

Postfire, natural regeneration of *Pinus brutia* forests in Thasos island, Greece

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Abstract — The natural, postfire regeneration of *Pinus brutia* forests has been studied in two 40–60-year-old forests of Thasos island, North Aegean sea, Greece, burned in the summers of 1985 and 1989. Within the latter burned area (5 700 ha), forty experimental sites of various aspects and site index values were established and successively monitored for 5 years, at 6-month intervals. Pine seedling emergence took place late in spring (due to a long drought in that particular year) but exclusively during the first postfire year. By the end of the recruitment period (May 1990), mean pine seedling density was considerably high (2–6 seedlings·m⁻²) while a significant drop in the first summer was observed. Thereafter, a relatively smooth decline was obtained and the density was almost stabilized to about 0.6–2 seedlings·m⁻² after 5 years: the kinetics of survival was found to follow a rectangular hyperbola. Significant differences in seedling density values were detected among site groups of varying aspect or site index: north-facing and index I sites showed the highest density values while south-facing and index V ones the lowest. Similarly, height kinetics showed a significant divergence among site groups; again, the north-facing and the index I sites were the fastest growing. Annual height growth showed a linear regression kinetics throughout the 5- (and conceivably 9-) year-long postfire period of study, with a yearly increment of 17 cm. Starting at an age of 4–6 years, an increasing fraction of the sapling population became reproductive so that after 9 years a considerable portion (5–15 %) had already produced cones with fully germinable seeds. © 2000 Éditions scientifiques et médicales Elsevier SAS

Pinus brutia / pine forest / natural postfire regeneration / seedling density / growth and survival

1. INTRODUCTION

Pinus brutia Ten. (brutia or east Mediterranean pine) is a tree of great ecological and economic importance for the eastern Mediterranean region [13, 14] and a significant forest tree species of the north-eastern coast and several Aegean sea islands of Greece. It grows prolifically in well lit conditions and is amply adapted to infertile soils and dry climates [17]. The geographical range of *P. brutia* Ten. subsp. *brutia* extends from the Greek Aegean islands through Turkey to Lebanon and northern Iraq [4, 17] and together with another three subspecies and its close relative *P. halepensis*, they constitute the subsection *Halepenses* Van der Burgh [19].

Fire has apparently acted as a powerful ecological factor in the evolution of the Mediterranean flora as well as in shaping the Mediterranean landscapes into their present, mosaic-like patterns with different levels

of regeneration and degradation [8]. Wildfires are natural events and are considered as an integral part of the Mediterranean environment. Fire resilience of Mediterranean-type ecosystems is generally well documented; thus, most of these ecosystems can regenerate naturally after a fire, provided that no secondary destructive disturbances (such as additional fires or grazing) is applied. Similar to the other two groups of Mediterranean-type ecosystems (namely maquis and phrygana), pine forests in the Mediterranean rim are well known to be highly flammable [1].

The shrub understory of brutia pine forests of Thasos island varies from site to site and in many cases, it is floristically rich, comprising various evergreen sclerophylls (maquis) species (e.g. *Quercus coccifera*, *Phillyrea latifolia*, *Pistacia terebinthus*, *P. lentiscus*, *Arbutus unedo*, *A. andrachne*, *Myrtus communis*) as well as phryganic subshrubs (e.g. *Erica*

