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Soil Nutrient, Woody Understory and Shoot and Root Growth Responses of *Pinus brutia* Ten. Saplings to Fire

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Abstract

Nine years after a wildfire, above- and below-ground morphology of *Pinus brutia* Ten. saplings and the microsite factors prevailing in understorey (unburned area) and postfire conditions (burned area) of the Forest Park of Thessaloniki were studied. Major stand characteristics (density, tree canopy cover, tree height, crown height, and diameter) were measured in the unburned area. Light and soil conditions as well as plant cover of woody species were recorded in both areas (burned and unburned). A random sample of pine saplings, of uniform age, was taken from both burned and unburned areas, and their above-ground (height, diameter, number and total length of branches, needle biomass) and below-ground morphological characteristics (taproot length, total length of coarse and fine roots, and number of coarse roots) were measured. Data analysis showed that above- and below-ground morphology of pine saplings was adversely affected in saplings grown in understorey conditions, compared to those grown in postfire conditions. *P. brutia* is a shade-intolerant tree species and thus the light conditions seem to be the critical factor affecting the growth of pine saplings. Light is not a limiting factor in the burned area compared to the understorey, where density of the tree canopy limits available light.

Keywords: burned ecosystems, light effect, plant growth, root morphology, Turkish pine, wildfires

Introduction

Pinus brutia Ten. forests cover large areas in the east Mediterranean basin and are of great ecological and economic importance (Quezel, 2000; Tsitsoni *et al*., 2004). Since they are also among the ecosystems frequently affected by wildfires (Boydak, 2004), reports focusing on their adaptive responses to fire are abundant in the literature (Raftoyannis and Spanos, 2005; Spanos *et al*., 2000; Thanos and Dousssi, 2000; Tsitsoni *et al*., 2004). However, *P. brutia* ecosystems, as most Mediterranean pine ecosystems, can successfully regenerate without fires, provided appropriate silvicultural treatments are applied (Boydak, 2004). The required silvicultural treatments depend on several factors, including species eco-physiological attributes and site conditions. Soil conditions, especially moisture, and available light play the most critical role, while understorey vegetation can also affect seedling establishment and growth (Boydak, 2004).

The success of forest regeneration is usually estimated based on seedling/sapling density and their height or growth rates (Spanos *et al*., 2000). However, knowledge on above- and below-ground morphological characteristics of regenerated saplings is necessary for estimating their performance and predicting future stand structure. Plant below-ground structure is essential for understanding and predicting ecosystem functioning (Tobin *et al*., 2007). The development of a root system capable of anchoring the shoot and obtaining water and nutrients is essential for the survival and growth of most terrestrial plants (Fitter, 1991).

Although the recovery of burned Mediterranean pine forests has been studied thoroughly, there are only a few studies examining postfire root and shoot growth of pine seedlings and saplings. Martinez-Sanchez *et al*. (2003) reported that in postfire conditions, *P. halepensis* saplings' root system was of herringbone type and changed to random branching over the time of sapling development. Hart *et al*. (1994) and Smith *et al*. (2004) concluded that the fine root mass of Ponderosa pine decreased after surface fires. Veselkin *et al*. (2010) compared pine root morphology in unburned and postfire conditions and reported that Scots pine seedlings had longer conducting roots in burned areas compared to unburned areas. In particular, for the root morphology of *P. brutia* saplings grown in an unburned environment, the only reference is that of Ganatsas and Spanos (2005), who reported that most of the roots of 5-year-old naturally regenerated saplings originated from the taproot and developed almost horizontally, parallel to the soil surface.

The present study was conducted to analyze shoot and root morphology of *P. brutia* saplings under unburned and postfire conditions. Shoot and root morphological traits of saplings could play an important role in postfire stand development. These traits have not been studied previously, justifying the present study.

The objectives of this study were to analyze and compare: 1) the microsite factors (soil and light conditions, plant cover) affecting sapling establishment in unburned *P. brutia* forest and in adjacent burned areas (postfire conditions), and 2) the above- and below-ground morphological characteristics of *P. brutia* saplings established naturally in the above areas.

