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Dynamics of postfire regeneration of *Pinus brutia* Ten. in an artificial forest ecosystem of northern Greece

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Abstract

This paper deals with the dynamics of postfire regeneration of *Pinus brutia* Ten. in an artificial forest ecosystem of North Greece, after a fire in 1982. The following issues are studied: the natural development of *P. brutia* stands 20 years after the fire, the current stand structure, and the influence of thinning treatment on stand population dynamics and tree growth patterns. The present work summarises and updates data taken during the years 1987–2002. The results show that the postfire regeneration was successful and contributed to the re-establishment of the pre-fire forest not only at the sites of good quality but at the medium quality sites as well. Regarding the postfire development, it is observed that an abundant *P. brutia* re-establishment is followed by a natural and gradual reduction of tree population caused by the influence of the physical environment during the early postfire years and caused by self-thinning later. The stands have entered the stem exclusion stage and they are growing at a narrow spacing in all cases. The evolution pattern and the stand structure were affected by thinning, which resulted in the improvement of tree quality and growth and accelerated their early fruition, thus contributing to higher ecosystem resilience.

Introduction

Disturbance of one kind or another is a pervasive feature of forests. Natural disturbances such as fire, wind, flooding, tectonic activity and insect infestation, which can remove one complement of plants and animals and over time replace it with another, are an integral part of ecosystems. More often than not, they are agents of renewal rather than destruction (Sousa 1984; Pickett and White 1985; Barnes et al. 1998). Fire is the most common disturbance in a wide variety of forest ecosystem types and affects their dynamics and productivity (Dafis 1987; Agee 1993). Species that are common to these forest ecosystems have adapted to fires in various ways and their persistence depends on periodic fire (Kruger 1983; Trabaud 1987; Naveh 1991; Thanos and Marcou 1991; Tsitsoni 1991; Arianoutsou 1998).

P. brutia and *P. halepensis* are Mediterranean conifers with the above-mentioned attributes which form extensive forests in the Mediterranean Basin. These forests have often become the target of arson because of the high value of land since these ecosystems extend mostly into areas of high touristic development (Dafis 1987; Tsitsoni 1991); this arson is further encouraged due to the Mediterranean climate and the flammable vegetation. However, when the fires destroy mature stands of the above species in Mediterranean ecosystems the forest regeneration is ensured provided the burnt area is protected from grazing (Le Houerou 1974; Naveh 1975; Tsitsoni 1997). The treatment of disturbance leads naturally to the consideration of succession in forest ecosystems (Peet and Christensen 1980; Oliver and Larson 1996). Generally, the vegetation of the Mediterranean forest ecosystems after fire disturbance follows a secondary succession pattern (Tsitsoni 1991; Arianoutsou 1998; Tsitsoni and Karagiannakidou 2000).

The investigation of the vegetation evolution and the dynamics of natural Mediterranean forest ecosystems after fire have already been studied in many cases (Trabaud et al. 1985; Thanos and Marcou 1991; Tsitsoni 1991; Ne'eman et al. 1995; Daskalakou and Thanos 1996; Tsitsoni 1997; Spanos et al. 2000) and it usually focuses on the early postfire regeneration. Only a few studies have been carried out dealing with the early postfire regeneration specifically of *P. brutia* (Tsitsoni and Zagas 1988; Thanos and Marcou 1991; Spanos 1992; Thanos and Marcou 1993; Spanos et al. 2000). Furthermore, in the case of artificial stands, little is known about the postfire evolution and dynamics. The results of these studies have applications in forest management, such as the reduction of silvicultural manipulation costs and the increase of forest productivity (Tsitsoni and Karagiannakidou 2000).

In this research, the postfire dynamics of a burnt *P. brutia* artificial forest ecosystem was studied, based on the following: i) the natural development of the stands 20 years after fire ii) the current stand structure, and, iii) the influence of thinning treatment on stand population dynamics and tree growth pattern.