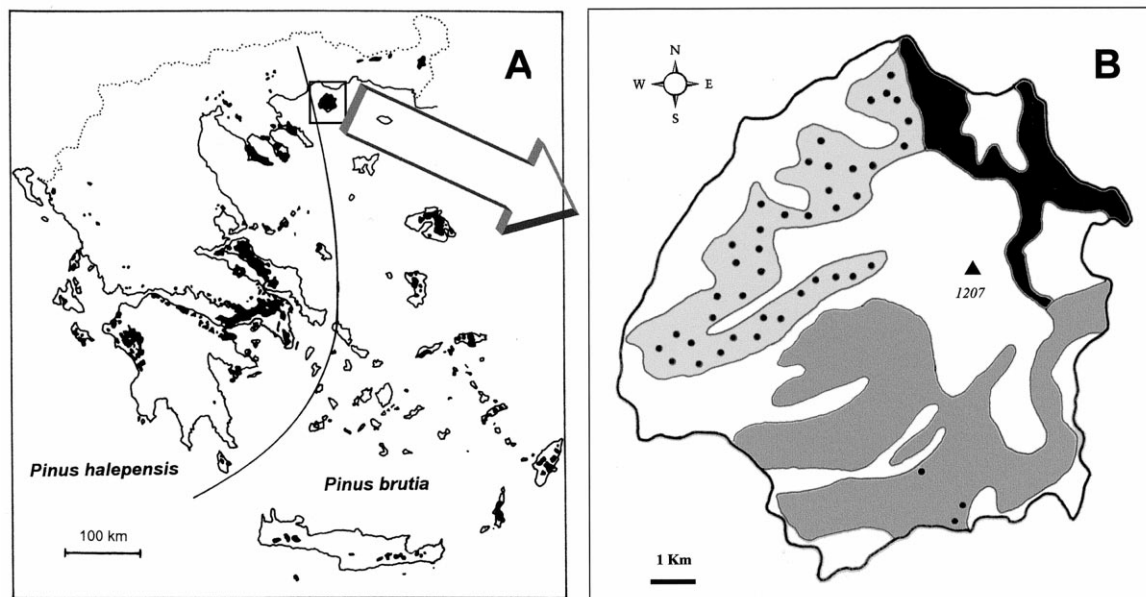


Figure 1. The distinct geographical distribution of the Mediterranean pines in Greece (A). Thasos island is located at the northern-westernmost edge of *Pinus brutia* distribution (inside the rectangle, A) and its brutia forests are shown as three areas (B): light grey (burned in 1989), dark grey (burned in 1985) and black (mature, unburned). Black dots represent experimental plots.

arborea, *E. manipuliflora*, *Cistus creticus*, *C. salviifolius*, *Paliurus spina-christi*, *Calicotome villosa*). The climatic and soil conditions of Thasos are quite favourable to the establishment and growth of *P. brutia* stands but during the last decades, the fire interval has gradually decreased [12] for most Mediterranean forests of Greece. Moreover, a large part of these forests have reached a critical stage due to both intensive grazing by goats and poor management. The wildfires of 1984, 1985 and 1989 have destroyed more than 80 % of the total forest area of Thasos [24, 25]. In particular, the wildfire of August 1989 burned 5 700 hectares of mature (40-60 years old) and productive forests; currently, only 2 024 hectares of mature *P. brutia* forests remain on the island.

Despite a recent investigation upsurge of natural postfire regeneration in the Aleppo pine forests (e.g. [3, 7, 15, 22, 27, 32, 35]), there still exists a scarcity of analogous works for *P. brutia* [2, 10, 16, 18, 24-26, 28, 29, 31]. The present work is a diachronic (1990-1995) investigation of the postfire natural regeneration of the brutia pine forests in Thasos island on a number of experimental sites of various aspects and site qualities. The aim of this study is, on the one hand, to describe and analyse the postfire regeneration on the basis of several parameters of pine seedling

populations (emergence, establishment, density, survival, growth and reproduction), and, on the other hand, to compare the results of this case with previously reported ones for both *P. brutia* and Aleppo pine forests.

2. MATERIALS AND METHODS

Thasos is a medium-sized Greek island (390 km²) of the north Aegean sea, very close to the north-western edge of the geographic distribution of *P. brutia* (figure 1A). The central, mountainous part of the island is covered by a *P. nigra* forest while virtually the whole coastal belt is dominated by *P. brutia*. The total area of the latter amounts to ca. 20 000 ha and, as shown in figure 1B, almost three-fourths of it were burned in two, very destructive incidents of wildfire, in the summers of 1985 and 1989.

