Long-term post-fire evolution of understorey biomass in *Pinus halepensis* Mill. forests of Central Greece

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Abstract: The long-term post-fire development of evergreen sclerophyllous shrub biomass was studied along a chronosequence of *Pinus halepensis* stands. These shrubs are regarded as the most important component of the understorey vegetation concerning the Mediterranean coniferous forests in question. Eighteen (18) forest stands of different post-fire age were selected for sampling in the Attica region (Central Greece) and the neighbouring island of Evia. Most of the forest stands were re-sampled for two to four consecutive years, depending on their post-fire age, since younger stands change more rapidly, and on the time available for this task. In every stand, the total cover and maximum height of evergreen sclerophyllous shrubs were recorded. Measurements were carried out within three 10x1 m randomly established plots. Each plot was divided into ten (10) 1x1 m quadrats. Thus, there were 30 quadrats per forest stand.

Using two published regression equations, with the product of shrub height with the square of cover as the independent variable, the total understorey fuel load (TLOAD) and the "active" fuel load (ALOAD) for fire modelling purposes were calculated. It was shown graphically and through regression analysis that, at least in Central Greece, there are two distinct types of *Pinus halepensis* forest stands in regard to the understorey vegetation. The first (type 1) is characterized by the dominance of evergreen sclerophyllous shrubs in the understorey, with a shrub cover of 50-80%. In the other (type 2), the cover of such shrubs is much lower, usually <20%, allowing the increased presence of dwarf shrubs, grasses and forbs. Regression equations were developed for estimating TLOAD and ALOAD as a function of stand type and post-fire age. Furthermore, the data set was broken by stand type and separate equations were developed for ALOAD using post-fire age as the only independent variable. These equations demonstrated that early fuel load accumulation makes type 1 stands vulnerable to fire much earlier than type 2 stands. Subsequently understorey fuel management efforts, at least in critical areas, must start much earlier. On the other hand, fuel management needs in type 2 stands are much lower and may come much later in the age of the stand.

Keywords: Mediterranean forest ecosystems, Aleppo pine, Pinus halepensis, shrub biomass, forest fuels, fuel model, fuel dynamics, vegetation structure

1. Introduction

The occurrence of fire in natural ecosystems depends on three factors: meteorological conditions, availability of ignition sources and adequate fuel quantity. The combination of the factors mentioned above defines the fire regime of a certain vegetation type, i.e. the frequency, season and intensity of natural fires. In this respect, fire is quite different from all other ecological disturbance factors, since the ecosystems, through their structure and function, either favour or prevent its occurrence (Bond & van Wilgen, 1996). Statistical interpretation of fire frequency of several ecosystem types with vegetation structure and fuel production has shown the high interrelationship of those factors. Fire events reduce fuel accumulations sharply, while subsequent fuel production rate defines fire frequency, behaviour and severity (Agee et al., 1978, Olson, 1981).

In Mediterranean type ecosystems all these factors result in a fire regime with fire intervals between 25 and 100 years for shrubland and forest communities, respectively (Arianoutsou, 2001). Although favourable meteorological conditions and availability of ignition sources are the case on an annual basis, the reason why a second natural fire event is not probable to burn the same vegetation patch at a shorter time interval is related to the time required for fuels to reach a minimum quantity level. The knowledge of the temporal, post-fire pattern of fuel development and evolution is necessary for fire management, as a basis for identifying areas with high fire risk and as an aid for developing fuel modification plans.

Pinus halepensis Mill. forests are among the most affected by fire in Mediterranean ecosystems. For example, in Greece, where *Pinus halepensis* stands cover almost 9% of the tall forest area, these forests accounted for more than 48% of the total burned area of tall forests over a period of 25 years (1965-1989) (Kailidis, 1992). Their distribution along the coastline, in areas of high human presence and activity, makes imperative the need for understanding and managing the fuel characteristics and dynamics of these forest ecosystems. This paper is a contribution in this direction.

