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Post-fire regeneration of *Pinus halepensis* Mill. stands in the Sithonia peninsula, northern Greece

Theocharis Zagas*, Petros Ganatsas, Thekla Tsitsoni & Marianthi Tsakaldimi
*Aristotle University of Thessaloniki, Faculty of Forestry and Natural Environment, Department of Silviculture, P.O. Box 262, 54 124, Thessaloniki, Greece; *Author for correspondence (e-mail zagas@for.auth.gr)*

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Abstract

This paper deals with the post-fire regeneration of *Pinus halepensis* Mill. ecosystems in the Sithonia peninsula in northern Greece. The pre-burning stands consisted of two storeys; the overstorey of the dominant tree species *P. halepensis* and the understorey of evergreen sclerophyllous shrubs. The wildfire took place in June 1994. Three months after the fire two experimental plots of 0.75 ha each were established on a northeastern and a southwestern facing slope. In each experimental plot different restoration treatments were applied by using *P. halepensis* reproductive material. The treatments were the following: (i) planting of paper- pot seedlings, (ii) planting of bare-root seedlings, (iii) seeding in patches, (iv) seeding in strips, (v) seeding in strips and lines. The results of these treatments were compared to the control (no treatment applied). The results showed that all applied restoration works accelerated the rate of regeneration, while the best results were obtained by the method of planting paper-pot seedlings.

Introduction

Pinus halepensis Mill. forests belong to the mediterranean ecosystems extending to the zone of evergreen sclerophyllous shrubs where fire plays an important role in their regeneration (Dafis 1987; Trabauld 1987; Naveh 1991). In most cases, after a wildfire, natural regeneration of *P. halepensis* mature stands is secured (Trabaud et al. 1985; Thanos and Marcou 1991; Ne'eman et al. 1995; Tsitsoni 1997; Thanos 2000; Arianoutsou and Ne'eman 2000). The experience and the research in different Mediterranean countries showed that in some cases, under the influence of some limiting factors (e.g., steep slopes, overgrazing), the natural regeneration of *P. halepensis* may not succeed (Dafis 1987; Tsitsoni 1997; Vallejo et al. 1999). *P. halepensis* is an obligate seeder and its natural stands require approximately 15 years to produce an abundant number of mature seeds (Tapias et al. 2001); even-aged *P. halepensis* forests reach reproductive maturity after the age of 15–20 years, depending on environmental conditions and site quality (Arianoutsou 1999; Thanos and Daskalakou 2000). Thus, if fire re-occurs at intervals shorter than that, there are no adequate quantities of seeds to germinate, resulting in the lack of post fire regeneration (Dafis 1987; Arianoutsou 2001; Arianoutsou et al. 2002). In addition, when the inclination of the slope is greater than 50%, post-fire regeneration may be reduced (Arianoutsou et al. 2000); as the inclination becomes sharper pine regeneration becomes quite difficult as seeds may be washed away from the slope (Tsitsoni 1997). In order to encourage *P. halepensis* regeneration in these cases artificial intervention is necessary.

Generally, the artificial establishment of *P. halepensis* seedlings does not present special difficulties (Hatzistathis et al. 1995; Hatzistathis et al. 1999; Vallejo et al. 1999; Tsakaldimi 2001). However, knowledge of the behavior of both seedlings and saplings and their evolution in the case of artificial restoration is lacking. Only a few studies exist in which differences between various establishment methods (seeding or planting) are examined (Hatzistathis et al. 1995; Hatzistathis et al. 1999; Tsitsoni et al. 1999).

Studies on the co-existence and intraspecific competition between planted and naturally regenerated Aleppo pine seedlings are also few (Tsitsoni and Zagas 1988; Hatzistathis et al. 1999). Results on *in situ* seeding techniques too are almost absent in bibliography. Furthermore, little is known about the management practices in recently burnt Mediterranean forests (Ne'eman et al. 1995; Martinez-Sanchez et al. 1999). Consequently, this study focuses on the following objectives:

(i) Which method is suitable to achieve a quick re-establishment of *P. halepensis* stands in the burnt area (planting, seeding, combination of them).
(ii) To what extent the artificial intervention should be applied (planting on the whole burnt area or on part of the area, seeding on the whole area).