Materials and methods

Study area

The study area is the artificial periurban forest of Thessaloniki and in particular the part of the forest that was burnt in 1982. This area was selected because this forest, named Kedrinos Lofos, presents great interest because it constitutes a unique 'greenbelt' for a fast developing city. This forest is in the NE part of the city and occupies an area of 2,979 ha. It is composed of reforestation, primarily of *P. brutia*; but after the big fire of July 1997, an effort has been made to convert from pure pine stands to mixed stands with pine and broadleaved species. The altitude of the area ranges from 50 m to 450 m. The climate is Mediterranean, with 135 dry days on the average; the dry period lasts from the middle of May to the end of September. The mean annual precipitation is 396.7 mm; mean annual temperature is 15.6 °C; minimum temperature of the coldest month is 6.2 °C and maximum temperature of the warmest month is 26.0 °C, according to the data from the meteorological station of the University of Thessaloniki 1987–1997. The soils of the area range from slightly acid up to neutral, shallow up to middle depth, poor of nutrients and contain a high percentage of stones and pebbles. The vegetation of the area belongs to the Quercetalia pubescentis zone and especially to the Ostryo-Carpinion orientalis alliance (Tsitsoni and Zagas 1988).

Methods

The research on dynamics of postfire regeneration was carried out from 1987 to 2002. The first field data were taken in 1987 on 38–48 year old stands that were burnt in 1982. More field data were taken 5 years later, in 1992. The new measurements were carried out in 2002. The sample plots were squares of 10 m × 10 m, and they were graded into types according to the site quality. Site type I represents the good (fertility) site and site type II, the medium according to dominant height (average height of the largest 100 trees per hectare). In the above area, 20 sample plots were randomly established, with 10 sample plots taken in each site type. In these plots the number of individuals of *P. brutia* was recorded at ages 5, 10 and 20 years. Thinning from below (the suppressed trees were removed) in a percentage of approximately 15% of the basal area was applied in a part of the stands of good site qualities in 1992, just after data recording. Thus, in the last recording the measurements took place in both thinned and unthinned stands of the site type I; five plots were taken in the thinned stands and five in the unthinned ones. In the site type II, the sample plots were taken only in unthinned stands, since thinning was applied only in the stands of the good site quality (due to financial reasons). For the last measurement period, the following measurements of the saplings were taken: the diameter at ground level in cm, the total height in m, the vitality and the developmental tendency according to IUFRO classification (Dafis 1990): Vitality: Grade 10 the vigorous saplings, grade 20 the normally growing saplings, grade 30 the declining growing saplings. Developmental tendency: Grade 1 the overgrowing saplings in height, grade 2 the normally growing saplings in height, grade 3 the saplings with reduced growth in height). Shrubby vegetation was recorded in each plot.

Stand dynamics were estimated based on measurements at 5, 10 and 20 years after the fire from tree sectioning. Stem discs determined the height growth patterns. Five dominant trees, free of any obvious insect and disease damage, were selected in the high site (thinned and unthinned) and medium site categories. They were cut at point '0', 0.3 m from the base and stem discs continually were taken meter intervals up to the peak of the saplings. Ring counts were determined in the laboratory and converted to actual age at each section point. Height curves were reconstructed based on the cross section data. Annual height values were interpolated from cross section data using the algorithm of Carmean (1972), since this method has been proved the best one to be used for height curve reconstruction; this algorithm gives the most accurate results (Dyer and Bailey 1987; Fabbio et al. 1994). The interpolation provides an estimation of the actual height at each cross section age, since the cross section height in itself does not often include the full measurement of the last growth height. Then, height at each age was estimated by Carmean algorithm.

The relationship among the number of seedlings, diameter, and height on the one hand and the parameters of site quality and stand treatments on the other were tested by analysis of variance (two-way ANOVA). The significance of the results was tested using the Duncan test (Norusis 1994).

Results

Current stand structure

The vegetation of the studied area is dominated by *P. brutia*, which comprises the overstorey. The understorey, which is dense in some places and absent in others, consists mainly of *Quercus coccifera* and less of *Phillyrea latifolia* and *Paliurus spina-cristi*. In good site qualities the species *Crataegus monogyna* and *Jasminus fruticans* are found; also *Fraxinus ornus* and *Ulmus campestris* are found in shrubby form. In these areas the ground flora vegetation is limited because the stand canopy is quite closed. In medium site qualities the more xerothermic species *Cistus incanus, Sarcopoterium spinosum* and *Anthyllis hermanniae* can be found. In these areas the ground flora appears richer because the canopy density is thin.