Postfire pine seedling emergence, establishment and survival were investigated at permanent plots established throughout the 1989 burned area (figure 1B). A total of forty experimental plots (10 × 10 m) were randomly chosen in April 1990. In all sites, *P. brutia* was the dominant species and the plots were located proportionally according to both site quality (site index) and aspect. Therefore, eight sites were selected

for each of the five classes of site index (I–V) which correspond to a decreasing value of the productive quality of a forest stand [24]. Since it is well known that, particularly during summer, the orientation of the site is correlated to moisture availability and consequently seedling survival, these same forty plots were located in a way to equally represent all four different site aspects (i.e. four groups of ten sites each, facing north, east, west and south, respectively). In each plot and during the following 5 years, the density of pine seedlings was monitored twice yearly (in May and October, except for October 1993 and May 1994) while the main climatic and soil parameters such as slope, depth of soil, topographical characteristics, type and extent of erosion, and vegetation cover were determined [24]. In the area burned by the 1985 wildfire, measurements were carried out in January 1995 (after the pine saplings had completed nine postfire growth seasons) at Potos (one site) and Thymonia (two sites). The data gathered included growth (height) and reproductive (cone production) parameters of the 9-year-old pine saplings while observations concerning reproduction were also performed with the younger (5 years old) saplings of the 1989 fire. Mature, closed cones were collected from 9-year-old saplings (Thymonia) and upon transfer to the lab, they were subjected to biometrical analysis and to a heat-induced opening for seed extraction [7].

The meteorological station of Thasos island is situated at sea level, in the main city of Limenas (in the north part) and pertinent data have been recorded by the National Meteorological Service (EMY) of Greece. The ombrothermic climatic diagram for the period 1961–1993 (*figure 2*) shows a typical Mediterranean climate with a, relatively high, mean yearly precipitation (742.3 mm) and a xerothermic period that starts in May and lasts through September. According to the formula of Emberger [9], the pluviothermic quotient Q for Thasos is 87.4 and the Mediterranean-type climate of the island can be further classified to the cold and subhumid variant. It should be noted that the meteorological conditions after the 1985 wildfire have been quite arid. In every one of the eight hydrological years (Oct–Sep) from 1985–86 through 1992–93, the total yearly precipitation fluctuated between 288.9 and 733.6 (i.e. for eight consecutive years rainfall has been below the 1961–93 average) while the 1985–93 average is only 440.4 mm (slightly less than 60 % of the 30-year-long average value).

Data were statistically analysed using the SPSS/PC software (descriptive statistics, means and standard

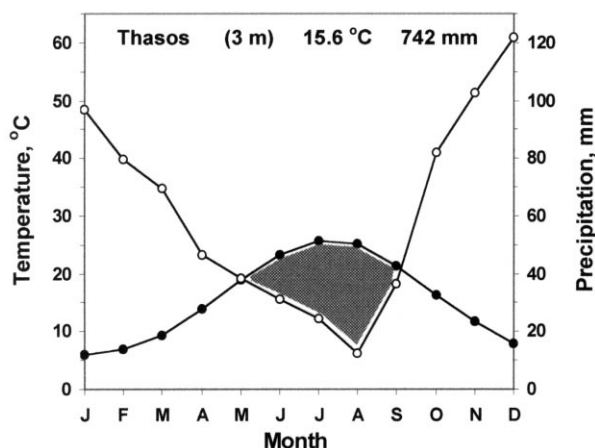


Figure 2. The ombrothermic climatic diagram of Thasos for the period 1961–1993. Average temperature and precipitation values are means of 28–32 and 26–32 monthly values, respectively. The xerothermic season is depicted by the stippled area.

errors of the means, t -tests of statistical significance between or among means). Curve fitting was performed by both linear and exponential regression analysis [39]; comparisons of the slopes between or among the linear regression equations were performed by using Student's t -test (two slopes) or by analysis of covariance (more than two slopes). The botanical nomenclature of plant species follows the Med-Checklist [11] and Flora Europaea [37].