Materials and methods

Study area

The study was performed in the Sithonia peninsula at Chalkidiki, northern Greece. The vegetation of the area belongs to the Mediterranean vegetation zone, *Quercetalia ilicis* and particularly to the association *Oleo-lentiscetum*. The climate of the area belongs to the Mediterranean type (Csa) according to Koeppen classification. The annual amount of rainfall reaches 420 mm and the dry period has an average duration of 5–6 months, lasting from April to September (data from the meteorological station in Ag. Mamas for the period 1988–1997). The region consists of low and hilly elevations (average height 80–100 m asl). Geologically, the Sithonia peninsula belongs to the Axios zone and Circum Rhodope zone. The parent rock materials of the peninsula are mainly igneous and crystalline-schists and only a small part of it is covered by sedimentary formations, such as limestone with tertiary and quaternary depositions (Mountrakis 1985).

The fire took place at the beginning of the summer of 1994 (6 of June 1994). The area had repeatedly been burnt prior to that. The last fire had occurred 45 years before as was proved by the age of the Aleppo pine trees (as the tree ring measurements showed). Before the last wildfire the vegetation of the experimental area was dominated mainly by evergreen broadleaf shrubs *Quercus coccifera* L., *Pistacia lentiscus* L., *Phillyrea latifolia* L., *Olea europaea* var. *sylvestris* Brot., *Erica arborea* L., *Arbutus unedo* L., *A. andrachne* L. and some seasonal dimorphic sub-shrubs *Anthyllis hermanniae* L, *Cistus creticus* L., *C. salviifolius* L., *C. monspeliensis* L. and *Calicotome villosa* (Poiret) Link. Scattered *P. halepensis* trees (ca. 50 trees per hectare) could also be found in the area.

Experimental design

All burnt pine individuals and shrubs were cut down and removed (cleared area) 3 months after the fire (September 1994). Two permanent plots of 0.75 ha were established on slopes of different aspects (NE and SW). Each plot was divided into three subplots of 50 m × 50 m (Figure 1). One subplot was left untreated as a control. The second subplot was fenced into prevent grazing and the third subplot was subjected to different treatments that were arranged in a 'Latin Square' design, with five replications with the same treatment (10 m × 10 m).

In all treatments *P. halepensis* reproductive material was applied. Planting was carried out in early December 1994, seeding in early January 1995. The seedlings were produced in the State Forest nursery of Thessaloniki. Selected seedlings had a height ranging from 20–35 cm, a diameter greater than 4 mm and a rich fibrous root system. Especially in the case of the bare root seedlings we tried to avoid any damage to their root system during extraction from the nursery and transportation to the field. Analytically, the treatments applied were:

A = Planting of one-year old paper-pot (FS615) seedlings at a spacing of 2 m × 2 m; 25 seedlings per subplot of 100 m^2, 250 in total (in the two plots).
B = Planting of one-year old bare-root seedlings at a spacing of 2 m × 2 m; 25 seedlings per subplot of 100 m^2, 250 in total.
C = Seeding in patches in a radius of 0.25 m; 25 patches per subplot of 100 m^2; the distance between the patches were 2 m, with 10 seeds in each patch; total number of seeds 250 per subplot or 3 seeds per m^2.
D = Seeding in strips; strip size 0.8 m × 10 m, with 1.5 m distance between the strips; 4 strips per subplot of 100 m^2; 1750 seeds (approximately) in each strip; total number of seeds 7000 per subplot or 70 seeds per m^2.
E = Seeding in strips and lines; strip size 0.8 m × 10 m, with a distance between two strips of 1.5 m; 4 strips per subplot of 100 m^2, distance between two lines in the same strip = 0.30 m, number of lines in each strip 3; 300 seeds per line; number of

A	**B**	**C**	**D**	**E**		
D	**E**	**B**	**C**	**A**	**AREA**	
E	**A**	**D**	**B**	**C**	**PROTECTED**	**CONTROL**
C	**D**	**A**	**E**	**B**	**FROM**	**AREA**
B	**C**	**E**	**A**	**D**	**GRAZING**	

|------------ 50 m --------------|------------- 50 m --------------| ---------- 50 m -------------- |

Figure 1. Experimental design of each plot. A = planting of paper-pot seedlings, B = planting of bare root seedlings, C = seeding in patches, D = seeding in strips, E = seeding in strips and lines.

seeds per strip 900; total number of seeds 3600 or 36 seeds per m^2.