Materials and methods

Study area

The study area is located in the suburban Forest Park of Thessaloniki in northern Greece (40° 39′ N, 23° 00′ E). The forest covers an area of 2,979 ha (Fig. 1), and the altitude ranges from 100 to 450 m. The natural vegetation of the area belongs to the lowest part of the Mediterranean vegetation zone (Dafis, 1973), the association *Coccifero-Carpinetum orientalis* Oberdorfer 1948 em Horvat, 1954, of the alliance *Ostryo-Carpinion orientalis* Horvat (1954) 1958, order *Quercetalia pubescenti-petraeae* Klika, 1933. The forest is mainly dominated by stands of *P. brutia* planted between the period of 1935-1960, with patches of *Cupressus sempervirens*, *P. pinea* and *P. halepensis*. The understorey vegetation is dominated by evergreen sclerophyllous species such as *Quercus coccifera* and *Phillyrea latifolia.* The climate can be characterized as cool and semi-arid Mediterranean, with cold winters, high temperatures in summer and an average annual precipitation of 448 mm. The dry season starts in mid-May and lasts until mid-September. The area belongs to the magmatic series of Chortiatis and consists mainly of green schists. The soils are shallow, infertile, have low porosity, and a high percentage of stones and pebbles (Ganatsas and Tsakaldimi, 2003).

Experimental design

A large wildfire occurred in the forest in July 1997, burning over 1,500 ha, almost half of the total area of the park. In spring 2006, a field sampling campaign was planned in adjacent unburned and burned areas in the forest to: i) determine stand characteristics in the unburned area, ii) record soil and light conditions in the two treatments (burned and unburned area), iii) determine plant cover differentiation in the two treatments, and iv) assess above- and below-ground morphological characteristics of pine saplings grown in the two treatments. Two contrasting sites (burned and unburned) with similar characteristics (altitude, type of bedrock, aspect, slope inclination, vegetation type, land uses, human history) were selected for comparison.

Stand characteristics were determined in the unburned area by randomly selecting three rectangular plots of 500 m^2 each, where the following measurements were carried out: tree density (number of all trees with diameter greater than 4 cm at breast height), overstorey canopy cover (visually assessed with a precision of 5% by two experienced persons), tree and crown height, and tree diameter at breast height.

For plant cover estimation, it was used 10 rectangular plots with their short side oriented parallel to the contour lines, which were randomly selected (five in the burned and five in the unburned area). Each rectangular plot had a size of 40 m × 4 m. The cover of all woody species was recorded along the two long borderlines of each plot, every

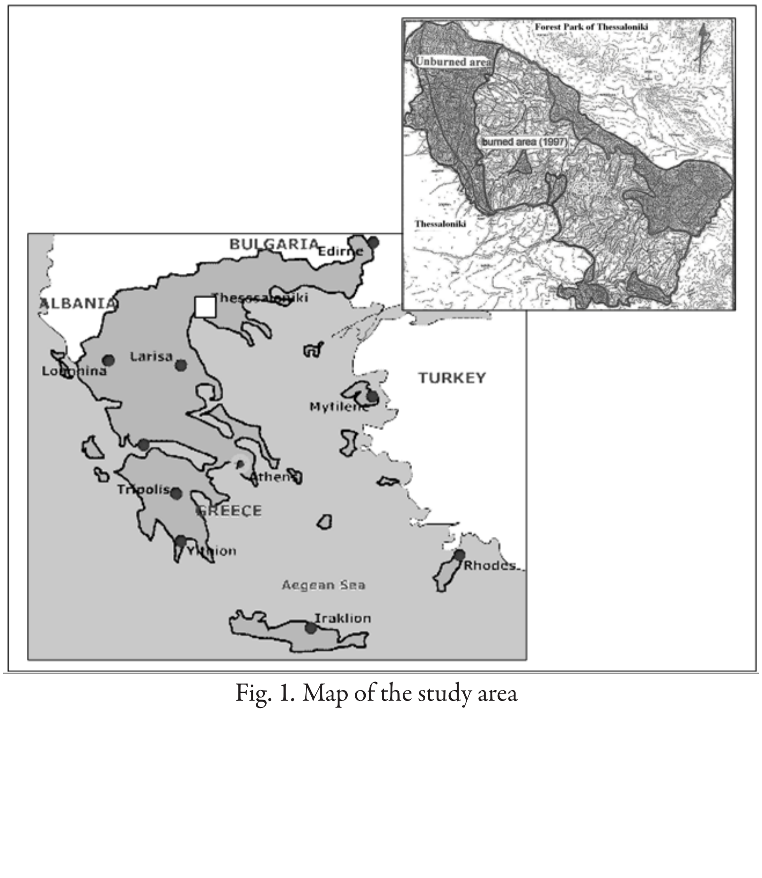

Fig. 1. Map of the study area

10 cm, using a metal pin vertical to the line (Raftoyannis and Spanos, 2005).

