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SHORT COMMUNICATION

Understorey fuel load estimation along two post-fire chronosequences of *Pinus halepensis* Mill. forests in Central Greece

**Dimitris Kazanis · Gavriil Xanthopoulos ·
Margarita Arianoutsou**

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Abstract *Pinus halepensis* forests are among the forest ecosystems in the Mediterranean Basin most affected by fire. Their distribution across lowland areas, in particular along the wildland–urban interface, increases the need to understand their ecology and responses to fire regime for their effective management. Apart from the extremely flammable tree layer, in several stands of these forests there is an increased fuel load attributed to the well-developed understorey of evergreen sclerophyllous shrubs. Taking into consideration that, in contrast with the long period required for full development of post-fire-regenerating pines, these shrubs resprout vigorously within the first post-fire weeks, it is important to explore the temporal trend of fuel accumulation to determine the risk of a second fire across a burned landscape. Two post-fire chronosequences of, in total, 12 *P. halepensis* stands were considered for sampling in Central Greece. The first chronosequence corresponds to pine stands characterized by the dominance of evergreen sclerophyllous shrubs in the understorey (Type 1) whereas the second chronosequence corresponds to pine stands where the cover of such shrubs was lower (Type 2). This study helps in understanding the fuel dynamics according to the type of *P. halepensis* forest stand and to anticipate future biomass growth. The proposed equations are simple tools, enabling land managers to estimate understorey total fuel load easily by visually recording the cover and height of the evergreen sclerophyllous shrub component, to justify understorey fuel reduction measures.

Keywords Aleppo pine · Fuel dynamics · Fuel models · Mediterranean forest ecosystems · Shrub biomass

Introduction

The occurrence of fire in natural ecosystems depends on the prevailing meteorological conditions, the availability of ignition sources and the quantity and characteristics of plant biomass (Pausas and Keeley 2009). In Mediterranean type ecosystems all these factors result in a fire regime with fire intervals between 25 and 100 years for shrubland and forest stands, respectively (Arianoutsou 2001). Although favourable meteorological conditions and availability of ignition sources occur on an annual basis, the reason why a second natural fire is unlikely to burn the same vegetation patch at a shorter time interval is related to the time required for standing biomass to reach a minimum level (Baeza et al. 2006). Knowledge of the temporal, post-fire pattern of plant biomass accumulation is necessary for fire management, as a basis for identifying areas with high fire risk and to support the development of fuel modification plans.

Pinus halepensis Mill. (Aleppo pine) forests are among the most affected by fire across the Mediterranean Basin. Although there are studies focussing on the accumulation of crown fuel biomass in these forests (Mitsopoulos and Dimitrakopoulos 2007), this is not the case as regards the role of understorey fuel development. However, it is

D. Kazanis (✉) · M. Arianoutsou
Department of Ecology and Systematics, Faculty of Biology,
School of Sciences, University of Athens,
157 84, Panepistimiopolis, Greece
e-mail: dkazanis@biol.uoa.gr

G. Xanthopoulos
National Agricultural Research Foundation,
Institute of Mediterranean Forest Ecosystems and Forest
Products Technology, Terma Alkmanos, Ilisia,
115 28, Athens, Greece

exactly this understorey fuel, mainly in the form of shrubs that is usually treated in the context of fuel reduction projects that aim to reduce the risk of fire in selected forest stands. As such fuel treatments are quite costly, forest managers would be helped greatly in their financial and technical planning by knowing how quickly these understorey fuels should be expected to accumulate in a particular stand. The objective of this study is to build an understanding of the long-term understorey woody fuel development in *Pinus halepensis* forest stands and to develop quantitative equations for understorey biomass accumulation with post-fire age, because in Mediterranean conditions, usually, nearly all surface fuel biomass burns during a fire. To achieve this objective, long-term understorey woody fuel development is estimated across two post-fire chronosequences of *Pinus halepensis* forest stands and the result is related to the post-fire increase of fire hazard.