Sampling and data analysis

The first sampling was performed six months after the establishment of the plots (June 1995) and the following parameters were recorded: number of dead plants (mortality percentage), number of germinated seeds, seedling height (cm) and seedling diameter at ground level (collar diameter, cm).

Subsequent measurements were taken in October 1995, June 1996, December 1996 and June 2002. These concerned the number of dead seedlings, the number of germinated seeds, seedling height, ground level diameter of seedlings or saplings, maximum (Dmax) and minimum (Dmin) diameter of crown of each seedling or sapling, vitality and developmental tendency. Crown cover of the saplings was estimated using the mean crown diameter of each sapling.

The vitality and the developmental tendency were estimated according to IUFRO classification as follows:

Vitality: 10 = vigorous saplings, 20 = normally growing saplings, 30 = declining saplings. Developmental tendency: 1 = overgrowing saplings (in height), 2 = normally growing saplings, 3 = saplings with reduced growth.

Statistical analysis was performed using the SPSS package. The effect of the treatments on seedling survival, height, diameter and diameter of crown was assessed by one-way ANOVA followed by Waller-Duncan test ($P < 0.05$, Norusis 1994). All figure bars indicated by different letters are statistically different. Error bars represent standard error of the mean.

Results

Emergence, mortality and density of seedlings

Before seeding in the field, seeds were tested in the laboratory and were found mature, performing high germination capacity (over 80%). However, germination in the field (% of the initial number of seeds) was found extremely low in all seeding treatments and it was less than 3% during the first year (Table 1). On one hand, this low germination was probably due to the very dry spring and autumn of 1995 (the monthly precipitation of April, May, June, October and November was only 11, 6, 0, 7 and 39 mm, respectively), and on the other hand, to the high consumption of seeds by rodents and especially by birds. Germination increased in the second year, reaching from 2.77% to 8.24% in the treatment ‘seeding in patches’. In the other two seeding treatments (seeding in strips and seeding in strips and lines) the germination reached only 2.09% in both treatments, while in the first year it was 0.83% and 1.12%, respectively. This means that germination in the second year increased three-fold in the treatments ‘seeding in patches’ and ‘seeding in strips’, and more than doubled in the treatment ‘seeding in strips and lines’. The above results were probably due to the better weather conditions of this year (1996). Germination continued after the second year and the final goal seven years after seeding was 0.36, 0.87 and 0.42 seedlings per m^2, respectively. At the same time, naturally regenerated *P. halepensis* seedlings per m^2 (control plot) were 0.15 in the first year, 0.16 in the second and 0.28 per m^2 seven years later. Because there was no grazing pressure during the experiment, no differences were found between the fenced and the control subplots. In addition, no significant differences were found between plots of the two aspects, so data are treated together (Table 1).

Table 1. Seeding results seven years after seeding.

Seeding treatment	6 months			12 months			18 months			24 months			7 years
	Germination	Mortality	Survival Seedlings	Germination	Mortality	Survival Seedlings	Germination	Mortality	Survival Seedlings	Germination	Mortality	Survival Seedlings	Seedlings
	%	%	/m^2	%	%	/m^2	%	%	/m^2	%	%	/m^2	/m^2
In patches	2.57	1.30	0.08	2.77	6.02	0.08	8.24	2.91	0.20	8.24	2.91	0.20	0.36
In strips	0.68	2.32	0.46	0.83	4.00	0.56	2.09	2.61	1.42	2.09	2.61	1.42	0.87
In strips and lines	0.96	4.35	0.33	1.12	7.69	0.37	2.09	5.2	0.71	2.09	5.20	0.71	0.42
Control						0.15			0.16			0.17	0.28