Light conditions were measured using a digital light-meter (EXTECH Instruments; model 40125) during March 2006-January 2007, in a two-month step. Measurements were recorded during the same 2 h time interval (at noon between 12.00 am-14.00 pm) over the course of two sunny days per month. The light intensity was measured at two sampling heights: in the position of each sampled sapling (after sapling removal) and 50 cm above the ground. On each sunny day, five light-rates per sampled sapling were recorded per sampling height (one at the centre of the excavated pine-hole, and four 50 cm away from the centre in the four directions N, E, W and S).

Soil conditions were determined by taking three soil profiles, at three random points per treatment. The sampling in the unburned stands was carried out within the stand characteristics' plots. Soil samples were transported to the laboratory for organic matter content, pH, mechanical (soil texture) analysis and phosphorus content measurements. Organic matter content (organic C) was determined by the wet oxidation method (Nelson and Sommers, 1982). Soil pH was measured from air-dried samples placed in deionized water (1:1 ratio) using a pH meter. Mechanical analysis was done by the pipette method. Extractable P was measured by the Olsen method, using $NaHCO_3$ as an extracting solution and determining P by visible spectrophotometry and the molybdenum blue method (Olsen and Sommers, 1982).

Thirty saplings were randomly selected for measurements of above- and below-ground morphological characteristics; fifteen were taken from under the canopy of mature pine trees, and fifteen from the burned area. All saplings were naturally regenerated. The saplings in the burned area were 8 years old and had emerged in the first growing season after the wildfire. Saplings growing in the unburned area were selected to have the same age, based on the number of annual rings in the root collar area.

The root systems of saplings were excavated manually and entire saplings were removed with special care to avoid any root damage or loss of lateral roots. All the extracted saplings were put in plastic bags and transported to the laboratory. The root balls of the excavated saplings were washed after 1 hour-soaking in water and the whole root system was extracted under running water, using a sieve to collect any root fragments detached from the system (Tsakaldimi *et al*., 2009). Afterwards, the following measurements were conducted: a) shoot characteristics: height, diameter at the base (1 cm above root collar), number of branches, total length of branches and total leaf biomass (needle biomass) and b) root system characteristics: taproot length, fine root (d < 2 mm) length, coarse root (d > 2 mm) length, and total number of roots with a diameter at the origin of greater than 1 mm. The largest vertical root originating from the stump was selected, measured and coded as a taproot (Danjon *et al*., 2007).

All the studied dependent variables were analyzed by means of analysis of variance (ANOVA), with treatment (burned and unburned area) as the independent variable. The homogeneity of variances was tested by Levene's test. Percentage data were arc-sin-transformed before the analysis. When the homogeneity of variances could not be assumed, the non-parametric Mann–Whitney test was used (Norusis, 2002); is been performed the Mann–Whitney test on the following parameters: leaf biomass, total length of branches, fine root length, coarse root length, and total number of roots. Differences in light interception over time were checked using repeated measures ANOVA. All statistical analyses were performed with SPSS (SPSS Inc., version 14). All tests for significance were conducted at $p \leq 0.05$.

Results

The analysis of soil profiles in both burned and unburned areas showed that variability of soil characteristics was low. The upper soil characteristics of the two areas were relatively similar, with the exception of a higher amount of organic matter and phosphorus in the surface horizon of postfire soils, compared to unburned soils. pH and mechanical characteristics were found to be similar (Tab. 1).

Light intensity in burned areas was almost ten times higher than that observed in unburned areas (Fig. 2). The average tree canopy cover in unburned sites was 60% (Tab. 2). The stand density of *P. brutia* trees was 420 trees ha^{-1}, the mean height of trees was 11.2±0.4 m, the mean diameter at breast height was 33.2±1.6 cm and the mean crown height was 7.8±0.3 m. Plant cover of understorey species was significantly greater in the burned area than in the unburned (61.2% and 30.7% respectively), due to the

Tab. 1. Physical and chemical properties of soils in burned and unburned areas

Soil parameters	Horizon	Depth (cm)	pH	Organic matter (%)	Phosphorus (mg 100g^{-1})	Clay (%)	Loam (%)	Sand (%)	Mechanical analysis (soil texture)
Burned area	A	0-5	7.2	5.0	3.36	6	27	67	SL*
	B	6-12	7.1	2.4	0.83	6	27	67	SL
	C	13-25	7.0	2.4	0.77	6	31	63	SL
Unburned area	A	0-7	7.2	3.4	1.12	6	23	71	SL
	B	8-15	7.4	2.1	0.95	6	29	65	SL
	C	16-30	7.1	0.7	1.06	6	29	65	SL