2. Methodology

2.1. Study Sites

In the context of a general study aiming to improve understanding of the long-term post-fire vegetation dynamics of *Pinus halepensis* forests, a chronosequence of 18 forest stands of different post-fire age was selected for sampling in Attica region (Central Greece) and the neighbouring island of Evia (Kazanis, 2005). Most of the forest stands were re-sampled for two to four consecutive years, depending on their post-fire age, since younger stands change more rapidly, and on the time available for this task. Criteria for the selection of the forest stands in question were the availability of data on fire history, the inclusion of as many age classes as possible, the inclusion of sites with different environmental characteristics (altitude, aspect, soil type) so as to test their influence on post-fire dynamics, and the relatively low influence of human activities. The characteristics of the studied stands are summarized in Table 1.

The five last stands in Table 1 represent mature forests. For them there were no data on when they were burned for the last time, so their age was estimated by using a Pressler borer to obtain samples from representative trees and counting the annual growth rings.

Table 1. Characteristics of the studied *Pinus halepensis* forest stands.

Location	Post-fire Age	Parent-rock Material	Altitude (m)	Aspect (°)
Mavrinora	1-3	Schists	420	280
Loutsa	1-4	Limestone	350	310
Pikermi	1-2	Tertiary deposits	180	200
Agios Stefanos	2-4	Tertiary deposits	310	10
Stamata	5-8	Schists	405	20
Avlona	6-7	Limestone	360	40
Fyli	8-9	Schists	410	230
Fyli	8-9	Limestone	410	270
Kamariza	12-13	Limestone	170	40
Dionisos	13-16	Schists	460	50
Beletsi	13-16	Limestone	590	180
Pikermi	17	Tertiary deposits	190	120
Bahounia	17-18	Schists	660	80
Tatoi	~40	Limestone	560	160
Pikermi	~40	Tertiary deposits	180	200
Stamata	~55	Schists	420	40
Markati	~55	Schists	180	340
Agios Merkourios	~65	Schists	580	240

2.2. Measurements

In every stand, the total cover and maximum height of evergreen sclerophyllous shrubs were recorded. Evergreen sclerophyllous shrubs form the most important group of understorey woody plants in the majority of *Pinus halepensis* forests (Quezel & Barbero, 1992, Kazanis & Arianoutsou, 2004a), a group that influences several aspects of the stand characteristics and dynamics (Trabaud et al., 1985, Kazanis & Arianoutsou, 2004b, Kazanis, 2005). Species of this group, such as *Quercus coccifera*, *Phillyrea latifolia*, *Pistacia lentiscus*, *Olea europaea* ssp. *sylvestris* and *Arbutus unedo* are widely distributed throughout the Mediterranean Rim (Greuter et al., 1984-1989).

Measurements were carried out within three 10x1 m randomly established plots. Each plot was divided into ten (10) 1x1 m quadrats. Thus, there were 30 quadrats per forest stand. Total sclerophyllous shrub cover was visually estimated on an annual basis for two to four consecutive years, at the end of the growing period (late June, July). Estimation was facilitated by a metal frame delineating the 1x1 m quadrats. As far as maximum height is concerned, it was measured annually in the plots belonging to stands of early successional stages (1-9 years old). Such measurements were only performed once at stands of middle and late successional stage, as yearly shrub height growth is insignificant at such age.

2.3. Fuel load estimation

The next step was estimation of the understorey fuel load for each stand. This was achieved using two allometric equations for Mediterranean shrubs proposed by Xanthopoulos & Manasi (2002):

$$TLOAD = 5.6680 + 0.00008 \times INT \quad (1)$$

where

TLOAD = Total fuel load (t/ha)

INT = (shrub HEIGHT in cm) x (shrub COVER percent)^2

and

$$ALOAD = 6.05713 + 0.00006\ INT \quad (2)$$

where

ALOAD = "Active" fuel load (t/ha)

INT = (shrub HEIGHT in cm) x (shrub COVER percent)^2

The variable called TLOAD refers to the total fuel loading in the understorey, in metric tons per ha (t/ha), and includes the few grasses available (usually < 1%), the litter and dead woody fuel on the ground, in addition to all parts of the shrubs. The variable called “active fuel load” (ALOAD) refers to the load in the biomass classes included in fuel models compatible with Rothermel’s mathematical fire spread model (Rothermel, 1972). This "active" fuel load does not include heavier living fuels (diameters larger than 0.64 cm). Obviously, ALOAD is by definition always less than or equal to TLOAD, as TLOAD also includes the live load of the shrubs larger than 0.64 cm in diameter.

