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Postfire regeneration of Aleppo pine – Density, survival and early growth of *Pinus halepensis* seedlings

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ABSTRACT: The ecological and economic importance of Mediterranean pine forests lends particular interest to the study of *Pinus halepensis* postfire regeneration. In five, recently burned, Aleppo pine forests of Attica (Stamata, Villia, Avlona, Kapandriti and Agios Stefanos), a number of permanent experimental plots were established at varying locations, exposures and slopes. All these plots were mapped in detail and emerging seedlings were marked with plastic rings at the initial stage of cotyledon expansion. Field observations in all sites were carried out at almost monthly intervals. This study is a follow-up of an earlier work, complementing previously reported results for the first postfire year. At this time, data concerning the Aleppo pine seedling density, survival and growth dynamics, obtained during the second postfire year, are presented and elaborated. High values of seedling density (1.3-3.0 seedlings/m^2) and survival (30-60% of the total number of emerged seedlings) during the second postfire year ensure the future constitution of a very dense forest. Monitoring of seedling height revealed that the major growth activity takes place in spring (February-May) and follows a typical sigmoid curve.

1 INTRODUCTION

The postfire regeneration of Mediterranean pines (Aleppo and brutia pine) has recently been investigated and reported in several publications. Both species do not resprout at all (obligate reseeders) and a typical Mediterranean wildfire usually kills the entire pine population. Therefore, the regeneration of the species, and of the forest as well, is totally dependent upon the canopy seed bank and the recruitment of a postfire cohort of seedlings (Thanos et al. 1989, Daskalakou and Thanos 1996, Thanos 1999). Since postfire conditions provide an ideal environment for the natural regeneration of these pines, seedling recruitment strategies are of paramount importance for the reestablishment of a burned pine forest (Thanos 1999). Postfire seedling density is considered as a reliable indicator of the success of postfire resilience and is often adopted in either synchronic or diachronic studies (Trabaud et al. 1985, Trabaud 1988, Richardson 1988, Thanos et al. 1989, Moravec 1990, Thanos and Marcou 1991, (1993), Saracino et al. (1993), Saracino and Leone (1993), Thanos et al. (1996), Daskalakou and Thanos 1997, Tsitsoni 1997, Trabaud 2000, Arianoutsou and Ne'eman 2000, Thanos and Daskalakou 2000, Verroios and Georgiadis 2002, Daskalakou and Thanos 2004). According to Trabaud (2000), the diachronic approach is more accurate since the dynamics of vegetation can be followed through time on the same site. In addition, in the present study, postfire monthly recordings and follow-up of seedling survival, density and growth have been obtained from large numbers of tagged Aleppo pine seedling, marked almost immediately after their field emergence; these data are believed to constitute a reliable baseline for a more or less accurate forecast of the forest re-establishment from a burned, bare soil.

Aleppo pine seedling growth has been studied quite extensively by other researchers: e.g. Panetsos (1981), Liphschitz et al. (1984), Calamassi et al. (1988), Matziris (1997), Broncano et al. (1998), Pardos et al. (2003); however, most of available data originate from nurseries or experimental *Pinus halepensis* plantations. Therefore, this work is the first to approach, at a population and biomass level, the natural, postfire regeneration of an Aleppo pine forest; survival, density and early growth of pine seedlings are recorded and analysed during the early postfire years, under natural conditions.

2 MATERIALS AND METHODS

Aleppo pine seedling emergence, establishment, time course of seedling density (Fig. 1), seedling survival and growth (Fig. 2) were studied in five burned locations of *Pinus halepensis* forests in Attica, Greece (Stamata, Villia, Avlona, Kapandriti and Agios Stefanos; burned in June 1990, July 1990, September 1991, September 1992 and July 1993, respectively). Five observation plots (1 x 10 m x m) were established at randomly selected sites, of varying exposures and slopes of the burned forests, soon after the fire and before the onset of the rainy season. Field observations were realised almost on monthly intervals (Daskalakou and Thanos 2004). All study plots were mapped in detail; each emerging Aleppo pine seedling inside the plots was recorded and tagged with a coloured plastic ring or a numbered label and monitored for survival throughout the observation period.

In two cases (Table 1), in the burned pine forests of Stamata and Villia, height measurements were taken from 100 randomly selected, surviving seedlings in each monthly observation. In the other three regions (Avlona, Kapandriti and Agios Stefanos) height was monitored on the individually tagged seedlings, which had emerged in all five observation plots.