From the recent measurements, 20 years after the fire, we can observe that the stands on both sites are in the stem exclusion stage (*sensu* Oliver 1981, Oliver and Larson 1996). The average number of individuals was high in both site qualities, reaching 12,000 stems per ha in the good sites and 10,600 in the medium sites (Table 1). Thinning decreased stand density where it was applied (good site quality) to 7,300 individuals per ha at the age of 20 years. The stems were widely distributed in height and diameter; however, this distribution follows, in all cases, more or less the characteristic normal distribution of even-aged stands (Ganatsas 1993; Figures 2 and 3). Because of the effect of site quality and thinning some differences were observed in tree distribution. Thinning improved height growth of the trees, which resulted in a relatively high frequency of trees in the class of 7 and 8 m, while only a few trees were recorded in the unthinned stands in these classes (Figure 1). The values of tree height follow the normal distribution and appear at a maximum in the class of 5 m in the thinned stands and in the class of 4 m at the unthinned stands in the site type I. The highest concentration of the stems, in the site type II, is noticed in the height class of 4 m. A similar influence was observed in diameter distribution. In the diameter classes of 9 and 10 cm there are many trees and few in the class of 11 cm in the thinned stands, but none in the unthinned stands. The biggest concentration of stems was noticed in the class of 5 cm in the thinned stands and in the class of 3 cm in the unthinned stands in the site type I; in the site type II the biggest concentration of stems is noticed in the class of 3 cm.

As a result of the above differences, the average height was statistically greater (5.77 m) in the thinned stands compared to that (4.79 m) in the unthinned ones (Table 1). The mean diameter also appeared significantly greater in the thinned stands than in the unthinned ones, with mean values 5.88 cm and 4.13 cm, respectively. This difference can be attributed to the more growing space available for the remaining individuals in the thinned stands.

The vitality and the developmental tendency fluctuated to satisfactory levels in the thinned stands in the site type I, with average values 18 and 1.8 respectively, because of the better growth conditions. In the unthinned stands the values of the vitality and the developmental tendency were better in the site type I (22 and 2.2 respectively) than in the site type II (27 and 2.7).

Statistical analysis by ANOVA revealed statistical differences for the diameter and height between thinned and unthinned stands as well as between the different site types (Table 1). The thinning treatment contributed to a better evolution of stands by improving their quality, accelerating tree growth and promoting the earlier fruition of the trees.

Dynamics of the stand density

The development of tree populations during the period 1987–2002 in the two sites, and in the thinned and unthinned stands as well is depicted in Figure 4. At the age of 5 years, the stands were still in the initiation