Materials and methods

In the context of a wider study with the objective of improving understanding of the long-term post-fire vegetation dynamics of *P. halepensis* forests, two chronosequences of six forest stands each were considered for sampling in Central Greece (Kazanis 2005). Each chronosequence corresponds to a different forest type (Table 1). "Type 1" stands are characterized by the dominance of evergreen sclerophyllous shrubs in the understorey whereas in "Type 2" stands the presence of such shrubs is scattered, usually allowing increased cover of dwarf shrubs, grasses, and forbs. Stands of the first type are primarily found on sites characterized by relatively wet conditions at an altitude varying from 350 to 700 m whereas stands of the second type are restricted to sites with drier conditions and, usually, significant human pressure (Kazanis 2005).

Evergreen sclerophyllous shrubs form an important component of the understorey in most *P. halepensis* forests (Quezel and Barbero 1992). Species of this group, for example *Quercus coccifera*, *Phillyrea latifolia*, *Pistacia lentiscus*, *Olea europaea* ssp. *sylvestris*, and *Arbutus unedo* are widely distributed throughout the Mediterranean Rim and form a well defined functional group characterized by high post-fire regeneration and resilience (Kazanis and Arianoutsou 2004).

In every stand, three 10 × 1 m plots were randomly established. Each plot was divided into ten 1 × 1 m quadrats (Fig. 1). Within each quadrat, the maximum height of the evergreen sclerophyllous shrub stratum was measured and the total sclerophyllous shrub cover was visually estimated at the end of the growing period (late June, July). In younger stands, maximum height and cover measurements were repeated for two to four consecutive years (Table 1), resulting in a total number of 12 mean values per chronosequence. Mean values of evergreen sclerophyllous shrub cover and maximum height were also used for estimation of the understorey "total fuel load". This task was carried out using an allometric equation for Mediterranean shrubs proposed by Xanthopoulos and Manasi (2002):

$$\mathrm{TLOAD} = 5.6680 + 0.00008 \times \mathrm{INT} \tag{1}$$

where

TLOAD total fuel load (t/ha)
INT (shrub HEIGHT in cm) × (shrub COVER percent)^2

Table 1 Characteristics of the two post-fire chronosequences of *Pinus halepensis* forests at Central Greece

Location	Post-fire age (years)	Altitude (m)	Dominant shrub taxa
Type 1			
Loutsa	1, 2, 3, 4	350	*Quercus coccifera*, *Pistacia lentiscus*, *Calicotome villosa*
Avlona	6, 7	360	*Quercus coccifera*, *Arbutus unedo*, *Pistacia terebinthus*
Fyli	8, 9	410	*Quercus coccifera*, *Phillyrea media*, *Pistacia lentiscus*
Beletsi	13, 16	590	*Quercus coccifera*, *Arbutus andrachne*, *Phillyrea media*
Bahounia	17	660	*Quercus coccifera*, *Arbutus andrachne*, *Bupleurum fruticosum*
Tatoi	40	560	*Quercus coccifera*, *Arbutus andrachne*, *Phillyrea media*
Type 2			
Mavrinora	1, 2, 3	420	*Cistus* spp., *Quercus coccifera*, *Genista acanthoclada*
Pikermi	1, 2	180	*Cistus* spp., *Pistacia lentiscus*, *Quercus coccifera*
Agios Stefanos	2, 3, 4	310	*Cistus* spp., *Quercus coccifera*, *Genista acanthoclada*
Fyli	8, 9	410	*Cistus* spp., *Quercus coccifera*, *Genista acanthoclada*
Agia Paraskevi	17	190	*Cistus* spp., *Quercus coccifera*, *Genista acanthoclada*
Pikermi	40	180	*Quercus coccifera*, *Sarcopoterium spinosum*, *Hypericum empetrifolium*

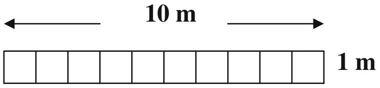

Fig. 1 Plot and subplots design for recording evergreen sclerophyllous shrub cover and maximum height

The TLOAD variable refers to total fuel loading in the understorey, in metric tons per hectare (t/ha), and includes the few grasses available (usually <1%), the litter and dead woody fuel on the ground up to 7.62 cm in diameter, and all parts of the shrubs. Dead woody fuels with a diameter >7.62 cm (1000-h time lag fuels), which is usually contributed by the pine trees, and duff load that does not contribute directly to the spread of the fire are not included in TLOAD.