For the description of seedling growth (Fig. 2C) the temporal pattern of seedling growth increment was drawn, expressed as the quotient of height difference (mm) over the intervened time (days). The temporal pattern of seedling growth increment was manufactured for the burned forest of Kapandriti, where measurements correspond to mean heights (cm) of all tagged seedlings within the observation plots.

Statistically significant differences were assessed using Single Factor Analysis of Variance (ANOVA) and the Newman-Keuls multiple range test (for more than two means) at P=0.05 level of probability Zar (1974).

Table 1. Mean seedling height values (cm) in all five burned pine forests of Attica measured at the end of the first (1) and second postfire (2) growth season. In the first two columns, Stamata and Villia, the values refer to seedlings randomly selected for each measurement. In the last three columns, mean height values were taken on the surviving, tagged Aleppo pine seedlings. Values statistically different (P<0.05) within rows are followed by different letters (Newman-Keuls multiple range test).

Forest / Postfire Year	Stamata H ± SE (n)	Villia H ± SE (n)	Avlona H ± SE (n)	Kapandriti H ± SE (n)	Agios Stefanos H ± SE (n)
1	8.99 ± 0.21^{b} (n = 100)	9.70 ± 0.24^{b} (n = 100)	5.79 ± 0.17^{c} (n = 139)	9.05 ± 0.27^{b} (n = 201)	10.64 ± 0.44^{a} (n = 169)
2	22.12 ± 0.79^{b} (n = 100)	17.81 ± 0.58^{c} (n = 100)	11.39 ± 0.56^{d} (n = 51)	21.44 ± 0.77^{b} (n = 160)	32.67 ± 1.92^{a} (n = 121)

3 RESULTS

3.1 *Pinus halepensis postfire seedling density*

Seedling density (Fig. 1) dynamics usually present an "explosive" increase during the first postfire, rainy months in most studied areas (Daskalakou and Thanos 2004). Time 0 is set at the onset of the first postfire hydrological year (1st October 1990, 1990, 1991, 1992 and 1993, respectively). For reasons of simplicity, time (days) 360 and 720 are set as the onset of the second and third postfire hydrological year, respectively.

The Aleppo pine seedling density, in Stamata, was 2.3 seedlings/m^2 at the beginning of the second postfire hydrological year (1st October, time 360). This density was not considerably decreased in the second postfire winter and diminished slightly during the following spring (2.1 seedlings/m^2 in June). At the onset of the third postfire hydrological year, which coincides with the last field observation, seedling density was found somewhat decreased (1.5 seedlings/m^2) but still quite high for the constitution of a very dense future forest (15.000 stems / ha).

A similar process in the postfire seedling density time course was also followed in the burned forest of Villia, Attica. However, seedling density was not considerably reduced during the first postfire winter, despite the severe cold events that took place during that period (Daskalakou and Thanos 1997, 2004). However, the seedling density was considerably decreased from 3.0 seedlings/m^2 in the first postfire February to 1.6 seedlings/m^2 in the following October. Afterwards, seedling density remained more or less constant until the onset of the third postfire hydrological year.

The maximum seedling density in Avlona was observed in the first postfire December (3.9 seedlings/m^2) and followed a progressive reduction over time. It is noticed that by the end of the first postfire summer (October), the density measured was 2.3 seedlings/m^2. In the second postfire winter, density dropped to 2.0 seedlings/m^2; a mean value that remained at the same level until the end of the following spring.