* SL=Sandy loam

presence of overstorey (tree storey) in the unburned area (Tab. 2). In both areas, the dominant species were *P. brutia* and the evergreen shrubs *Q. coccifera* and *Cistus incanus.* In the shrub layer, *P. brutia* cover in the burned area was significantly greater (18.5%) than in the unburned area (4.9%). Also the cover of *Q. coccifera, C. incanus*, *Sarcopoterium spinosum* and *Asparagus acutifolius* was significantly greater in the burned area (Tab. 2).

Tab. 2. Plant cover (%) of overstorey and understorey species found in the burned and unburned area (mean±SE)

Species	Plant cover (%)	
Overstorey (tree layer)	Unburned area	Burned area
Pinus brutia	60.0 ± 8.8	-
Understorey (shrub and grass layer)	30.7 ±6.3 b	61.2 ±8.6 a
Pinus brutia	4.9±7.5 b	18.5±2.9 a
Quercus coccifera	8.7 ±3.1 b	16.3 ±5.1 a
Cistus incanus	6.6±1.7 b	13.4±3.4 a
Phillyrea latifolia	3.6±1.5	4.3±1.2
Anthyllis hermaniae	2.6±1.3	3.1±1.1
Asparagus acutifolius	1.2±0.2 b	3.1±0.6 a
Sarcopoterium spinosum	1.3±0.3 b	2.7 ±0.8 a
Jasminus fruticans	1.0±0.1	0.8±0.2
Crataegus monogyna	0.8±0.2	0.8±0.1

Means followed by different letters within a row are significantly different (ANOVA, $p \leq 0.05$)

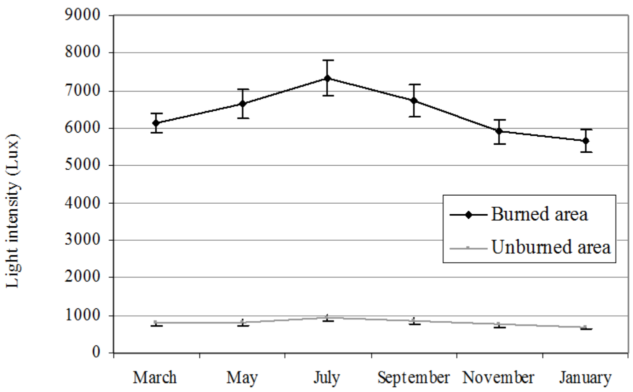

Fig. 2. Means (± SE) of light intensity (Lux) in the burned and unburned area, during March 2006-January 2007. Significant differences between the means of the two studied areas were observed during the whole period (repeated measures ANOVA, $p \leq 0.05$)

Morphological characteristics of *P. brutia* saplings greatly differed between the two treatments. The main above-ground parameters (height, diameter, total length of branches, number of branches, and needle biomass) were significantly greater in saplings grown under postfire conditions (burned area), compared to those grown in the understorey of the unburned forest (Tab. 3). Generally, pine saplings grown in the understorey were found to be thin, with fewer branches and reduced leaf biomass. Similarly, root parameters (taproot length, fine root length, coarse root length and total number of roots with d > 1 mm) were significantly greater in saplings grown in the burned area compared to those grown in the unburned area (Tab. 3).

Discussion

Even though site conditions (altitude, bedrock, aspect, slope inclination, land uses) were similar, a few topsoil characteristics differed between the two treatments; postfire soils were found to have a higher amount of organic matter and phosphorus in the surface horizon compared to unburned soils. Higher soil organic matter mineralization and higher ash deposition, and thus higher soil fertility, have been reported often for the first years after a fire (Grogan *et al*., 2000; Pausas *et al*., 2003). The available P in surface horizons may rise immediately after a fire, but these are short-term increases (Turrion *et al*., 2010). The increase of soil fertility in surface horizons observed in this study may be partially attributed to post-fire plant community response, characterized by high biomass production and enhanced nutrient cycling (Carter and Foster, 2004; De Marco *et al*., 2005; Skre *et al*., 1998). During early postfire years plant growth is usually high due to high soil nutrient availability caused by the fire.