The mortality of seeded seedlings was very low and varied from 2.91% in the treatment 'seeding in patches', to 2.61%, in 'seeding in strips' and 5.2% in 'seeding in strips and lines' and was almost the same during the first and the second semester but lower in the second year. Seven years after the seeding, mortality of saplings reached 38.9% in the treatment 'seeding in strips' and 41.2% in the treatment 'seeding in strips and lines'. The high mortality at this stage always appeared in microsites where saplings density was very high (distance between saplings less than 10 cm). This high density resulted in very close crown development of the saplings, which developed extremely thin branches within this limited space of 10 cm. As a consequence, many saplings in these positions died, probably as a result of high intraspecific competition.

The planted seedlings also exhibited low mortality during the seven years after planting (Figure 2). The paper-pot seedlings had a very low mortality rate (4.8%), which was significantly lower than bare-root seedlings (20.2%) one year after planting. It is remarkable that not one seedling died after the second semester; mortality in both treatments was observed only during the first period after planting (before the summer) and it was attributed to the transplanting shock. Eventhough young trees reached a height of over 3 meters and the crown in many cases exceeded the width of 2-m (space available for each sapling), no sapling death was observed during the latter years. Thus, no evident sign of strong competition between saplings for aboveground or belowground resources was observed.

Eventhough the best germination two years after seeding was observed in the treatment 'seeding in patches', the final sapling density (survived seedlings per m^2), was found greater in the treatment 'seeding in strips' (1.42 seedlings per m^2), because of the higher initial number of seeds (Table 1). The treatment 'seeding in strips and lines' followed with 0.71 seedlings per m^2, while the 'seeding in patches' resulted in 0.20 seedlings per m^2. Finally, eight years after the fire (seven years after treatments application), the saplings surviving in the treatment 'seeding in patches' were 0.36 per m^2, 0.87 saplings per m^2 in the treatment 'seeding in strips', 0.42 saplings per m^2 in the treatment 'seeding in strips and lines' and 0.28 saplings per m^2 in control plots (natural regeneration). Sapling density in planting treatments was similar to that of the seeding. Seven years after planting the density reached 0.35 and 0.34 saplings per m^2 for paper-pot and bare-root seedlings respectively. How-

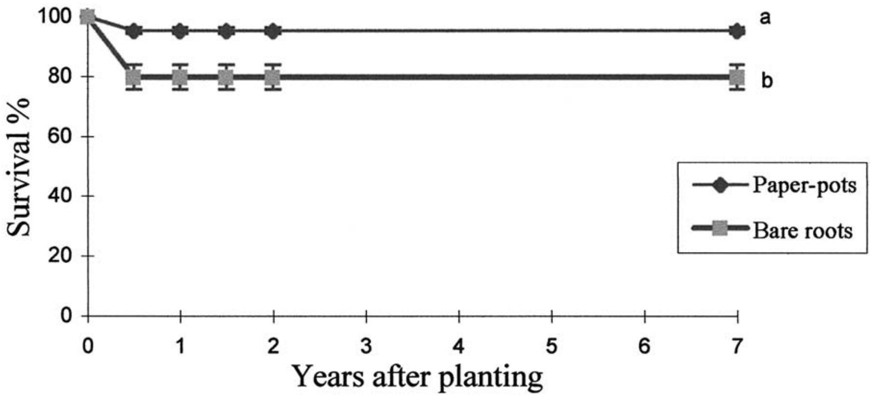

Figure 2. Survival rate (%) of planted seedlings of *P. halepensis*, seven years after planting. Values followed by a different letter are significantly different at the 0.05 level (Duncan test).