The cover estimate used for each plot was the cover of the group of sclerophyllous shrubs in that plot. Equations (1) and (2) require average shrub height and not the maximum that was recorded in the field. Hence, maximum shrub height values were converted to average values through multiplication by 0.7, following Burgan & Rothermel (1984) who suggested that 70% percent of the maximum shrub height is a reasonable estimate of the average height.

3. Analysis and Results

The sampling work performed in the *Pinus halepensis* forest understorey along the established post-fire chronosequence in Central Greece showed that these forest stands can be distinguished in two different types. The first corresponds to stands characterized by the dominance of evergreen sclerophyllous shrubs in the understorey (type 1, Picture 1). In the second case, the presence of such shrubs is scattered, allowing the increased presence of dwarf shrubs, grasses and forbs (type 2, Picture 2). Type 2 can be further divided in stands where the relatively sparse shrubs in the understorey are mainly *Quercus coccifera* (sub-type 2a), and can be found primarily on limestone and schists, and stands where the sparse understorey shrubs are mainly individuals of *Pistacia lentsicus* (sub-type 2b).

Pinus halepensis forest stands of type 1 are primarily found on sites characterized by relatively wet conditions at an altitude varying from 350 to 700 m. In these sites, the anthropogenic influence is reduced in comparison to the forest stands of type 2. The latter are found on sites where conditions are drier and human pressure more intense. Usually, stands of the sub-type 2b are distributed at low elevations (< 200 m a.s.l.), near the coastline, while stands of the sub-type 2a are more continental and mountainous, still along the urban-wildland interface.

Picture 1. The dense understorey of a type 1 *Pinus halepensis* forest stand at the site of Agios Merkourios, Mt. Parnitha National Park.

Picture 2. The sparse understorey of a type 2 *Pinus halepensis* forest stand at the site of Markati, Sounion Peninsula National Park.

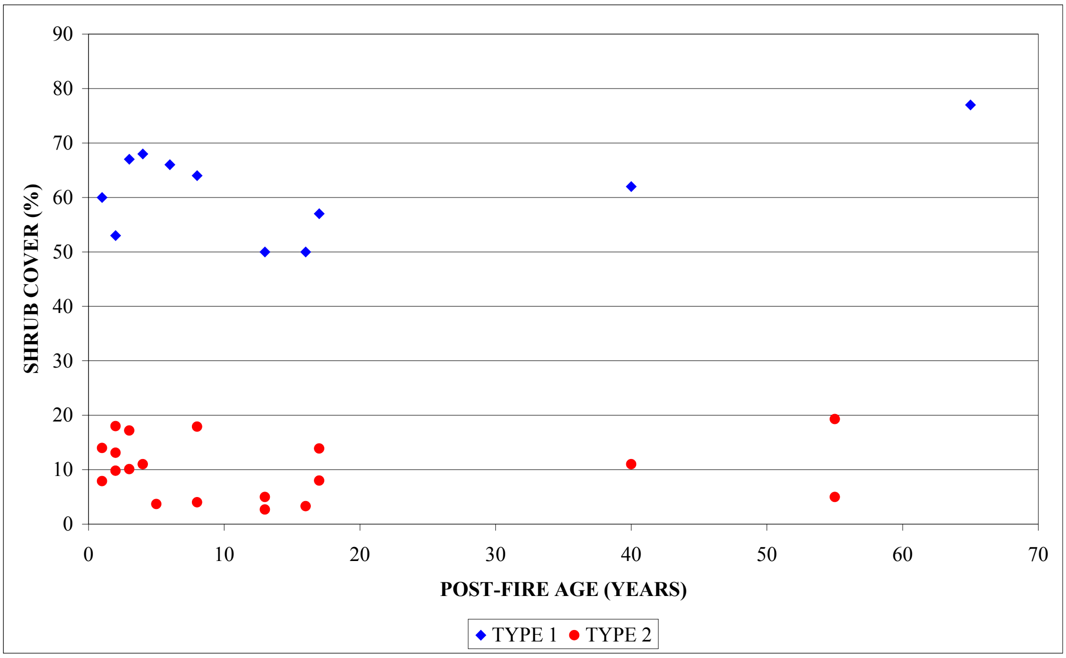

Figure 1. Evergreen sclerophyllous shrub cover along the post-fire chronosequence of *Pinus halepensis* forest stands of Central Greece.

