Silviculture treatments for reducing fire's potential severity in urban forests, N. Greece

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Abstract

Urban forest fires constitute a natural disaster presenting many particularities and specific difficulties. Such difficulties include the high number of people visiting urban forests as well as some specific forests characteristics which include the flammable species involved and the high levels of accumulated combustible biomass. The main purpose of the current research is to quantify the optimum combination of silvicultural treatments in order to efficiently reduce forest fire potential severity and contribute to their successful suppression by firefighting crews under field conditions. In order to simulate the basic fire environment of urban forests, two main experimental plots were established and several tree and topographical characteristics were estimated. Additionally, the NEXUS wildfire system was used to simulate forest fire potential behavior before and after the adoption of the silvicultural treatments that altered critical characteristics of the forest fire environment. The results clearly showed that specific silvicultural prescriptions altered the type of forest fire spreading potential, revealing the overall efficiency of preventing actions during forest management.

Keywords: urban forests, silvicultural treatments, NEXUS, simulation, fire

1. Introduction

Fire is the most frequent natural threat to forests and wooded areas of the Mediterranean basin. It destroys many more forests and forest lands than all other natural threats, such as parasite attacks, insects, tornadoes, snow and frost. Unlike other parts of the world where a large percentage of fires are naturally caused (especially lightning), the Mediterranean basin is marked by the prevalence of human-induced fires. Natural causes represent only a small percentage of all fires (1-5%, depending on the country) (Alexandrian *et al.* 2008). During the last 30 years, destructive forest fires burned millions of hectares of forest in Greece. The most devastating incidents took place in Lesvos 1982 and Ikaria 1993, Samos 1983 (Thanos *et al.* 1989; Thanos and Markou 1991; Thanos and Doussi 2000), Attika 1984 (Zagas 1987) and 2008, Thasos 1985 and 1989 (Spanos *et al.* 1996; 2000; 2001), Thessaloniki 1997 (Tsitsoni *et al.* 2004; Spanos *et al.* 2010), Chalkidiki 1990 and 2006 (Spanos *et al.* 2005), Peloponnese and Evia 2008). The peri-urban forests are very vulnerable in terms of fire occurrence and spread. They cover a total area of 105,353 hectares in Greece, mainly from afforestation activities of Forest Service during 1950 (Christopoulou *et al.* 2007). However, the rapid spread of urban areas occupying bordering forested and agricultural land created the Wildland Urban Interface (WUI), a new regime of land use intermix notably distinguished in a typical Mediterranean landscape. Currently available individual and public community transport to urban areas implies that an even greater proportion of land has urban development potential. Nevertheless, the main issue is the steadily growing interface between wildland and urban areas, in particular with the development of diffuse individual house construction, in relation to loose policies in the approval of building permit. Relationships can be established between spatial repartition of forest fire ignition points and wildland urban interfaces (Vélez 2008). Studies have shown that around three quarters of fire ignition points are located in the interfaces and the majority of them occur at the interface type characterized by high aggregation of vegetation and high density of houses. Moreover, when forest fires break out the priority in fire suppression is logically given to the protection of people and houses, leaving the forest to be burnt (Caballero *et al.* 2007; Vélez 2002). Suburban forests fires constitute a natural disaster, with many particularities and specific difficulties. Fires of suburban forests is a problem that in the last twenty years has become a distinctive and of high importance theme drawing great interest from scientists and professionals dealing with forest fires worldwide (Fischer and Arno 1988; National Wildfire Foundation 1992; Queen 1993; Slauther 1996). In addition, fires in the suburban zone are very frequent in Greece. During 2000-2011, about 2692 fires had been recorded only in the Attiki region (Salvati 2014). The suppression of the suburban fires present some difficulties related to the following characteristics of the fire environment (Xanthopoulos 2000), such as:

- high risk of human life loss
- existence of properties e.g. homes, businesses

- possible existence of significant differences in the composition and distribution of the fuel space
- potential impact on the environment components (fuel, wind) buildings and other residential development elements in the area
- existence of infrastructure such as roads, water points, electricity and telephone networks etc.

Key element in firefighting activity is to prevent some aspects of fire behavior which precludes any successful suppression, by altering fuel characteristics of the fire environment. In the world literature, a significant number of studies have been contacted on methods of fuel treatment for lowering wildfire's severity (Agee and Lolley 2006; Harrington *et al* 2006; Horschel 2007; Huggett *et al* 2008; Roccaforte *et al* 2008; Molina *et al* 2011). In the majority of these studies, the evaluation of fuel treatment effectiveness has been mainly based on the application of several fire models such as FARSITE, FlamMap and NEXUS, simulating wildfire behavior before and after the establishment of various silvicultural treatments. The aim of this study was to assess the potential effectiveness of simulated silvicultural treatments on wildfire severity in urban pines forests in Greece. The research is based on two installed sample plots across two typical peri-urban forests located in Northern Greece. Since real experiment is impractical and unacceptably risky, simulation is an alternative approach to testing potential fuel treatment effectiveness (Schmidt *et al* 2008).