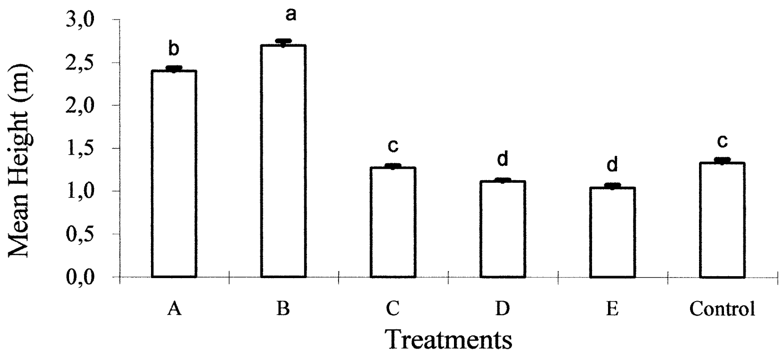

Figure 3. Mean height (m) of the saplings in the different treatments, 8 years after the fire. A = paper-pot seedlings, B = bare-root seedlings, C = seeding in patches, D = seeding in strips, E = seeding in strips and lines. Values followed by a different letter are significantly different at the 0.05 level (Duncan test).

ever, approximately 1/3 of that density was attributed to natural regeneration.

Growth and quality of seedlings

Concerning the seedlings growth, this ranged widely between the treatments. The planted seedlings were more than doubled in height than the seeded ones; seven years after the planting, the average height was 2.40 m for paper-pot seedlings and 2.70 m for bare-root seedlings (Figure 3). In all seeding treatments the average height of seedlings was significantly lower, ranging from 1.04 to 1.33 m. The naturally established seedlings had similar height to those of 'seeding in patches', while 'seeding in strips' and 'seeding in strips and lines' gave the lowest seedlings, as it is shown in Figure 3.

Similar statistical differences were observed in the seedlings' root-collar diameter (Figure 4); thus, the mean collar diameter of the planted seedlings was significantly greater (6.17 and 6.33 cm) than that of the seeded seedlings; the average diameter of the last seedlings ranged from 1.69 to 2.19 cm. Naturally established seedlings had a similar diameter to that of 'seeding in patches' while 'seeding in strips' and 'seeding in strips and lines' treatments gave the thinnest seedlings. Crown dimensions also ranged among the treatments and they were significantly greater in the planted seedlings (Figure 5).

Quality of seedlings was better in planted seedlings, followed by the naturally regenerated seedlings and seedlings coming from seeding in patches (Table 2). All the planted saplings exhibited good vitality and a high developmental tendency that was the same for both planting treatments. Among the seeding treatments the most vigorous saplings in both aspects were those of the treatment 'seeding in patches'. A possible explanation for this is that these saplings were more homogeneously distributed in the area, having adequate space and thus probably they did not

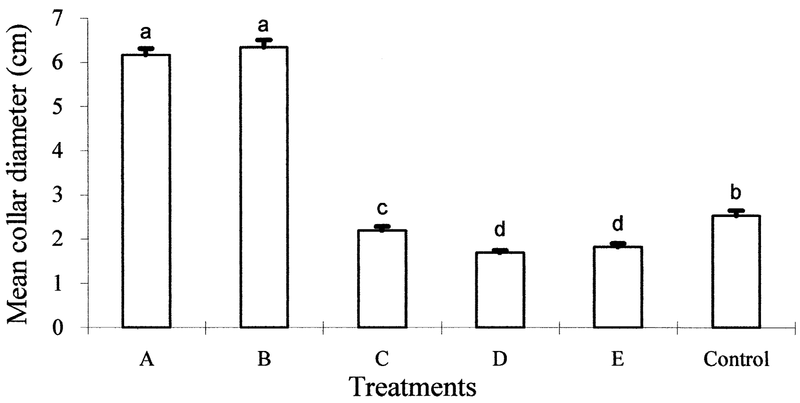

Figure 4. Mean collar diameter of the saplings (cm) in the different treatments, 8 years after the fire. A = paper-pot seedlings, B = bare-root seedlings, C = seeding in patches, D = seeding in strips, E = seeding in strips and lines. Values followed by a different letter are significantly different at the 0.05 level (Duncan test).