3. RESULTS

After the 1989 wildfire in Thasos, an extremely severe and lengthy drought prevailed, extending from August 1989 to April 1990; thus, postfire pine seed germination and seedling emergence took place as late as in May 1990. Growth kinetics for the postfire cohort of pine saplings are presented in *figure 3*; each one of the four regression curves (corresponding to a particular aspect) follows a remarkably statistically-significant ($P < 0.001$) linear equation. Pine saplings on N-facing slopes are growing at the fastest annual rate, followed by those growing on E-, W- and S-facing sites. Despite the gradual decrease (in the order N, E, W and S) of the slope (growth rate) of the four lines, no statistical differences are observed among the slopes of the former three; on the other hand, the S line shows a statistically different slope (lower growth rate). Nevertheless, if the saplings from all aspects are treated together, the resulting 'average' linear regression curve (not drawn in *figure 3*) almost

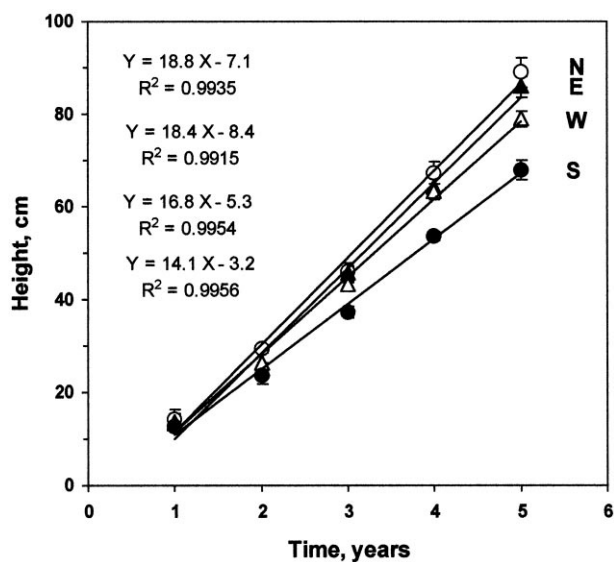


Figure 3. Postfire growth of *Pinus brutia* saplings in north (N), east (E), west (W) and south (S)-facing experimental plots of the 1989 burned forest, ten plots for each aspect, ca. 150 randomly selected pine saplings for each aspect. Linear regression curves and equations are given separately for each aspect (equations: N, E, W, S downwards); vertical lines represent standard errors (SE).

concur with that of the W-facing sites ($Y = 17.0X - 6.0$, $R^2 = 0.9948$, $P < 0.001$).

Maximum density of pine saplings was observed in May 1990, 9 months after fire (figure 4); it was the result of a single, massive wave of seed germination and seedling emergence which followed the spring rains. These initial density values varied considerably among sites (1–10 seedlings·m⁻²) while significant differences were obtained among the average values for sites grouped according to aspect (figure 4A) or site quality index (figure 4B). N-facing sites showed the highest density values, followed by E- and W-facing ones while S-facing sites were by far (and statistically significantly) the poorest ones throughout the 5-year-long monitoring period. Similarly, pine sapling density showed decreasing values along the gradient of sites with lower productivity (figure 4B) although this decline was much more gradual than in the previous aspect grouping.

The overall kinetics of pine sapling density showed a gradual reduction from an initial, gross average value of around 4 seedlings·m⁻² to a more or less stabilized average density of ca. 1 sapling·m⁻², a value reached 4–5 years after fire. Figure 5 depicts the survival of pine sapling populations; the seedling cohort in May 1990, considered as the end of the seedling recruitment