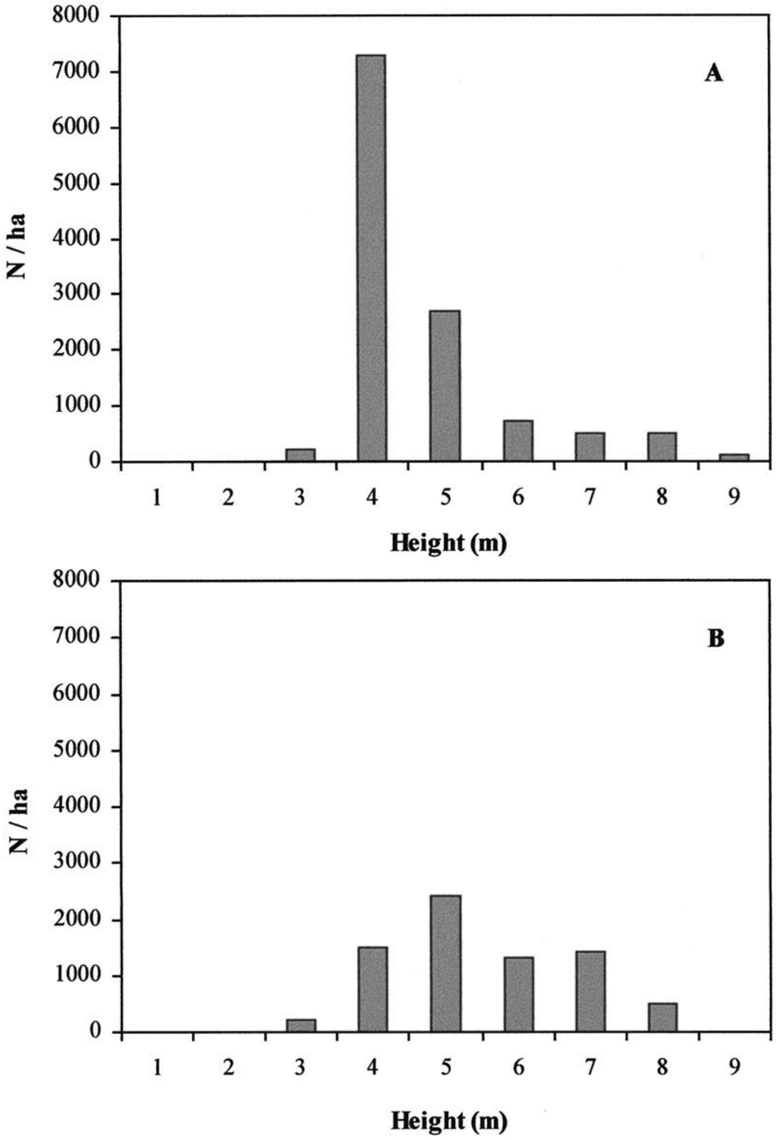

Figure 1. Distribution of tree height in the good site qualities; (A) unthinned stands and (B) thinned stands.

Table 1. Mean stand statistics 20 years after fire.

Site Type I							
Treatments	N/ha	Diameter (cm)		Height (m)		V	DT
		Mean	St.d	Mean	St.d		
Thinned stands	7,300	5.88a*	2.10	5.77a	1.25	18	1.8
Unthinned stands	12,000	4.13b	1.42	4.79b	1.19	22	2.2
Site Type II							
Unthinned stands	10,600	3.81c	1.66	3.34c	0.61	27	2.7

*Means followed by different letters are significantly different (within columns) at the 0.05 level (Duncan test).