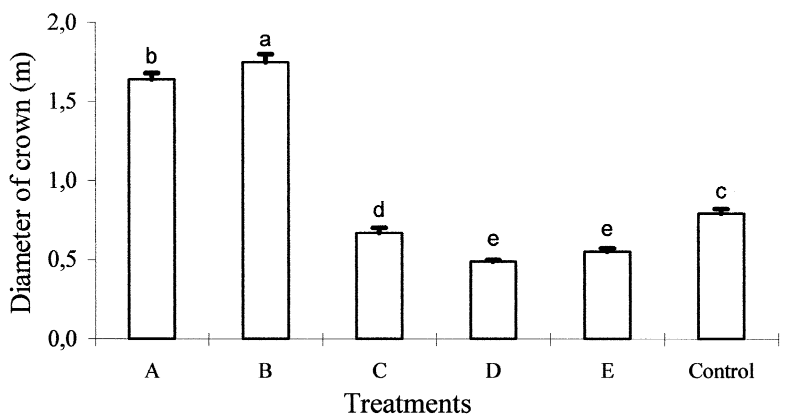

Figure 5. Mean diameter of the sapling crown (cm) in the different treatments, 8 years after the fire. A = paper-pot seedlings, B = bare root seedlings, C = seeding in patches, D = seeding in strips, E = seeding in strips and lines. Values followed by a different letter are significantly different at the 0.05 level (Duncan test).

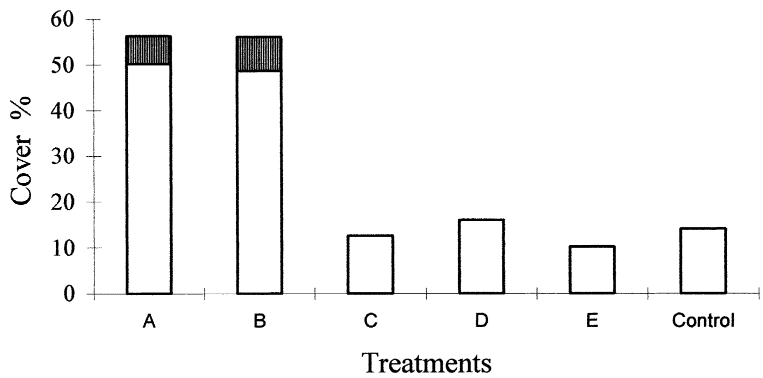

Figure 6. Mean *P. halepensis* cover (% of the surface) in the different treatments. The grid bars represent the percentage cover of natural regeneration of this species. A = paper-pot seedlings, B = bare root seedlings, C = seeding in patches, D = seeding in strips, E = seeding in strips and lines.

Table 2. Mean developmental tendency (DT), mean vitality (V) and number of seedlings per ha (N/ha) of each treatment applied. * = Natural regeneration. A = planting of paper-pot seedlings, B = planting of bare-root seedlings, C = seeding in patches, D = seeding in strips, E = seeding in strips and lines.

Treatment	DT	V	N/ha
A	1.61	16.1	2375 +1225*
B	1.60	16	2025 +1475*
C	2.10	21	3550
D	2.26	22.6	8675
E	2.23	22.3	4175
Control	2.11	21.1	2825

suffer from intensive competition imposed by other individuals.

Canopy cover

The canopy cover of *P. halepensis* saplings was much higher in the case of the plantations (in both A and B treatments) reaching over 55% of the total vegetation cover (Figure 6). In contrast, the canopy cover in the seeding treatments was significantly lower, ranging from 10.1% to 16.0%. The control presented similar results to the seeding. It is worth mentioning that between the seeding treatments, the crown development of saplings was greater and more uniform in 'seeding in patches' while in the other two seeding treatments, the crown was smaller probably because of the intraspecific competition. This happened due to the lack of uniform spatial distribution of saplings in these treatments; in some positions saplings were observed at a low density while in others the saplings were growing at a high density. Naturally regenerated seedlings and saplings coming from 'seeding in patches' have developed larger crown exploiting the abundant available space.

Discussion

In situ germination of *P. halepensis* seeds was very low in all seeding treatments due to the harsh climatic conditions following the seeding, and to the high consumption of seeds by rodents and especially by birds that usually happens in these cases (Prodon et al. 1987; Saracino et al. 1997). Among treatments the 'seeding in patches' presented advantages because it combined relatively good germination, good distribution of saplings in the area, good qualitative and quantitative characteristics of saplings. Perhaps an overdoubling of the quantity of seeds will significantly improve the results of this treatment. However, the main disadvantage of the 'seeding in strips' is the lack of uniform spatial distribution of saplings, which results in many negative consequences regarding their quality and growth, requiring early silvicultural intervention as well.