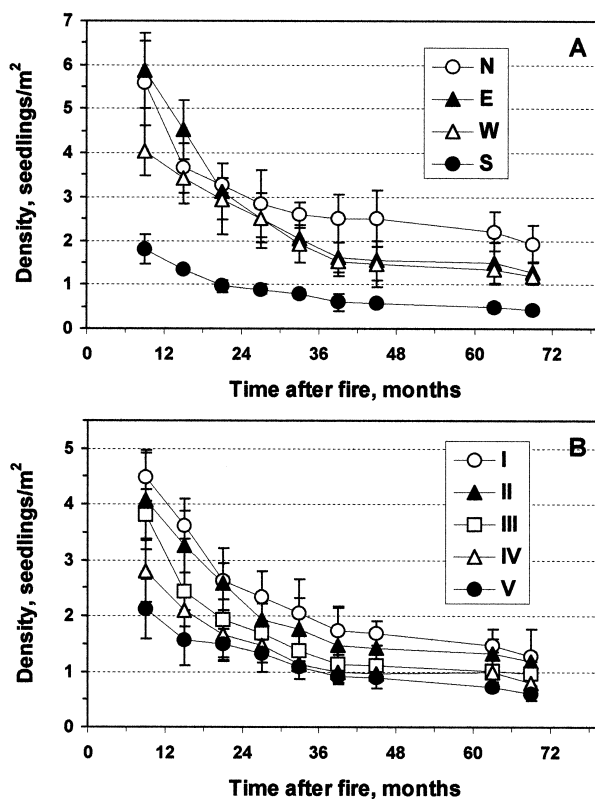


Figure 4. Postfire densities of *Pinus brutia* saplings shown according to plot aspect (A) or site index (B) of the 1989 burned forest. In A, kinetics of density is illustrated for north (N), east (E), west (W) and south (S)-facing experimental plots (ten plots for each aspect). In B, the same forty plots are grouped according to site index (I–V). Time 0 is August 1989; vertical lines represent standard errors (SE).

season, is taken as 100%. After the first postfire summer, about 75% of the seedlings were still alive; afterwards, a much less pronounced gradually declining mortality prevailed and the overall pine sapling survival was about 28%, 5 years after fire. It is worth noting that despite the significant differences in absolute seedling density values among various site groups, the corresponding survival percentages were remarkably close to each other, implying that all sites have been following similar survival kinetics. Through regression analysis and using the average survival percentages from all forty sites, a statistically acceptable, best-fit curve of a rectangular hyperbola was obtained (figure 5).

Figure 6 illustrates the height-diameter relationships in two postfire, even-aged (9 years old) populations of *P. brutia* saplings (Thymonia, figure 6A and Potos, figure 6B). A very strong linear relationship between

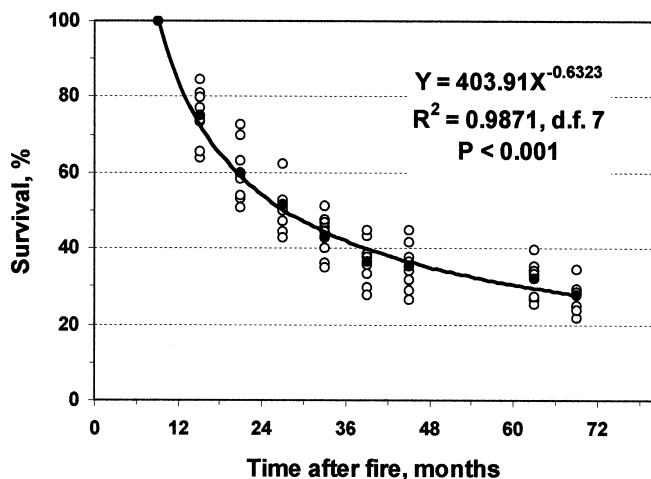


Figure 5. Postfire survival of *Pinus brutia* saplings established by the end of the first postfire spring (May 1990, 9 months after the wildfire). Time 0 is August 1989 and 100 % of survival is set at the end of the seedling emergence season. Open circles represent percentages of survival for nine groups of experimental plots (four according to aspect and five according to site index) while solid circles are the average values for all forty plots. The curve drawn is the best fit of a rectangular hyperbola (the equation is given on the graph).

height and canopy diameter was obtained for both sites. The average saplings for the two sites were respectively: 152.6 ± 3.9 and 139.3 ± 3.7 cm tall and 118.9 ± 3.5 and 93.6 ± 2.8 cm wide. Despite this obvious and significant size difference, the diversity between the two sites is not unexpected (cf. figure 3) and should be attributed to a site quality difference and, more specifically, to soil properties. Nevertheless, and more importantly perhaps, the pine sapling populations of the two sites differ considerably in their reproductive properties. It is obvious that most of the tallest plants of the former population had already entered the reproductive phase while almost the entire latter population (where such a tall sapling subgroup was absent) still remained juvenile.