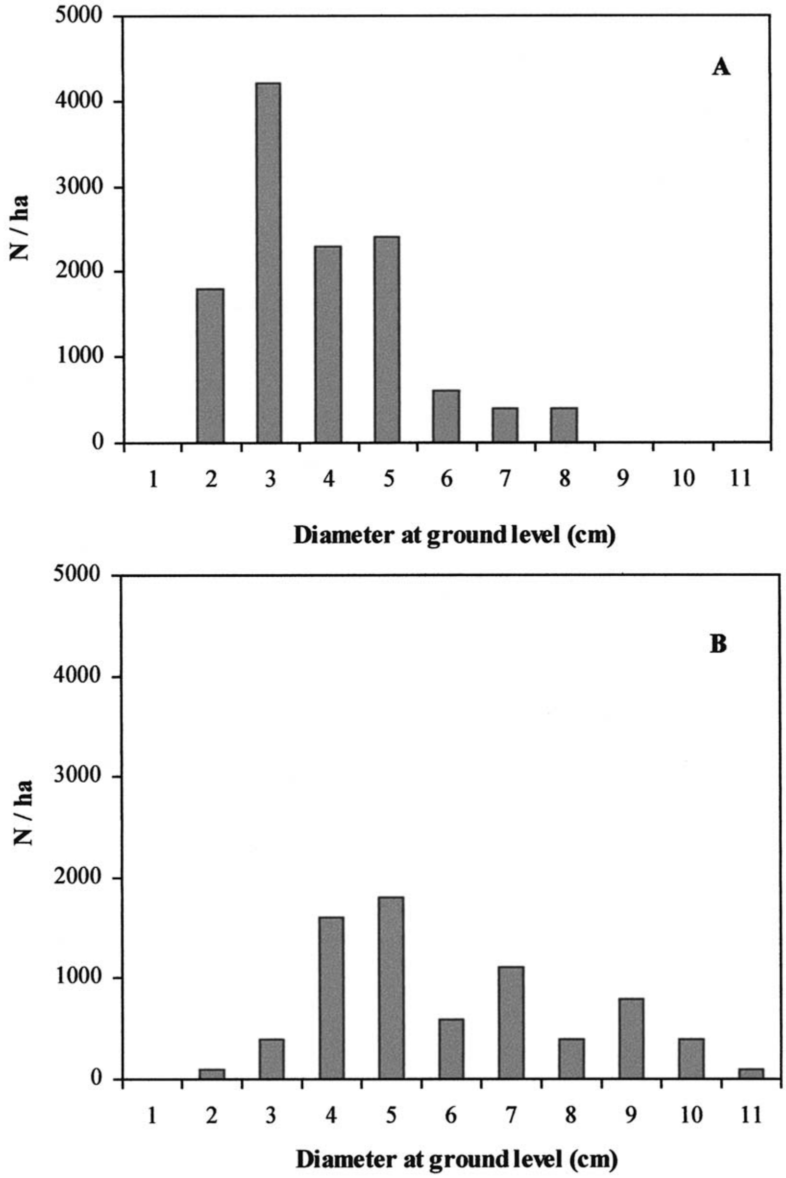

Figure 2. Distribution of diameter at ground level of the stems in the good site qualities; (A) unthinned stands and (B) thinned stands.

stage and the seedlings grew in the open; they expanded and filled unoccupied growing space without direct plant competition. The density was high, 41,500 individuals/ha in the site type I and 21,400 individuals/ha in the site type II. At the age of 10 years the density decreased and the sapling death was even because of the effect of the physical environment, mainly the deficiency of the limiting factor, water, during the summer period. At this age, however, the stands had already been in a competition phase since the saplings had almost filled the growing space. The number of individuals were 24,000 and 17,500 individuals/ ha respectively in the site type I and II. At the last measurements at the age of 20 years, the stands were in a strong self-thinning process because of the competition for light. The numbers of trees in the site type I were 7,300 individuals/ ha in the thinned stands and 12,000 individuals/ ha in the unthinned stands. In the site type II, 10,600 individuals/ha were found, which shows that a self-thinning process had already began; therefore, these stands should also be thinned in a sci-