Forest canopy is considered to be the main factor limiting understorey illumination (Ganatsas, 1993; Jennings *et al*., 1999). In the present study, the tree canopy layer significantly restricted light availability in the unburned stands, where light intensity was found to be almost 10 times lower than in open postfire conditions. Light conditions are considered the key factor, which can be manipulated by suitable opening of the overstorey cover. The degree of canopy opening necessary for the regeneration and survival of seedlings and saplings depends on the species' ecophysiological attributes; the more light-demanding the

Tab. 3. Above- and below-ground morphological parameters of *P. brutia* saplings in burned and unburned areas (mean±SE)

Treatments	Stem parameters					Root parameters			
	Height (cm)	Diameter (cm)	Leaf biomass (g)	Number of branches	Total length of branches (m)	Tap root length (cm)	Fine root length (cm)	Coarse root length (cm)	Total number of roots (d > 1 mm)
Burned area	148.1±7.2 a	4.41±0.24 a	526.5±44.0 a	39.0±1.6 a	77.8±6.8 a	79.3±2.3 a	277.2±28.9 a	1599.1±123.6 a	58.0±4.9 a
Unburned area	84.1±8.2 b	0.89±0.1 b	22.1±4.9 b	10.6±0.5 b	3.8 ±0.8 b	31.1±2.3 b	116.6±22.2 b	130.9±27.6 b	19.0±1.9 b

Means in the same column followed by a different letter are significantly different (ANOVA, $p \leq 0.05$). The non-parametric Mann-Whitney test was used for comparison of the following parameters: leaf biomass, total length of branches, fine root length, coarse root length, and total number of roots species, the more opening of the canopy is needed. *P. brutia* as a shade-intolerant species grows well after intensive opening of the canopy (Boydak, 2004), as well as in post-fire conditions, where usually a large number of pine seedlings emerge during the first years after fire (Eron, 1987; Neyisci, 1993; Spanos *et al*., 2001; Thanos and Doussi, 2000).

Based on the total height and age of saplings, the mean annual height growth of *P. brutia* saplings in unburned and burned conditions was 10 cm to 16.6 cm, respectively, while Thanos and Markou (1993), studying post-fire regeneration growth of *P. brutia* for ten years, found a smaller annual height increment (10 cm). Generally, shoot dimensions of saplings from the unburned area (understorey conditions) were significantly smaller than those of saplings from the burned area and their stem thickness was very small in relation to their height. Similar results were found by Kuechler *et al*. (2006), who report that in central Louisiana the 5-year-old *P. palustris* saplings' growth was significantly greater in burned plots than in the control (unburned) plots. Evidently, shoot growth of saplings in understorey conditions was suppressed due to low illumination penetrating to the forest floor, given the low degree of vegetation competition in the unburned area. *P. brutia* is a shade-intolerant species (Boydak, 2004) and thus light conditions seem to be the critical factor affecting growth of pine saplings. This agrees with Trabaud (1994), who reported that Mediterranean pine species are not exclusively dependent on fire, but are light-demanding plants occupying open disturbed sites, particularly those without aggressive competitors.

The root system of all the studied saplings is characterized by a woody deep tap root with vigorous laterals. Roots were more abundant in topsoil layers than in the deeper horizons, allowing efficient water and nutrient uptake from surface layers. Similar results for *P. brutia* saplings were reported by Ganatsas and Spanos (2005), studying 5-year-old naturally regenerated saplings.

Root morphological traits were significantly affected by the treatments. Means for all root morphological traits increased among saplings grown in burned compared to unburned areas. This can be mainly attributed to the much greater availability of sunlight for saplings grown under postfire conditions, favouring plant metabolism and thereby shoot and root growth. Shoot growth and morphology are strongly correlated with root systems (Chiatante *et al*., 2006). In addition, below-ground competition of saplings with the parent trees may play an important role in limiting the root growth of saplings.

The findings of the present study and results of similar studies (Raftoyannis and Spanos, 2005; Spanos *et al*., 2000, 2001; Thanos and Markou, 1993; Tsitsoni *et al*., 2004) suggest that *P. brutia* above- and below-ground growth is favoured under postfire conditions. This is very important for the conservation of the species' habitat in the Mediterranean region, where fires are very common. The suppression of above- and below-ground growth of pine saplings due to dense canopy should be considered in the cultivation of unburned *P. brutia* stands, and appropriate silvicultural treatments should be applied.

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