The reproductive shift of those 9-year-old populations was further investigated by analysing the age of cones found on the saplings (figure 7). It is thus deduced that conelet formation took place for the first time and in a very small fraction of each population at an age of 4 and 6 years, respectively. Thereafter, an increasing but yearly-variable increment to the reproductively mature subpopulation was observed while a very significant difference (estimated to a delay of 2–3 years) between the two sites was noted. From a total of ninety cones found on the saplings (and

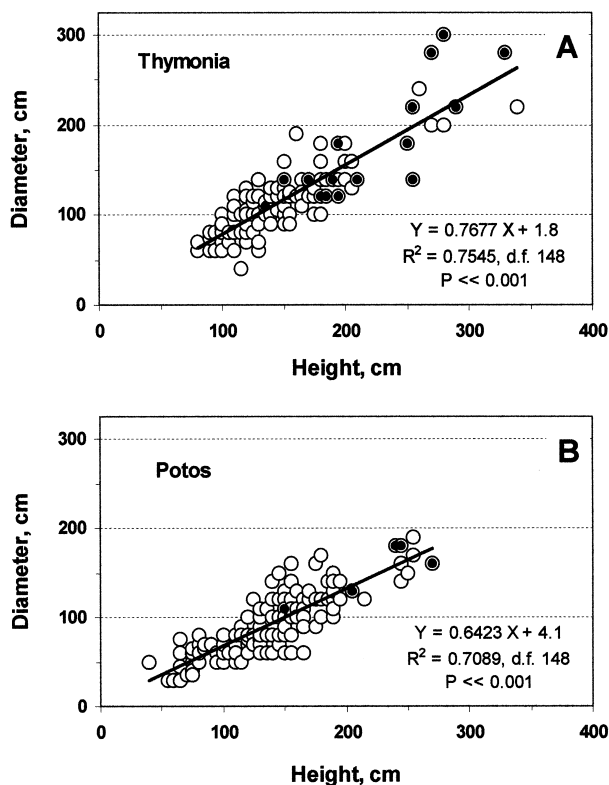


Figure 6. Height-diameter relationships in two postfire, even-aged (9 years old) populations of *Pinus brutia* saplings in Thymonia (A) and Potos (B), Thasos island (wildfire of 1985). Open and solid circles represent juvenile and reproductive saplings, respectively. Straight lines represent linear regression best fits (equation details in the graph).

matured 8 months to 5 years ago at sapling ages 6–9 years) a large majority of 84 % were closed (serotinous or bradychorous). A number of closed cones (matured at the 9th year of age, $n = 39$) were collected at the site of Thymonia and were subjected to measurements and subsequently to heat-induced opening and seed extraction (data not presented in graphs). The cone biometrical characteristics were: 24.6 ± 1.1 g (air-dry weight), 6.3 ± 0.1 cm (length), 3.4 ± 0.1 cm (basal diameter); the average number of seeds per cone was 39.5, the average seed weight 37.9 mg and the germinability 80–90 %.