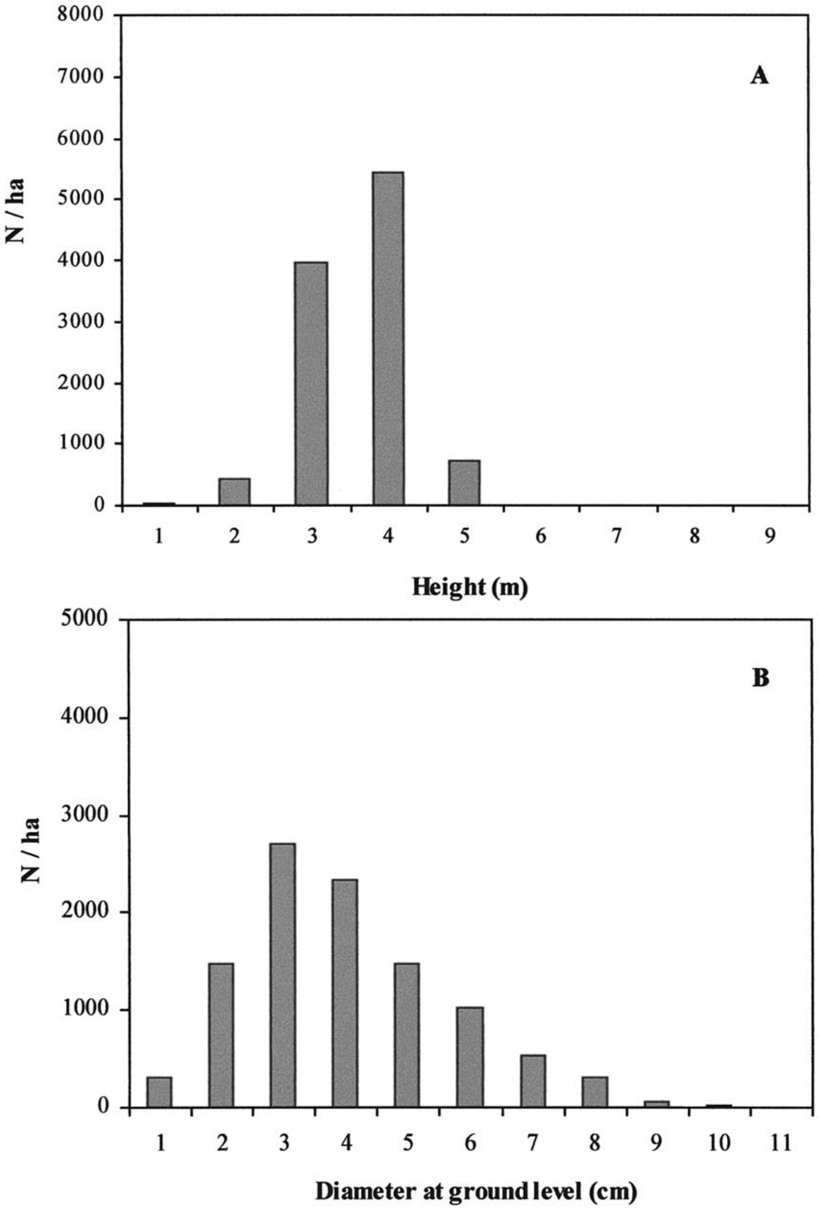

Figure 3. Distribution of height (A) and diameter at ground level (B) of the stems in the medium site qualities.

entific way according to the existent knowledge (Dafis 1987).

The regeneration in the study area developed according to the theory of natural forest development after disturbance and follows in autosuccession. For the first 5 years after fire, because there were no available data, we depended on the data taken after the big fire of 1997; these measurements show that during the first wet season only a part of the site was colonised by *P. brutia* seedlings. The number of the individuals increased in the second year after the fire and continued until saturation. The establishment of the natural regeneration seems to have been completed at the age of 5 years (Tsitsoni 1991). During this period of the early initiation stage, *P. brutia* seeds annually invaded germinated and established themselves; however, the wave of the first postfire year could not fill the area. Thus, new seeds germinated and new seedlings colonised the burnt area while the stand density increased until saturation (Ming 1987). The last waves of seed-

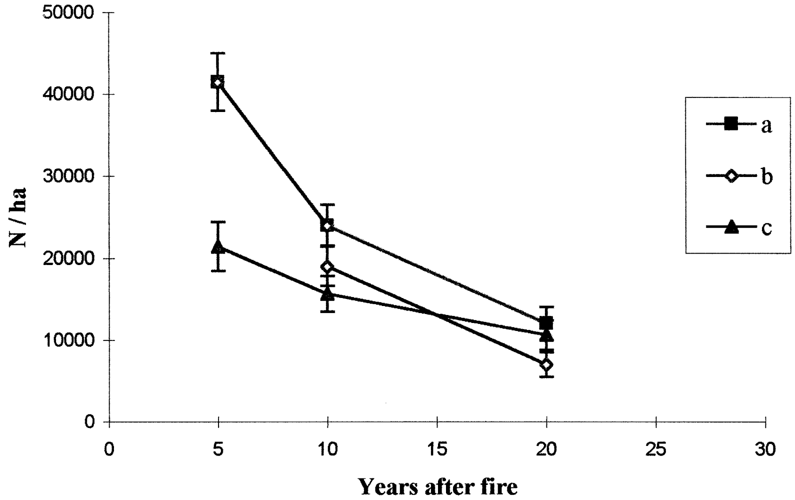

Figure 4. Dynamics of stand density. a = site type I - unthinned stands, b = site type I - thinned stands, c = site type II - unthinned stands. Values are the means * standard error.

lings can be attributed mainly to the aerial seedbank (canopy seedbank of the neighbouring stands) and less to the non-germinated seeds in the soil. The new seedlings' emergence probably happened because of the facilitation model that assumed to allow certain autogenic environmental changes that may increase the input of seeds and the establishment of new seedlings (Finegan 1984). The numbers of individuals at ages 5 and 10 years were much higher in site type I than in site type II, probably because of the site conditions. Later, when canopy closure had been completed and differentiation of the storeys had begun, the number of individuals was reduced with time, because of the lack of necessary growth space. The thinning applied influenced stand density in the stands by decreasing the number of trees (Figure 4).