The distinction of the two forest stand types based on the total cover of evergreen sclerophyllous shrubs is evident independently of the post-fire age of the stands. In type 1 stands, evergreen sclerophyllous shrub cover very quickly exceeds 50% and then gradually increases remaining in the 50 – 80% range. In type 2 stands, shrub cover generally remains below 20% independent of stand age (Figure 1).

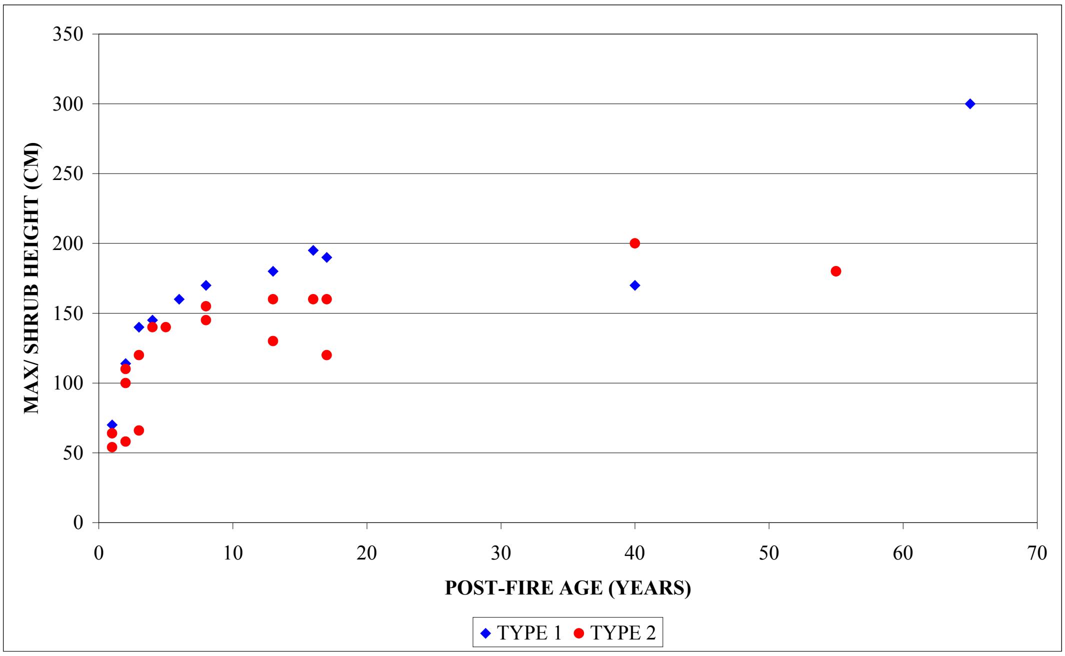

Figure 2. Evergreen sclerophyllous shrub maximum height along the post-fire chronosequence of *Pinus halepensis* forest stands of Central Greece.

If the long-term post-fire evergreen sclerophyllous shrub cover pattern differs between type 1 and type 2 stands, this is not the case regarding maximum height dynamics (Figure 2). In both cases, the shrubs reach a height of 150 cm within the first post-fire decade. Their height growth rate drops significantly after that and they rarely become more than 2 m tall.