4. DISCUSSION

Pinus brutia is an obligate reseeded and a typical, east Mediterranean tree species. A wildfire usually kills the entire pine tree population and, therefore, the

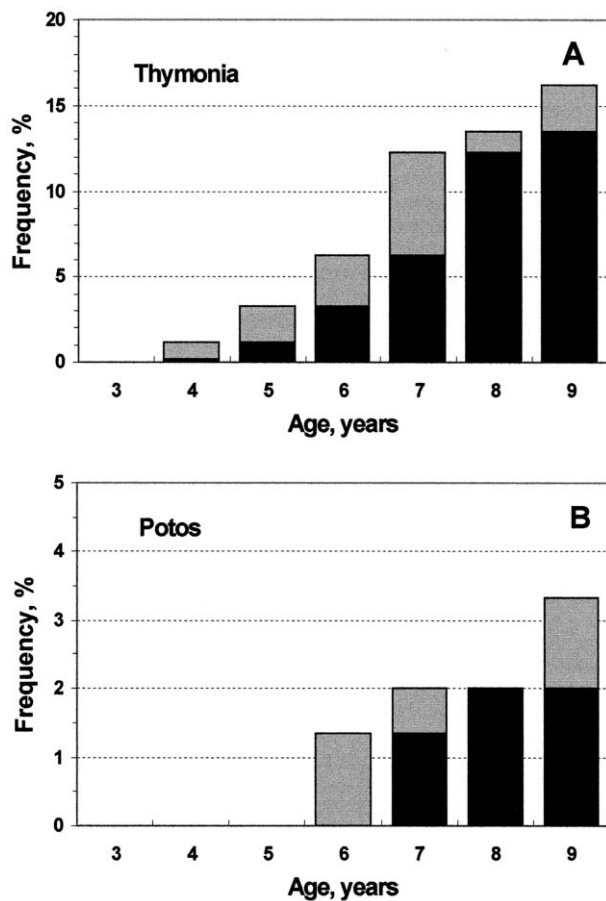


Figure 7. The shift from juvenile to reproductive phase in postfire, even-aged populations of *Pinus brutia* saplings (331 and 150 individuals, respectively) in Thymonia (A) and Potos (B), Thasos island (wildfire of 1985). Bars represent values for current years (grey) and accumulated ones from previous years (black).

regeneration of the species, and of the forest as well, is totally dependent upon the recruitment of a postfire cohort of seedlings. A certain fraction of pine seeds can survive the fire, protected by the scales of the closed, serotinous cones; moreover, as a result of heat, these cones open and disperse the enclosed seeds shortly after fire (as documented for Aleppo pine [7, 20]). Pine seed germination and seedling emergence takes place almost exclusively during the first postfire wet season. More specifically, its occurrence usually takes the form of a massive wave either early in fall (during October–January, as in Aleppo pine and southern *P. brutia* forests [32]), or during winter and early spring (as in the case of *P. brutia* in Samos island [31] or in other, northern provenances as postulated by Skordilis and Thanos [23]). This latter, spring pattern

was followed in the present case of Thasos island although the very late seedling emergence was also due to the severe drought of the particular year 1989–1990. Furthermore, it is noteworthy that no additional pine seedlings were observed emerging during the subsequent years, thus verifying the single-wave regeneration pattern for both Aleppo and brutia pines [27, 31].

In both Aleppo and brutia pine species and with the unusual exception of extremely rich soils, an average growth increment between 5 and 20 cm per year has been observed, during the first 10 years of age, in several cases ([6, 28, 29, 32, 34], Thanos et al. unpubl.). Moreover, in all these studies, postfire growth kinetics has shown that pine seedling height tends to follow a linear regression curve for the first ten (at least) postfire years [27]. The height kinetics of pine saplings in Thasos followed linear curves with statistically significant differences between the slopes of the lines representing northern or southern aspects and fertile or infertile sites. The 9-year-old saplings (wildfire of 1985) also showed a significant difference between the height values of the two sites studied; nevertheless, the gross average, for the two sites, was 146 cm, remarkably close to an estimated value of 147 cm predicted for 9-year-old saplings from the equation of the ‘average’ growth kinetics of the 1989 wildfire (introduced in the first paragraph of the results section). Therefore, a ‘gross average’ yearly increment of 17 cm is estimated for the particular growth of pine saplings in Thasos island, a value considerably higher than that for *P. brutia* of Samos island (ca. 10 cm [28, 29]) and at the same time comparable with those in the fast-growing part of the range observed for Aleppo pine ([27], Thanos et al. unpubl.).