Height growth pattern

Reconstructed height curves for both site qualities followed a sigmoid curve with a very low increment during the first four years. Afterwards the saplings grew faster (Figure 5). Saplings of medium site quality also exhibited a very low growth rate during the period of 10–14 years while saplings in the good site quality grew faster during the period of 9–12 years. Thinning affected growth rate of the stands as mentioned before. The height differences between thinned and unthinned stands started just after thinning, demonstrating the great importance of taking the appropriate silvicultural measures at the correct time. Thinning mainly favoured the superior trees by reducing the number of competing trees, giving them more growth space. It also helped the stands to overcome the risk of stagnation, which is a common phenomenon in young even-aged stands and especially when the individuals have the same characteristics (and consequently the same competition ability) and the stand density is high (Oliver and Larson 1996). Comparison of the height and diameter distribution (Figures 1 and 2) in the high site types (I) suggests that some of the taller trees in the unthinned stand had height/diameter ratios greater than 100. The larger trees in the thinned stand had larger diameters and lower height/diameter ratios. It is possible that the lower height growth of the unthinned stands is because the dominant trees were becoming stagnant, first reducing their diameter growth and then their height growth.

Discussion

The woody plant floristic composition of the regenerated forest ecosystems was similar to others recorded, as expected (Thanos et al. 1989; Thanos and Markou 1991). As well as *P. brutia*, the presence of the other shrub species can be attributed to the post-fire strategy of the existing species (Trabaud 1987; Arianoutsou 1998). These are either resprouters such as *Quercus coccifera, Phillyrea latifolia* or seeders such as *Cistus incanus* and *Anthyllis hermanniae*. The vegetation is dominated by *P. brutia*, which comprises the overstorey; the understorey consists mainly of *Quercus coccifera, Paliurus spina-cristi* and *Phil-*

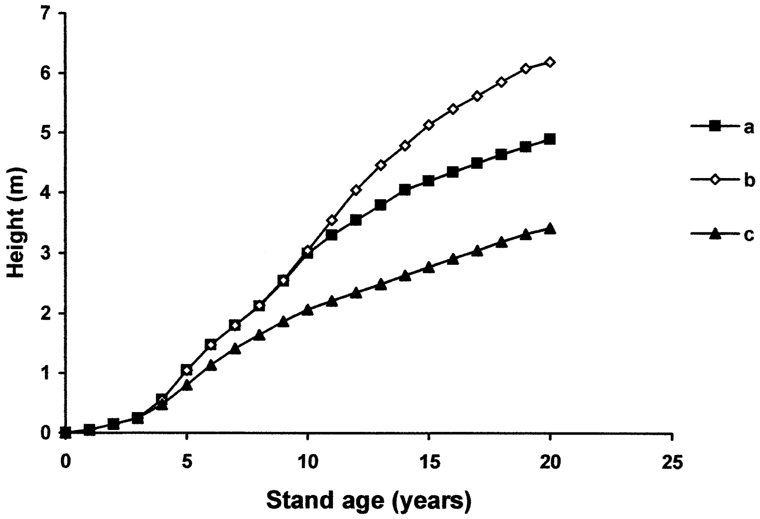

Figure 5. Height curves of the trees in good and medium site qualities and in thinned and unthinned stands. a = site type I - unthinned stands, b = site type I - thinned stands, c = site type II - unthinned stands.

lyrea latifolia. The above species are accompanied by the species *Crataegus monogyna, Jasminus fruticans*, and (in shrubby form) by *Fraxinus ornus* and *Ulmus campestris* in good sites while in medium sites the more xerothermic species *Cistus incanus, Sarcopoterium spinosum* and *Anthyllis hermanniae*, appear.

P. brutia is an obligate seeder and a typical east Mediterranean tree species. A fact that can be attributed on one hand to the adaptation mechanisms evolved by the species, and on the other to the favourable conditions prevailing in the area (northern slopes with favourable soil conditions). One of these mechanisms is the closed, serotinous cones which protect the pine seeds from the fire and open shortly after fire (Dafis 1987; Thanos and Marcou 1991; Spanos et al. 2000; Thanos and Daskalakou 2000). The above mechanism has been well documented for *P. halepensis* as well (Saracino and Leone 1993; Daskalakou and Thanos 1996; Saracino et al. 1997; Tsitsoni 1997). Pine seed germination and seedling emergence take place during the first wet season and continue for the following five years till saturation (Ming 1987; Tsitsoni 1997).