2. Material and methods

2.1. Study area

The study areas were located in the urban forests of municipality of Thermaikos, 20Km northwest of Thessaloniki, Greece (40°31΄N, 23°37΄N) along the road "Thessaloniki - Ag. Triada - N. Michaniona" crossing the districts Peraia - N. Epivaton and Agias Triadas. The climate is typical Mediterranean, with clear continental influence during the different seasons: the temperature presents higher values in July (26.6°C) and the lowest in January (5.2°C), the annual temperature range exceeds 20°C, while during the cold season sudden very cold air masses occur and often frozen water surfaces. Characteristic also are the mild and sunny days that happen around the middle of winter. The annual average relative air humidity rises to 78.11% and the average annual rainfall at 431.5 mm. Winds directions are different depending on the seasons: a northern dominates during the winter coming from the Axios river Valley (Vardar), in the spring the most frequent are southwest (sea breezes), and the summer is dominated by northern and southwestern winds (sea breezes). The Thermaikos Municipality area is characterized by the crystal and sedimentary rocks. Within the areas of interest, the dominant tree vegetation consists of artificial pine stands (*Pinus halepensis* & *brutia*) and cypress (*Cupressus sempervirens*) along the road Perea -N. Epivates -St. Triada and Quercus ilex. Also in the region can be found:

- herbaceous vegetation mainly in riverbeds in the urban area, with characteristic species *Phragmites communis*, *Typha angustifolia* and *Xanthium strumarium.*
- shrubby vegetation of the river bed and slope streams, with characteristic species of *Rosa* sp., *Rubus canescens*, *Ramnus rupestris* and *Asparagus* sp.
- other tree vegetation, located mostly on steep slopes from the side of the road to the hinterland. Other species that appear are *Ulmus campestris*, *Salix* sp., *Populus alba* and *Tamarix* sp.

2.2 Experimental design and sampling

The effects of silvicultural treatments for reducing fire's potential severity in urban forests were evaluated in two plots (20m x 25m), by estimating several dendrometric characteristics of each tree located within these plots (Figure 1). The two plots were selected for their different structure. At the first plot there has been no treatment, while at the second plot clearcuttings (mechanical treatments) of all shrubs and pine pruning to the height of 2m from the ground, were installed by the managing local authorities .

Figure 1. A general aspect of the two experimental plots. On the left plot 1 and on the right plot 2

In both plots a series of observations were recorded at tree and stand level, such as the total numbers of stems, the height (H) of each tree, the canopy base height (CBH) and diameter at breast height ($DBH_{1.30}$). The CBH corresponds to the average distance between the lowest continuous live or dead branches of the tree canopy down to the ground (Ottmar *et al.* 1998). In addition, inside small rectangular plots (1 m x 1 m), we evaluated the ground biomass and moisture by collecting plant litter and plants. For the needs of the research, five rectangular subplots per experimental plot were established. Samples were transported to the laboratory in airtight containers, weighted, oven dried for

24 h at 105°C and then reweighed (Spanos *et al*. 2005). The slope of each plot was estimated using a Meridian clinometer as well as the canopy cover through a spherical densiometer (Lemmon 1956).

Figure 2. Collecting plant debris and plants in the rectangular plot

2.3 Fuel characteristics

2.3.1 Aerial fuel

The allometric equations for *Pinus halepensis* Mill. proposed by Mitsopoulos and Dimitrakopoulos (2007) were used for the estimation of the total Canopy Fuel Load (CFL). Based on the above equations, the available crown fuel load (needles and branches 0.0-0.63cm) for each tree was calculated. The CFL was estimated by summing the available fuel load of each tree and diving it to the area occupied by each experimental plot (500 m^2). The total above ground biomass fuel was considered to be uniformly distributed and continuous. Also the Canopy Bulk Density (CBD) was estimated by diving CFL to the average canopy length of the individuals of each sample plot (Alexander 1988; Fernades *et al*. 2004).