In addition to the inter-site variation of growth, an even more remarkable variation of seedling density was observed in Thasos. In particular, the differences between northern and southern expositions were striking throughout the 5-year-long monitoring period; however, this result has been previously obtained in almost every large-scale Mediterranean pine regeneration investigation and reflects both the mosaic nature of the forest and the non-uniform wildfire impact as well (cf. [31, 32]). Maximum density of pine saplings is generally observed during the first postfire spring and may amount to an average of several seedlings·m⁻², exactly as in the present case [27]. Despite the considerable variability among sites and burned areas, the overall trend is considered to display a gradual decrease of pine sapling density during the first two postfire years. A more or less stabilized

average density of around 1–2 or 0.4 saplings·m⁻² is reached at year 2 or 3 and onwards (previous cases of Parnes, Aleppo pine, [32] and Samos, *P. brutia*, [28]). By using regression analysis, nicely fitted negative exponential curves were obtained in both studies; the asymptotic level of survival was 20 and 40 %, respectively, of the seedlings established during the first postfire spring. In Thasos, the best fit curve was represented by a rectangular hyperbola while the survival level was almost 30 %. The actual density values were much higher than those of *P. brutia* in Samos [31] but strikingly comparable to the *P. halepensis* ones of Mt Parnes [32]; the only discrepancy to the latter case was that a similar value of the average stabilized density (ca. 1–2 saplings·m⁻²) was reached considerably later in Thasos, i.e. after a period of 4–5 years.

The main causes of pine seedling mortality were grazing and trampling by goats [25] as well as the harsh meteorological conditions, particularly summer drought (as previously found for Aleppo pines [32]). Moreover, a previous study on the island of Thasos has already revealed that large numbers of seedlings on north and eastern expositions were destroyed by goats since the latter prefer wet and cool sites during the hot days of summer [25]. In addition, a number of seedlings perished as a result of intensive felling and removal of burned trunks, activities which took place on all expositions and lasted until July 1990, well after the germination of seeds [24]. Overgrazing by goats under the canopy of forests is considered to be a severe problem for Greek forestry [5, 24] and this disturbance becomes acute during postfire regeneration conditions. It is estimated that more than 50 % of the pine seedlings emerging after the 1989 wildfire were extinguished by grazing; nevertheless, the final sapling densities reached are certainly sufficient for a prolific natural regeneration as it has been shown in previous investigations dealing with burned forests of both *P. brutia* [2, 16, 28, 29] and *P. halepensis* [6, 15, 21, 32, 33, 36, 38].

The reproductive shift in Aleppo and brutia pines has been investigated in the nursery [17] and only recently under field conditions [27, 29]. Nevertheless, it is empirically known that both species have a remarkably short juvenile phase, a fact leading to an early cone (and seed) production. In the burned forests of Parnes (*P. halepensis*) and Samos (*P. brutia*) as early as 4 and 6 years, respectively, after germination, a small fraction of pine sapling population was seen to produce female conelets. The kinetics of the reproductive shift of the sapling population seem to follow

either an exponential or a linear increase, although research is still ongoing [27]. Nevertheless, considerable fluctuations among consecutive years may occur, a fact also observed in the present case; it is suggested that the entire sapling population will have reached reproductive maturity by the age of 20 years. In regard to the cone characteristics, there exist no relevant data from mature plants of nearby unburned stands; however, unpublished data (Thanos et al.) from several *P. brutia* forests of Greece provide cone weight values in the range of 30 and 40 g, seed number per cone between 40 and 50 and, from a single seedlot, an average seed weight of 60.2 mg ([30] although seed weight in *P. brutia* is very variable – [23, 29] and Thanos et al. unpubl.). Since the relevant values from the early matured cones of the 9-year-old postfire stand are considerably lower, it may be suggested that cones formed at an early sapling stage are somewhat smaller with perhaps slightly lesser and smaller seeds which nevertheless are equally (or almost) germinable to those produced by mature trees.

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