Equation 1 requires average shrub height and not the maximum that was recorded in the field. Hence, maximum shrub height values were converted to average values by multiplication by 0.7, following Burgan and Rothermel (1984), who have suggested that “70% of the maximum shrub height is a reasonable estimate of depth for grass, shrubs and slash”. Their suggestion was a generalization of the findings of previous work carried out by Hough and Albini (1978) who found that “a value of two-thirds of the visual understorey fuel-bed depth gave the most consistent agreement between observed and predicted rate of spread values and flame lengths” for the palmetto–gallberry fuel complexes they modelled.

Results

Understorey plant cover of evergreen sclerophyllous shrubs, soon after fire, exceeds 50% in stands of Type 1 and remains high thereafter (Table 2). In contrast, in Type 2 stands, understorey shrub cover remains below 20% irrespective of stand age. However, mean maximum height of shrubs exceeds 150 cm within the first post-fire decade, following the same pattern in both types of forest stand monitored. Mean maximum height of understorey shrubs reaches 2 m approximately 20 years after fire, remaining constant from that age onwards.

TLOAD was calculated for the two types of stand by applying Eq. 1 (Fig. 2). As a result of the differences in plant cover, a consistent difference of TLOAD throughout the post-fire chronosequence is evident between the two types of stand. A linear regression equation, calculated for each of the two stand types, expresses TLOAD increase with age in a mathematical form. Both equations are statistically significant. The equations are as follows:

For Type 1 stands:

$$\mathrm{TLOAD}_1 = 37.634 + 1.010\ \mathrm{AGE}_1 \qquad (2)$$

Table 2 Mean cover and mean maximum height of evergreen sclerophyllous shrubs across the two post-fire chronosequences of *Pinus halepensis* forests at Central Greece

Post-fire age (years)	Mean cover ± SE (%)	Mean max. height ± SE (cm)
Type 1		
1	59.80 ± 7.86	69.57 ± 3.90
2	53.20 ± 7.58	112.39 ± 6.26
3	67.30 ± 7.07	140.73 ± 4.34
4	67.90 ± 6.84	141.92 ± 4.38
6	66.20 ± 4.33	159.77 ± 5.10
7	66.53 ± 4.19	160.03 ± 5.21
8	64.20 ± 6.57	165.70 ± 4.12
9	64.43 ± 6.55	166.07 ± 4.16
13	49.90 ± 4.99	178.32 ± 6.53
16	52.30 ± 4.77	197.72 ± 7.89
17	56.50 ± 4.61	193.73 ± 3.94
40	62.30 ± 6.30	192.78 ± 5.50
Type 2		
1	8.57 ± 2.72	53.60 ± 5.32
1	13.60 ± 4.07	62.40 ± 4.37
2	13.13 ± 4.28	58.80 ± 5.40
2	17.60 ± 5.29	100.10 ± 11.36
2	9.80 ± 3.83	108.10 ± 15.46
3	17.20 ± 4.95	67.50 ± 5.76
3	10.10 ± 3.87	119.70 ± 15.93
4	10.97 ± 3.94	139.70 ± 16.31
8	9.90 ± 3.85	158.67 ± 7.37
9	10.40 ± 4.04	160.33 ± 7.80
17	7.52 ± 3.32	120.40 ± 15.66
40	11.30 ± 2.52	198.95 ± 9.02