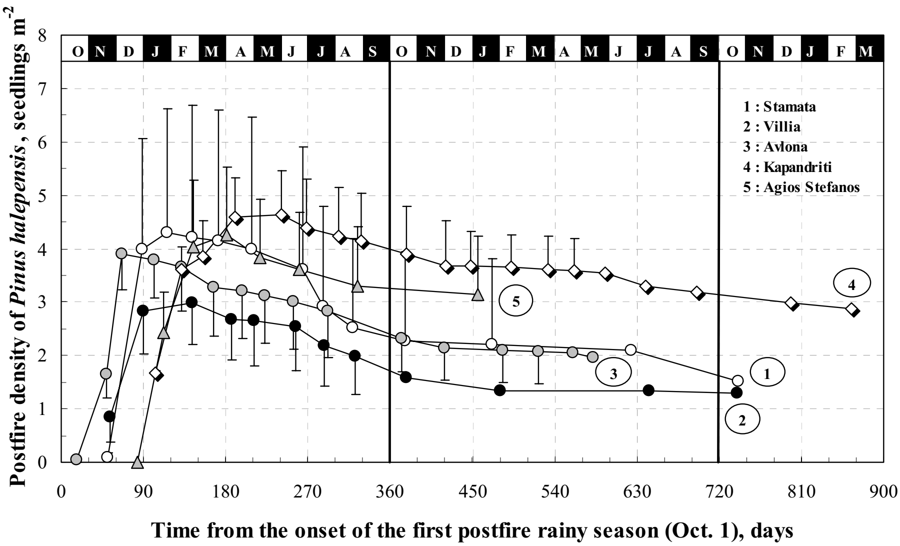

Figure 1. The dynamics of *Pinus halepensis* seedling density during the first two, successive, postfire years, in five, pine forests of Attica (burned in different years). The vertical bars represent ±SE (n=5 for each value).

Field observations in most study sites were unfortunately interrupted due to human activities (illegal building construction, opening up of forest roads, burned areas deforcement, overgrazing and woodcutting) before the programmed time schedule of the first three postfire years field observation period was completed. It was found that observation plots were partly or even completely destroyed in most of the burned forests of Attica. Thereby a diachronic follow-up of natural regeneration has been unfortunately impossible for more than 2-3 years. Three out of five observation plots were destroyed in the second postfire June, July and April in three burned pine forests (Stamata, Villia and Avlona, respectively). Despite the observation plots destruction, field observations were carried out in all remaining plots for the next postfire years.

In Kapandriti and Agios Stefanos (Fig. 1), the time course of seedling density reached its highest value in the first postfire spring months (May and April, 4.6 and 4.2 seedlings/m^2, respectively). Time differentiations of the postfire seedling density are obviously due to the climatic conditions and mainly to the onset of the first postfire rainy season, which varied from year to year (Daskalakou and Thanos 2004). In Kapandriti, a gradual density reduction led to 4.1 seedlings/m^2 at the end of the first postfire summer and through a consecutive, slightly declining process to 3.0 seedlings/m^2 in the second postfire year (December); that value was maintained almost constant during the third postfire year. In Agios Stefanos, the maximum seedling density value was 4.2 seedlings/m^2 in the first postfire spring months (April). Its gradual reduction was observed during the following dry period (3.3 seedlings/m^2) and dropped to 3.1 seedlings/m^2 in the second postfire winter (December).

3.2 *Pinus halepensis postfire seedling survival*

An intensely declining process in seedling survival was noted during the first postfire wet season in almost all burned pine forests of Attica; a reduction which corresponds to the first critical stage of seedling establishment (Daskalakou and Thanos 2004). However, at the same time, new seedlings kept on emerging in the field (at relatively low numbers).

Throughout the first postfire year (Daskalakou and Thanos 2004), the total toll of dead seedlings, in each of the five forest sites, respectively, amounted to (in parentheses the total number of seedlings emerged and the percentage of mortality): 125 (250, 50%), 89 (188, 47.3%), 86 (228, 37.7%), 61 (265, 23%), and 69 (240, 28.8%). Therefore, the overall annual mortality of pine seedlings ranged between 23 and 50% with an average (±SE) of 37.4±5.2% (n=5). By the end of the second postfire year the total numbers of surviving seedlings found were (in parentheses the percentage of surviving seedlings) 77 (30.8%), 65 (34.6%), 90 (39.5%), 154 (58.11%) and 162 (67.5%), respectively. Therefore, the overall survival of pine seedlings ranged between 30.8 and 67.5% with an average (±SE) of 46.1±7.1% (n=5).

3.3 *Pinus halepensis postfire seedling growth kinetics*

Mean seedling height values (cm) were not found statistically different at $P<0.05$ (Newman-Keuls multiple range test) in three out of five burned forests of Attica (Table 1), by the end of the first postfire growth season. In the second postfire growth season seedlings ranged from 11.39 to 32.67 cm and just in two postfire environments (Stamata and Kapandriti) seedlings found similar.