2.3.2 Surface fuel

The data obtained from the installed subsample plots leaded to the creation of custom fuel models for the area, following the methodology proposed by Scott and Burgan (2005) and the NEWMDL tool of the BEHAVE modeling system. Surface fuels divided into four classes, based on the diameter of each component (1 h, 10 h, 100 h, and 1000 h). The surface per volume ratio (SAV – m^2/m^3), the heat content (kj/kg) and the extinction moisture obtained from Dimitrakopoulos and Papaioannou (2001), Fire Star (2007) and Bacciu (2009). The results are presented in Table 1.

2.3.3 Simulation

The NEXUS modelling system has been widely used by many researchers to evaluate the effectiveness of fuel treatment scenarios. It provides the possibility to calculate key indicators, such as Torching Index (TI) and Crowning Index (CI) that allow direct comparison of the effectiveness of various possible scenarios arising from silvicultural treatments (Scott 1999). The NEXUS modelling system from the array of available models, couples the most widely used for this analysis: Rothermel's surface (1972) and crown fire models (1991), and Van Wagner's (1977) models of transition to crown fire (Scott 1998; 1999; Fule *et al* 2001; Cheyetee *et al* 2008).

2.3.4 Silvicultural Treatments

At first stage, the current conditions of fuel regime was used as input to the NEXUS simulation system so as to estimate the potential fire behavior by calculating critical values of fire front (Rate of Spread, Fireline Intesity, Flame Length and CI). In the second stage, the effects of thinning and clearings were evaluated by reducing the corresponding stand parameters while keeping the same weather and topographical conditions. The treatment of mechanical removal of the understory (clearings) was simulated in the first plot by replacing surface fuel load with pine litter and debris, obtained by plot 2. Furthermore, the thinning effects applied only in plot 2 by reducing the basal area and the corresponding canopy fuel load to 25% from the initial value. It was theorized that tree cutting would not change the surface fuel load significantly, following the findings of Silva *et al* (2000) in a Mediterranean-type ecosystem.

3. Results

The following table (Table 1) indicates the main physical and chemical properties of the mean values of total surface fuels in each plot. The mean value of litter's surface biomass measured in the first experimental plot surface was 1,640 kg/m² and for the second experimental plot 2,020 kg/m². The highest values of litters' surface load on the second plot may be attributed to the clearings effects and the remained biomass during mechanical treatments. The following table (Table 2) indicates the main dendrometric data measured in the field. The values consist of the imputed data to NEXUS simulation system in order to estimate the potential fire behavior. Fuel moisture content values (percent) by size class for seasonal moisture conditions was estimated using NEXUS module for estimating moisture content (Table 3) and the "Normal Summer" moisture values proposed by Rothermel (1991). The shading parameter follows the values obtained from Canopy Cover estimation (%). The simulation results before treatments for the first and second experimental plots are presented in Table 4. It was theorized that removing 25% of the initial basal area has not reduced canopy cover lower than 50% and the moisture content of the surface fuels remained stable. However, during heavy thinnings (50%) the canopy cover reduced significantly and the moisture content re-calculated, using canopy cover input lower than 50%. The simulation results after silvicultural treatments are presented in Table 5.

Table 1. Physical and chemical properties of the total sample

Properties	**Custom Fuel Model**	
	CFM 1: Pine litter	**CFM 2: Shrub (kermes oak)**
1h (tonne/ha)	1.232	1.109
10h (tonne/ha)	0.408	0.522
100h (tonne/ha)	-	0.389
Live Herbaceous Fuel Load (tonne/ha)	-	-
Live Woody Fuel Load (tonne/ha)	-	8.857
1h SA/V (m^2/m^3)	6,249	2,427
Live Herbaceous SA/V (m^2/m^3)	-	-
Live Woody SA/V (m^2/m^3)	-	5,960
Fuel Bed Depth (m)	0.210	1.977
Extinction Moisture (%)	35	25
Dead Heat Content (kJ/kg)	22,137	19,460
Live Heat Content (kJ/kg)	-	19,460

Table 2. The primary data of the two experimental plots

	Experimental plot 1	**Experimental plot 2**
Stems per hectare	460	360
Diameter at Breast Height (cm)	20.16	30.27
Tree Height (m)	12.27	17.19
Canopy Base Height (m)	4.97	10.57
Canopy Fuel Load (kg/m^2)	0.577	0.862
Crown Bulk Density (kg/m^3)	0.079	0.134

Table 3. Weather scenarios and topographical conditions used for the simulation

Weather	**Inputs**
Temperature (^oC)	31.5 – 42.4
Relative humidity (%)	20-25
Month	August
Hemisphere	Northern
Time	15:00-17:00
Wind (km/h)	25
Wind direction	Upslope
Shading (Canopy Cover - %)	>51
Topography	
Slope (%)	30