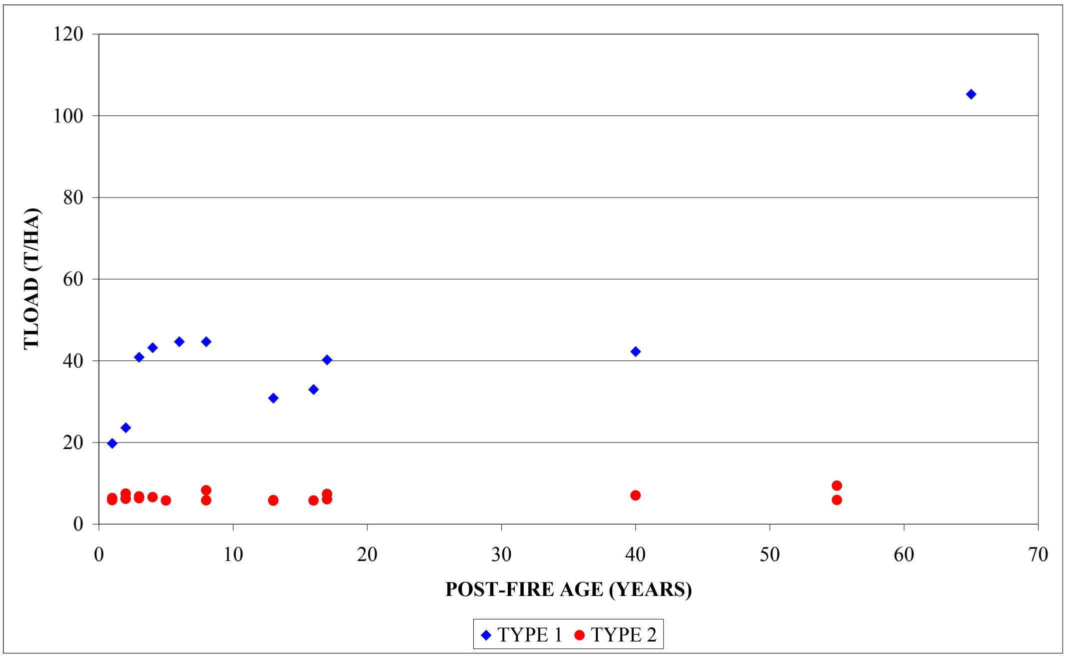

Figure 3. Total fuel load (TLOAD) along the post-fire chronosequence of *Pinus halepensis* forest stands of Central Greece.

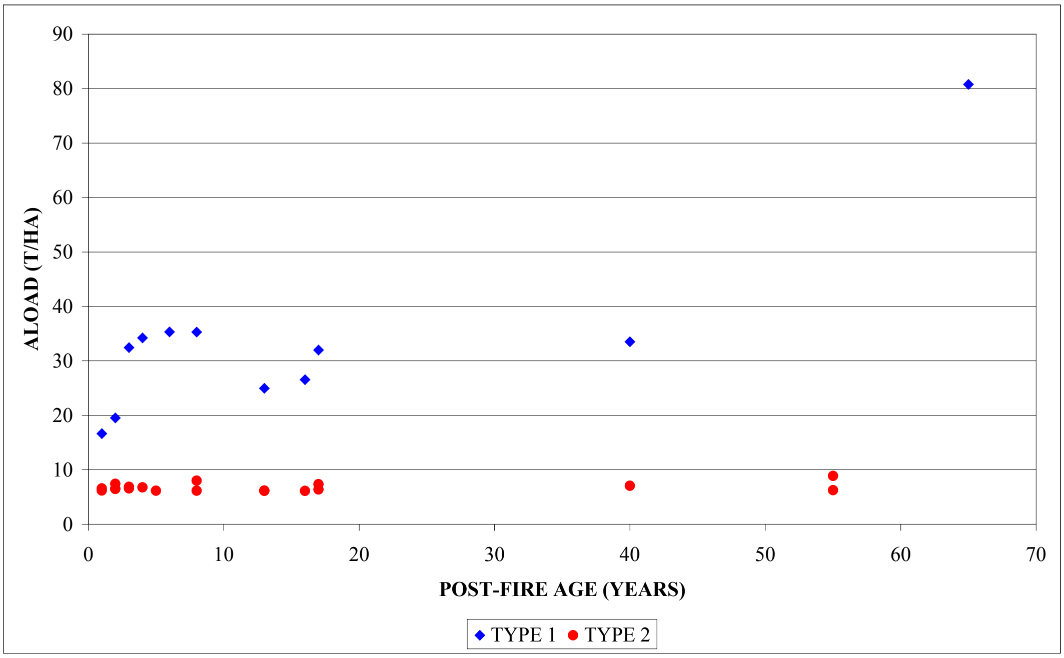

Figure 4. Active fuel load (ALOAD) along the post-fire chronosequence of *Pinus halepensis* forest stands of Central Greece.

By applying equations (1) and (2), TLOAD and ALOAD along the established chronosequence were estimated respectively (Figures 3 and 4). The difference of the values for the two distinct stand types is evident throughout the temporal gradient.