Monitoring the annual seedling growth rate in all five mentioned Aleppo pine burned forests results in height growth curves that follow linear kinetics in all cases and at least for the first 5 postfire years (Fig. 2A). Moreover, a detailed study of growth kinetics was realized in the burned pine forests of Avlona and Kapandriti. Mean height values correspond to all individually tagged seedlings, which survived inside the observation plots, therefore avoiding errors caused by random measurements. The study of the postfire seedling growth kinetics showed that, within an individual growth season, height growth follows a typical sigmoid curve (Fig. 2B). In particular, postfire seedling growth activity in the burned pine forest of Avlona was observed during the first postfire spring months and the final mean height of young pine saplings reached up to 6 cm (July). The next

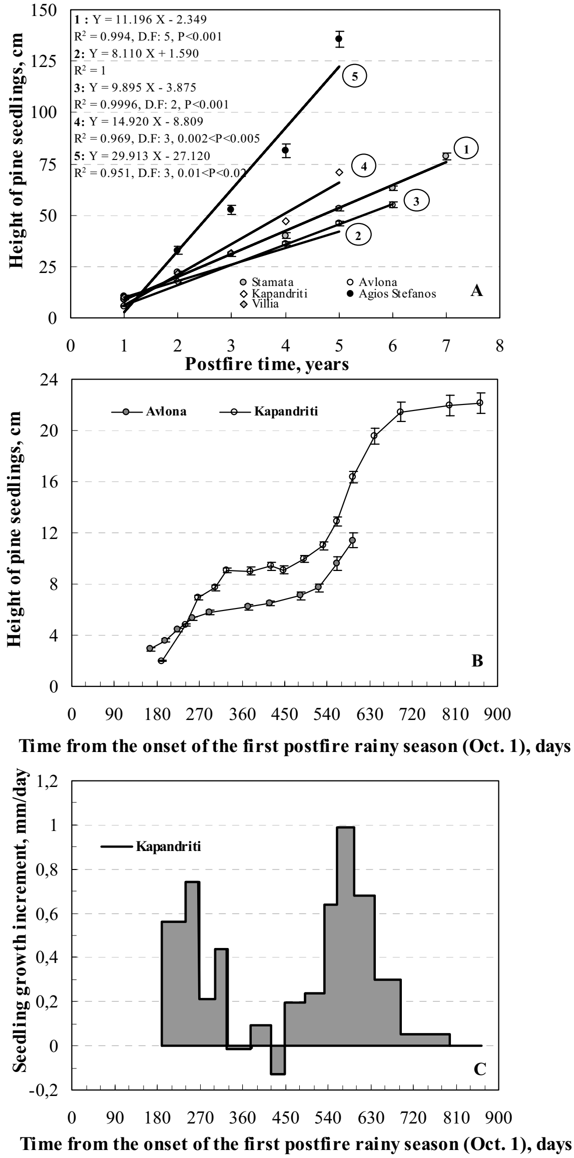

Figure 2. (A). Early postfire annual growth of *Pinus halepensis* seedlings in all five burned forests of Attica Mean values represent the annual heights of postfire, tagged pine sapling populations at the end of each growth period (years after fire). Correlation equations are given above and left. Vertical bars represent standard errors (±SE). (B). Postfire seedling growth kinetics in the burned pine forests of Avlona and Kapandriti, Attica. Sample sizes include a varying number of tagged seedlings within the observation plots (the result of either seedling emergence or seedling mortality). (C). Temporal pattern of growth increment (mm/day) in *Pinus halepensis* seedlings established in the burned pine forest of Kapandriti, Attica.

growth season was observed in the second postfire spring as well (mean heights: 7.8 and 11.4 cm in March and May respectively). Statistical significant differences of mean height values were obtained: a. during the first postfire spring months (March-June, time 167-254) and b. in the same time period of the second postfire year (March-May, time 522-595). The seedlings growing in the burned pine forest of Kapandriti also followed the same pattern of growth kinetics. The main growth activity season was noted during the first postfire spring months and it is possible that it extended somewhat into summertime (particularly if the available soil humidity was favourable); mean heights: 5.0 and 9.0 cm in May and August, respectively. Similarly, during the second postfire year the height values observed were 13.0 and 21.4 cm (in April and August, respectively). Statistical significant differences of mean height values were also obtained: a. during the first postfire spring months (April-June, time 190-268) and b. spring up to late in summer of the second postfire year (April-August, time 553-687).

The temporal pattern of growth increment (mm/day) was based on height measurements of the postfire pine seedling population in the burned forest in Kapandriti, Attica (Fig. 2C). It is once more verified that seedling growth takes place mainly in the spring months. Seedling growth increment, calculated for the first postfire year reached peak values of 0.56 and 0.74 mm/day in May and June, respectively. In the meantime, August-October (time 328-378) the growth increment was negligible; in comparison to zero, it was not found statistically different. In the second postfire year the maximum growth increment value (0.99 mm/day) was obtained in May. Growth increment was virtually missing in winter months (December-February, time 798-865), where values do not differ statistically from zero.