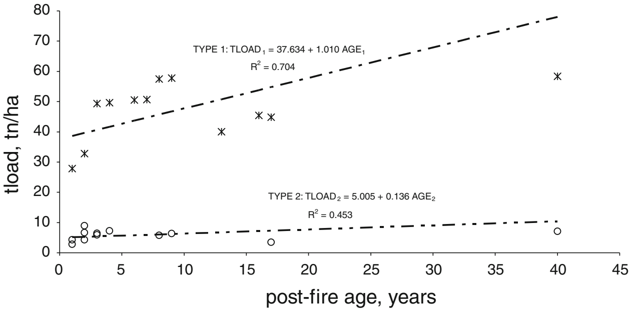

Fig. 2 Total fuel load (TLOAD) across the two post-fire chronosequences of Pinus *halepensis* stands at Central Greece

with adjusted multiple correlation coefficient $R^2 = 0.704$

$N = 12$
p value for the model <0.001
p value for the constant <0.001
p value for the coefficient of AGE_1 <0.001.

For Type 2 stands:

$$\mathrm{TLOAD}_2 = 5.005 + 0.136\ \mathrm{AGE}_2 \tag{3}$$

with adjusted multiple correlation coefficient $R^2 = 0.453$

$N = 12$
p value for the model $= 0.006$
p value for the constant <0.001
p value for the coefficient of $\mathrm{AGE}_2 = 0.006$.

Discussion and conclusions

Stands in which evergreen sclerophyllous shrubs dominate are expected to be more prone to a second fire, and this may come earlier because of more phytomass growth. The biomass that corresponds to these shrubs builds up rather quickly and may approach pre-fire levels within a few years after the disturbance (Guo 2001; Raison 2005). It is this fact that makes ‘stand type’ a factor of prime importance for understanding fuel dynamics across heterogeneous landscapes.

Equations 2 and 3 should be used with caution. They represent the long-term evolution of understorey biomass and they are not appropriate for use in the first few years after the fire. It is quite clear that, in those first few years, shrub biomass increases from nearly zero, when there is little live biomass, and dead litter is practically non-existent, to a substantial load very quickly. An equation that would attempt to represent this would have to be non-linear. For example, Clemente et al. (1996) reported, for Portuguese maquis, approximately 4 t/ha total shrub biomass practically without any litter 1 year after fire, that grew to approximately 16.9 t/ha by the second year including 1.9 t/ha of litter. Montes et al. (2004) found the understorey biomass of *Cistus albidus* and *Quercus coccifera* in a burned *Pinus halepensis* forest to have reached 16.2 t/ha 3 years after the fire and 49 t/ha in the 10th post-fire year. Similarly in Greece, Hatzistathis et al. (1999), who studied post-fire regeneration of a *Pinus halepensis* forest site in Northern Greece, reported that total biomass reached 1.7 and 3.3 t/ha at the end of the first and second post-fire year, respectively. Arianoutsou (1984), studying the post-fire dynamics of a phryganic ecosystem found a total biomass of 1.5 t/ha at the end of the first post-fire year, increasing to 11.3 t/ha in the following years and reaching 48.8 t/ha 7 years later. A similar trend is evident in Fig. 2. However, efforts to model fuel accumulation by use of non-linear curves (growth, power, exponential, logarithmic) did not produce statistically strong relationships, probably as a result of the very small number of observations in stands over 20 years old.

On the basis of the above values and considering the high value of the constant in Eqs. 2 and 3, which results in high biomass estimates even for the first post-fire year, it is reasonable to suggest that these equations can only produce plausible biomass estimates for post-fire ages of 4–5 years or more.

In conclusion, the long-term rate of fuel accumulation in the understorey of *Pinus halepensis* forests is very different for the two different stand types. Recognizing the type of *Pinus halepensis* stands existing near high fire vulnerability areas, for example urban–wildland interfaces, can help in planning future fuel management action, taking the cost and ecological effects of such management practices into consideration. This study helps in understanding the fuel dynamics according to the type of *Pinus halepensis* forest stand and anticipating future biomass growth.

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