejo, V.R., Bellot, J., 1996. Mycorhization et application du compost urbain pour l'amélioration de la survie et de la croissance des semis de *Pinus halepensis* en milieu semiaride. Options Méditerranéennes 20, 87–104.

Vallejo, V.R., Bautista, S., Cortina, J., 1999. Restoration for soil protection after disturbances. In: Trabaud, L. (Ed.), Life and Ecosystems in the Mediterranean. WIT Press, Southampton, pp. 301–344.

Vilagrosa, A., Caturla, R.N., Hernández, N., Cortina, J., Bellot, J., Vallejo, V.R., 2001. Reforestación en ambiente semiárido del sureste peninsular. Resultados de las investigaciones desarrolladas para optimizar la supervivencia y el crecimiento de especies autóctonas. In: Ponencias del III Congreso Forestal Español. Consejería de Medio Ambiente, Granada, Spain.

Vilagrosa, A., Seva, J.P., Valdecantos, A., Cortina, J., Alloza, J.A., Serrasolsas, I., Diego, V., Abril, M., Ferran, A., Bellot, J., Vallejo, V.R., 1997. Plantaciones para la restauración forestal en la Comunidad Valenciana. In: Vallejo, V.R. (Ed.), La restauración de la cubierta vegetal en la Comunidad Valenciana. Centro de Estudios Ambientales del Mediterráneo y Generalitat Valenciana, Valencia, Spain, pp. 435–546.

Vázquez, A., Pérez, B., Fernández-González, F., Moreno, J.M., 2002. Recent fire regime characteristics and potential natural vegetation relationships in Spain. J. Veg. Sci. 13, 663–676.

Vélez, R., 1986. Fire prevention in Aleppo pine forests. Options Mediterranéennes 1986-I, 167–178.

V.V.A.A., 2001. Segundo Inventario Forestal Nacional. Obra completa. 50 provincias. CD-ROM. Ministerio de Medio Ambiente, Madrid.