4 DISCUSSION – CONCLUSIONS

Previously reported postfire Aleppo pine seedling densities range widely due to several reasons, such as the characteristics of the burned forest, the conditions prevailing during postfire regeneration and the postfire stages (Thanos et al. 1996). In relevant, postfire regeneration studies realised in burned pine forests of S. France (Trabaud et al. 1985) the seedling density was found exceptionally low, 0.1 seedlings/m^2 and was correlated to burned adult “mother” tree density or the adjacency to unburned sites. In another case of burned pine forest (Montpellier, S. France) mean seedling density, recorded in the first postfire June, showed low values: 0.07 seedlings/m^2 (Trabaud 1988). In burned *P. halepensis* stands in S. Africa, seedling density ranged from 6.6 to 13.4 seedlings/m^2, 8 months after fire (Richardson 1988). In burned pine forests of NW Algeria, a density of 0.16-0.23 seedlings/m^2 was found two years after fire, while it was dramatically higher (15.8 seedlings/m^2) inside the protective firebreak belts. Five years after fire, pine sapling density was 3.6 seedlings/m^2, while its important reduction observed at the 20th postfire year (Moravec 1990). The Aleppo pine postfire regeneration study in Italy (including natural ecosystems of coastal dunes), in the first two postfire years, resulted in an impressive density during the first postfire winter (14-20 seedlings/m^2) with a rapid reduction at the drought period (Saracino and Leone 1993, Saracino et al. 1993). In Mount Carmel (Israel) the measured density was about 10 seedlings/m^2 (ranging between 5 and 22) in the first postfire year (Ne'eman et al. 1992). In N. Greece (Kassandra, Chalkidiki) the postfire regeneration was measured between 0.6-14.26 during a period of 1-8 years after fire (Tsitsoni 1997).

In a burned *Pinus brutia* forest of insular Greece (Samos) mean density was found 0.30 seedlings/m^2, 18 months after fire. During the 6th postfire year, density was decreased to 0.15 saplings/m^2. Then, sapling mortality was negligible until the 10th postfire year (Thanos et al. 1989, Thanos and Marcou 1991, 1993). In a burned brutia pine forest of Thasos Island (Spanos et al. 2000) seedling emergence was temporally determined late in the first postfire spring (May), due to the extended intermediate drought period. Despite the delayed seedling emergence in the field, seedling density was significant, 1.8-5.9 seedlings/m^2. Nevertheless, increased postfire pine populations were observed in northern and eastern sites in burned pine forests of Thasos Island (Spanos et al. 2000).

An "explosive" increase in time course of Aleppo pine seedling density presented at the duration of first postfire rainy season. In the majority of study regions, maximum density values (3.9-4.3 seedlings/m^2) were observed in the winter months (December-February). In the rest study regions, maximum postfire density values were recorded in spring months (4.3-4.6 seedlings/m^2), a justified time differentiation, taking into consideration various climatic conditions (particularly the seasonal rainfall distribution). An important density reduction was marked during the first postfire summer (Daskalakou and Thanos 1997, 2004). By the end of the first postfire year, seedling density was found 1.9-4.0 seedlings/m^2, an efficient value for the reconstitution of a burned pine forest. During the second postfire year, seedling density followed an almost constant course. Despite the dramatic seedling density reduction observed in the first postfire summer months, 1.3-3.0 survived seedlings/m^2 correspond to a very dense forest (13.000-30.000 trees/ha).

Important period for seedling survival is the first postfire year (Thanos et al. 1989, Saracino et al. 1993, Thanos et al. 1996, Daskalakou and Thanos 1997, Spanos et al. 2000). In particular, the most crucial period is the initial stage of cotyledon expansion, observed in the first part of the rainy season immediately after fire, when germination and early seedling development - establishment takes place (Thanos et al. 1996). In addition, the capability of either Aleppo or brutia pine seedlings to survive during the summer period is very limited. Natural summer conditions and particularly the postfire conditions (high air and soil temperatures and simultaneous absence of humidity) are exceptionally unfavourable for young seedling survival. In most study areas, seedling survival followed an almost stable phase during the second postfire year. In relative seedling survival studies in burned brutia pine forest of Samos, the survival amounted to 70% at the first postfire year (Thanos and Marcou 1989) and remained constant afterwards until the 6th postfire year in a percentage 40-50% (Thanos and Marcou 1993). In burned forests of Thasos Island, only a very small percentage of seedling mortality (4%) was attributed to summer drought while a large one was attributed to grazing (up to 55%). In the following years, dead seedlings due to summer drought accounted to 5-18% of total mortality while grazing contributed dramatically again (60%) (Spanos 1992).