In spite of the considerable variability of the stand density among site qualities, the overall trend is a gradual decrease of pine sapling density during the 5–20 years after fire. Thinning further reduced stand density in the stands where it was applied. The actual density values (ca. 2–4 saplings per m^2) were higher than those of *P. brutia* in Thasos (ca. 1–2 saplings per m^2; Spanos et al. 2000) and much higher than those in Samos (ca. 0.15 saplings per m^2; Thanos and Marcou 1991) at the age of 5 years after fire. These differences can be explained by the better site conditions, the canopy seedbank of neighbouring stands, and the fire intensity. By the age of 10 years, the sapling density reduced to 1.7–2.4 saplings per m^2 while in Samos it remained the same (Thanos and Marcou 1993). Compared to the postfire sapling density of *P. halepensis* species, this was more similar to that recorded for *P. brutia*, and greatly varied between the different studies (Ne'eman et al. 1995; Daskalakou and Thanos 1996; Tsitsoni 1997); however, the postfire seedlings recruitment of both species is almost totally dependent upon canopy seed bank (Habrouk et al. 1999; Thanos 2000; Thanos and Daskalakou 2000; Eshel et al. 2000) and less to soil seedbank (Tsitsoni 1997).

Seedlings height growth was low during the first 4 postfire years in both sites, with an annual increase of 5–1 cm. Afterwards, the height increased faster than the previous years and reached 25–35 cm per year in the medium site, and 30–50 cm in the good sites. These values exceed those recorded by Spanos et al. (2000) for postfire height growth of natural *P. brutia* stands in Thasos island (5–20 cm per year during the first 10 years) and those recorded by Thanos and Marcou (1991, 1993) for burnt *P. brutia* stands in Samos island (ca. 10 cm per year). Height was significantly greater in good sites compared to the medium; Spanos et al. (2000) made the same observation in Thasos Island. However, the general height growth pattern seems to follow a sigmoid curve in the present study; by contrast, Spanos et al. (2000) found the growth in height to follow a linear pattern. The saplings 20 years after fire also exhibited good vitality and developmental tendency in good sites and in thinned stands. This means that appropriate silvicultural treatments such as thinning (Ne'eman et al. 1995) or pruning (Schiller and Cohen 1998) contribute to the acceleration of the stands' development.

Stand structural analysis showed that all the stands exhibit the characteristics of even-stands in the stem exclusion stage (Oliver and Larson 1996). The silvicultural treatments (thinning), where it took place, showed that it comprises an appropriate tool to improve stand evolution according to the management goal (Zagas et al. 1998).

To summarise the findings of this study, it is obvious that the stand density is quite high in all cases; however, lower density was observed in the medium sites. The thinning treatment contributed to a better stand development by improving tree quality and accelerating tree growth. From a silvicultural point of view, thinning mainly favoured the superior trees by reducing the number of competitive trees and giving them more growing space. As a result, saplings that exhibit greater growth and better silvicultural characteristics appeared.

From the above-mentioned results the main conclusions obtained are the following:
(1) The postfire regeneration in artificial, mature stands of *P. brutia* was successful and contributed to the re-establishment of the previous forest in good and medium sites. This regeneration must be taken into consideration by the responsible forest authorities who could allow the forest to regrow by natural postfire regeneration except in the case of the scarcity of regeneration and when the management goal is the creation of mixed stands.
(2) The number of seedlings of the postfire *P. brutia* regeneration was very high, especially in site type I. For this reason the young stands should be cultivated according to the principles of silviculture. Priority should be given to the stands of the site type I, which must be thinned for the first time before the age of 10 years.
(3) Thinning contributes to a better tree growth and differentiation of young stands, as well as to the earlier fruition of the trees, which is very important from the financial and ecological points of view, for this forest type. The thinned stands excel as far as the mean diameter, the mean height, the vitality, and the developmental tendency compared to the unthinned stands. The difference is greater in the dominant trees in both cases than in the other storeys.
(4) As far as the development of the vegetation after the disturbance of fire is concerned, prompt re-establishment of *P. brutia* with a natural, gradual reduction of the trees by age occurs when fire burns mature stands.
(5) Finally, *P. brutia* is a very important Mediterranean pine that can also be used in plantations. After the destruction of the artificial stands, autosuccession occurs with the natural regeneration of *P. brutia*. In comparison the results are similar to those of the natural forests. For this reason *P. brutia* could be managed according to the existing silvicultural knowledge and experience, which secures the best growth and the greatest productivity of this species.

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