Concerning the planting of *P. halepensis* paper-pot and bare-root seedlings, the mortality of the seedlings was low, 4.8% and 20.2 attributed to transplanting shock since it was observed during the early months after planting and before the dry summer period. These findings, in combination with the results of other studies, argue that the establishment of new plantations of *P. halepensis* is quite easy.

The planted seedlings also exhibited high growth and very good vitality and developmental tendency. These high growth rates of the saplings, even in the case of the naturally regenerated saplings, exceeded the values reported for *P. halepensis* by others (Daskalakou and Thanos 1996; Martinez-Sanchez et al. 1999; De las Heras et al. 2002). This observation can be mainly attributed to the fact that *P. halepensis* reached its optimal growth in the study area (Tsitsoni 1997). In addition, as De las Heras et al. stated (2002) clearing of a site may affect positively the growth rate of the saplings. In both treatments (paper-pots and bare-roots), the crown of *P. halepensis* saplings presented a uniform development and their ground projection cover was over 55% of the total vegetation cover. At the age of seven years, almost all saplings have cones, which show that the planting method accelerates the ending of the juvenile phase of the saplings, which enter their reproductive phase earlier. The juvenile phase in an even-aged Aleppo pine population may end at an age of 3–6 years (Thanos et al. 1998) and it is estimated to encompass the entire population after 15–20 years (Arianoutsou 1999; Thanos and Daskalakou 2000). However, appropriate silvicultural treatments such as thinning (Ne'eman et al. 1995) and pruning (Schiller and Cohen 1998) could contribute to the acceleration of the stands' evolution in order to achieve the management goal.

In summarizing the results of all treatments, we may claim that stand density is quite high in all cases; however, the lowest density was observed in the control and the highest in the method of 'seeding in strips' and it is clearly due to the higher amount of seeds per hectare that has been used in this treatment. The remaining treatments gave similar results in sapling density. Beyond that, there is a great variability in sapling spatial distribution and as a consequence the saplings have different morphological characteristics in each treatment. From a silvicultural point of view, saplings in the plantations exhibit better characteristics that can forecast a desirable stand evolution.

Naturally regenerated *P. halepensis* seedlings were spatially distributed due to the variation of seedbank size (Daskalakou and Thanos 1996; Eshel et al. 2000). Density values were similar to those recorded by Daskalakou and Thanos (1996) in Attica, Greece, but quite lower compared to those recorded in Kassandra, northern Greece (Tsitsoni 1997), in Spain (De las Heras et al. 2002) and in Israel (Ne'eman et al. 1995). However, since *P. halepensis* recruitment after fire mainly depends on canopy seed bank (Daskalakou and Thanos 1996; Habrouk et al. 1999; Arianoutsou and Ne'eman 2000), the observed relatively low sapling density of natural regeneration can be attributed to the very low *P. halepensis* tree density (ca. 50 trees per ha) before the fire. Similar results were also reported from another experiment, concerning Forest Service seeding practice and *P. halepensis* natural regeneration in an adjacent area (Tsitsoni et al. 1999).

In conclusion, it can be said that for the particular site conditions, the most appropriate method for improving the regeneration process of *P. halepensis* ecosystems is 'planting in pits' with paper-pot or bare-root seedlings. This method accelerates the re-establishment of young fertile trees in the burnt area, which is a key factor for the stands to be able to regenerate if another fire occurs. These stands are not of direct economic interest but they are very important for many ecosystem functions such as soil protection, aesthetic value of the landscape, recreation, tourism, improvement of the environment, apiculture etc. For this reason, in the case of artificial intervention the number of planted seedlings can be reduced to a minimum (300 seedlings per ha), since soil protection is secured from the dense evergreen broad-leaved vegetation (Zagas 1994). This choice has an additional economic advantage; the fact that the seedlings are planted in the final position and no further silvicultural treatment is needed.

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