The regression analysis that followed, took into consideration this observation. A multiple linear regression model with forest TYPE (values 1 or 2) and post-fire AGE (in years) as the independent variables was produced for the estimation of the two dependent variables of interest TLOAD and ALOAD:

$$TLOAD = 71.228 - 35.198\ TYPE + 0.412\ AGE \quad (3)$$

with

adjusted multiple correlation coefficient $R^2 = 0.733$
N = 30
p-value for the model < 0.001
p-value for the constant < 0.001
p-value for the coefficient of TYPE < 0.001
p-value for the coefficient of AGE = 0.002

and

$$ALOAD = 55.227 - 26.398\ TYPE + 0.309\ AGE \quad (4)$$

with

adjusted multiple correlation coefficient $R^2 = 0.733$
N = 30
p-value for the model < 0.001
p-value for the constant < 0.001
p-value for the coefficient of TYPE < 0.001
p-value for the coefficient of AGE = 0.002

Equations (3) and (4) are quite successful statistically. They share the same statistics since the values of TLOAD and ALOAD have been calculated through the allometric equations (1) and (2) that use the same independent variables. However, they provide different information as they not only have different constant values but they also have different coefficients for AGE and TYPE. A graphical representation of equation (3) plotted as two parallel lines corresponding to the two forest types, along with the original calculated TLOAD values, is presented in Figure 5. Figure 6 is a similar graph for equation (4) and the original ALOAD values.

Variable ALOAD, which is of interest for fire behaviour modelling, was further examined. ALOAD is actually predicted by AGE, along two parallel lines corresponding to the two values (1 or 2) of forest TYPE. In Figure 6, it can be observed that the data might be represented better by separate lines of different slope, one for each forest type. Based on this observation it was determined to analyze each forest stand type independently, separating type 1 from type 2, and then further subdividing type 2 into two subtypes, the *Quercus coccifera* dominated one (type 2a) and the *Pistacia lentiscus* dominated (type 2b), using post-fire age as the independent variable in each case. The results were equations (5), (6) and (7):

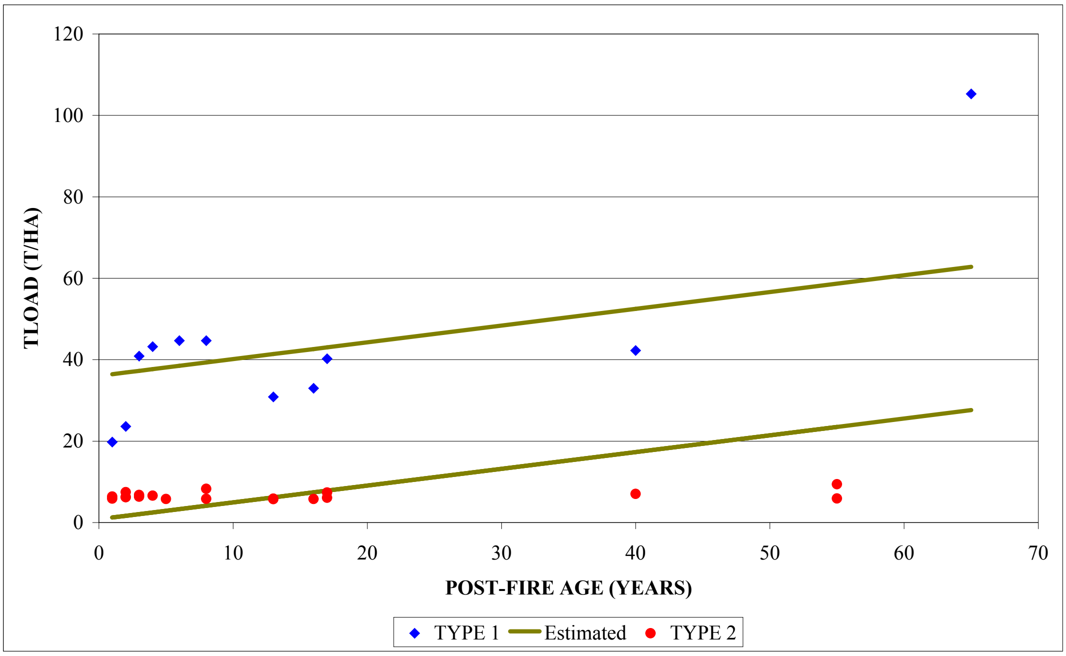

Figure 5. Estimated total fuel load (TLOAD) along the post-fire chronosequence of *Pinus halepensis* forest stands of Central Greece.