Table 4. Fire behavior according to NEXUS outputs before treatments

Pyric parameters (before treatment)	Plot	
	1	2
Fire type	Passive crown fire	Intermediate crown fire
Rate of spread (m/min)	18.63	15.3
Fireline Intesity (kW/m)	19,153	7,737
Flame length (m)	18	10.4
Crowning Index (km/h)	35.6	26.4

Table 5. Fire behavior according to NEXUS outputs after treatments

Pyric parameters (after treatment)	Plot		
	1	2 (25%)	2 (50%)
Fire type	Surface fire	Surface fire	Surface fire
Rate of spread (m/min)	1.46	0.81	0.87
Fireline Intesity (kW/m)	149	82	93
Flame length (m)	0.8	0.6	0.6
Crowning Index (km/h)	35.6	33.3	44.3

4. Discussion

The basic objective of silvicultural treatments is to prevent the initiation and the propagation of a crown fire in order to create favorable conditions for fire-fighting crews to launch a successful attack. In this sense, Loureiro and Fernandes (2006) set the level of 2,000kW/m as the maximum withstandable fireline intensity for the firefighting ground forces, while beyond 4,000kW/m indirect methods are needed for fire suppression. According to the results of table 4, the simulated fireline intensity reached 19,153kW/h in plot 1 and 7,737kW/h in plot 2, precluding any direct suppression of the fire's front. However, based on the results of table 5, the proposed treatments prevent fire from crowning in both plots, retaining it on the surface. In these occasions, the pyric parameters remained at low levels so as to be easily contained by firefighting forces.

A set of "firescale principles" as adapted from Agee and Skinner (2005) can be defined (Table 6). Forests treated with these principles will be more resilient to wildfires.

Table 6. Principles of fire resistance for dry forests (Agee, 2002 and Hessburg and Agee. 2003).

Principles	Effect	Advantage	Concerns
Reduce surface fuels	Reduces potential flame length	Control easier; less torching	Surface disturbance less with fire than other techniques
Increase height to live crown	Requires longer flame length to begin torching	Less torching	Opens understory; may allow surface wind to increase
Decrease crown density	Makes tree to tree crown fire less probable	Reduces crown fire potential	Surface wind may increase and surface fuels may be drier
Keep big trees of resistant species	Less mortality for same fire intensity	Generally restores historic structure	Less economical; may keep trees at risk of insect attack

The effectiveness of two of the four proposed principles is assessed in the current research. In plot 1, the low CBD affected fire type and prevent from active crowning. However, the dense understory increased available fuel load and resulted to high levels of flame length and intensity. On the contrary, in plot 2 the dense canopy provided the necessary conditions for active crowning since CI factor is low, but the reduced surface load due to thinning, prevent torching of the low canopy parts. In this experimental plot, it is not expected foliar ignition during the early stages of fire as a result of the vegetation characteristics. However, if foliage ignition may occur at some point within the stand, then active crowning is expected. The simulated silvicultural treatments aimed at the most critical parameters of the two stand structures. In plot 1, clearings reduced surface load significantly and the potential fire could not transmitted to tree foliage. It should be mentioned that in conjunction with a thinning treatment corresponding to 10% of the basal area, can be obtained even milder combustion conditions judged as treatable by ground firefighting forces. In plot 2, thinning reduced the available aerial fuel load for combustion and the crown fire cannot be sustained without higher wind speed. However, intensive thinning may result in increased wind-speeds inside stand lowering the fuel moisture content, thus 25% removal of the initial basal area is seems to be effective. Removal of any dead trees, branches and twigs will improve fuel moisture conditions within the stand, while, in final stage planting with deciduous trees will increase foliar moisture content. Pruning of the lowest points of tree crowns (over 3 meters from ground level) is actually unnecessary due to the high levels of CBH. The combination of silvicultural treatments (thinning and clearings) changed the forest structure altering the behavior of a potential fire. The results reveal that the fuel treatments had a direct influence upon fire behavior lowering significantly its potential severity.

5. Conclusions

Very few forests will receive fuel treatment over their entire area due to economic constraints. The forest challenge needs to be confronted and where strategic fuel treatment will be more effective at reducing wildfire damage. Simulations help us decide where and how we will apply necessary treatments to forests. The challenges are real, and become more important each year. Mediterranean urban forests continue to burn at unprecedented rates, emplacing undesirable landscape patterns and reducing opportunities for restoration. Our greatest challenge is to expand that scale with socially acceptable treatments to sustain these forests.

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