Several records attribute seedling mortality to various causes: plant interspecific competition, fungal infection, invasions of predators and water stress. In five different burned regions of Montpellier (S. France) mortality ranged at relatively low levels: only 11% the three first years after fire and approximately 20% at the 5th postfire year (Trabaud 1988). On the contrary, in burned pine forests of Italy (Taranto) seedling mortality was considerably higher, 65% during the establishment period Saracino et al. (1993). Also, postfire seedling mortality in Mount Carmel (Israel) amounted to high percentages, approximately 60%, between the first and second postfire year (Ne' eman et al. 1993).

According to a previous work (Daskalakou and Thanos 2004) the temporal pattern of seedling mortality presented two important peaks: at the initial, critical seedling establishment phase (early in winter and spring) and during the first postfire summer. Since the majority of dead seedlings remained as "skeletons" inside the observation plots, mortality was not attributed to grazing or predation. In the second postfire year, the Aleppo pine seedling populations have been almost stabilised, presenting only a negligible, additional occurrence of mortality, a fact that allows the prediction of a safe re-establishment of the pine forest in the near future.

In the present study, postfire seedling growth activity was realised mainly in spring, a temporally determined event, most probably controlled by seasonal light conditions (photoperiodism), a phenomenon already observed in several pine species (Kramer and Kozlowski 1979). Seedling growth activity is temporally determined during the spring season, as observed both in the first and the second postfire year, and could last until late in summer if the environmental conditions prevailing lead to soil humidity values higher than the "critical" one for seedling survival (Lipschitz et al. 1984).

In all five burned Aleppo pine forests of Attica, height of one and two years old seedlings reached up to 10 cm and 20 cm respectively, result that agrees with data of postfire seedling growth in S. France, where mean height increment was found 10 cm/year in the first ten postfire years. In the following postfire years (10-30 years after fire), growth rate reach up to 40 cm/year (Trabaud et al. 1985). Nevertheless, in another 5 year long study near Montpellier, mean seedling heights found 4.9, 12.3 and 23.4 cm in the first, second and third year after fire (Trabaud. 1988). In a relative study realised in the burned pine forest of Mount Parnis in Attica, the corresponding mean heights were 5, 15 and 22 cm, respectively, while no additional growth was recorded during summer period (Thanos et al. 1996). However, height of one-year-old pine seedlings in Mount Carmel (Israel) was found ca 10 cm (Ne'eman et al. 1993). In burned pine forests of Italy (Taranto), the mean seedling height reached up to 6.0 and 14.4 cm in the first and second postfire years, respectively (Saracino et al. 1993). In the burned pine forest of NW Algeria, the postfire average height was 10 cm after 2 years, compared to a much higher value of 23 cm obtained inside the firebreak protection belts (Moravec 1990). The slow growth of seedlings reported in dunes of Taranto (Italy) may be related to the poor nutritient conditions (Saracino and Leone 1993). In the burned brutia pine forest of Samos, seedlings measured 6 and 11 cm high by the end of the first and second growth period, respectively (Thanos et al. 1989). Six and ten years after fire, brutia pine seedlings were found 50-60 and 100 cm high, respectively (Thanos and Marcou 1991, 1993). Remarkably, a sapling bank, consisting of very short saplings, was reported both for Aleppo (Thanos et al. 1996) and brutia pine (Thanos and Marcou 1991, 1993).

According to Calamassi et al. (1988), Aleppo pine seedling growth was characterized as "monocyclic", with expansion of summer shoots. In a relevant study with either young or adult pine individuals (Serre-Bachet 1992), apical growth was observed to follow four phases (circles) during a single vegetation season. The first and more important phase of growth was presented in full spring (April-May), the rest ones during summertime (June-July) until September. According to Thanos et al. (1996), the growth season of Aleppo pine seedlings coincides to spring months (starting from early in January and extending until late in June); however the possibility of a minor growth peak in autumn cannot be entirely excluded, a result that compares well with data of the present study.

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