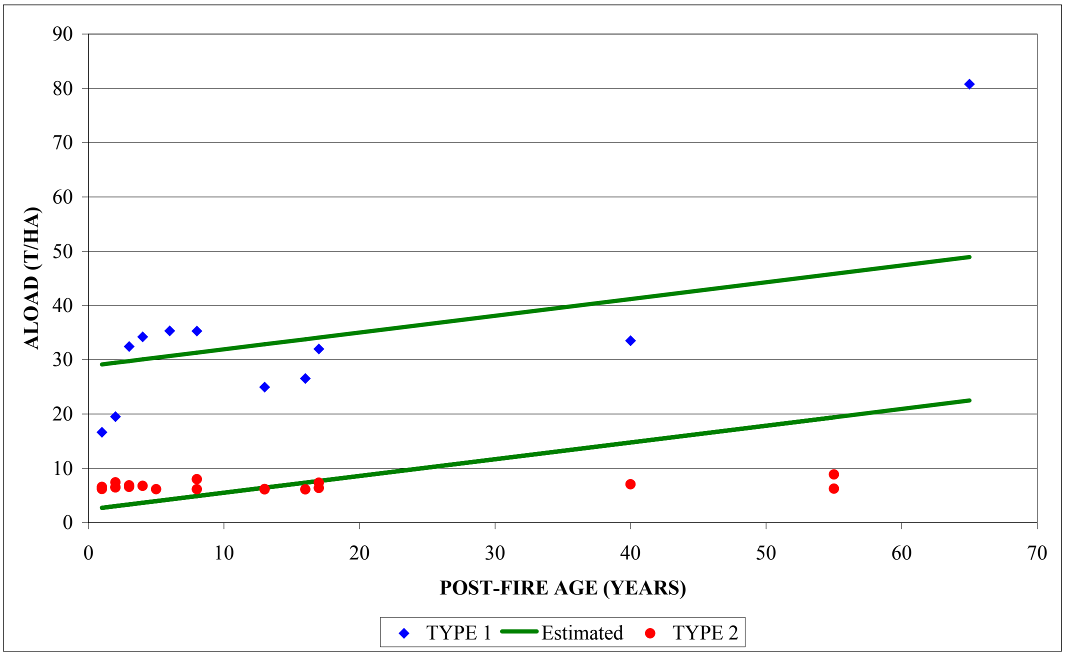

Figure 6. Estimated active fuel load (ALOAD) along the post-fire chronosequence of *Pinus halepensis* forest stands of Central Greece.

Forest type 1:

$$ALOAD = 22.436 + 0.711\ AGE \quad (5)$$

with

adjusted multiple correlation coefficient $R^2 = 0.655$
N=11
p-value for the model < 0.001
p-value for the constant < 0.001
p-value for the coefficient of AGE = 0.002

Forest type 2a:

$$ALOAD = 6.338 + 0.042\ AGE \quad (6)$$

with

adjusted multiple correlation coefficient $R^2 = 0.480$
N=13
p-value for the model < 0.001
p-value for the constant < 0.001
p-value for the coefficient of AGE = 0.005

Forest type 2b:

$$ALOAD = 6.778 + 0.006\ AGE \quad (7)$$

with

adjusted multiple correlation coefficient $R^2 = -0.162$
N=6
p-value for the model < 0.611
p-value for the constant < 0.001
p-value for the coefficient of AGE = 0.611

Equations (5) and (6) are significant and perform quite well but the same is not true for equation (7) which is based on an extremely small sample size. Figure 7 is a graph of equations (5) and (6), plotted as lines, along with the original ALOAD values.

4. Discussion and conclusions

Evergreen sclerophyllous shrubs are characterized by vigorous resprouting that starts a few days after the fire event (Trabaud, 1987, Arianoutsou, 1997). This fact explains why several studies conclude that the higher the participation of these shrubs in the pre-fire vegetation composition, the shorter the time period required for vegetation cover to reach adequate levels for significantly reducing the risk of erosion (Trabaud et al., 1985, Clemente et al., 1996, Vallejo & Alloza, 1998, Calvo et al., 1998). As reported from other Mediterranean ecosystems (Papanastasis, 1977, Trabaud & de Chanterac, 1985, Moravec, 1990, Clement et al., 1996), the high growth rate of evergreen sclerophyllous shrubs is exhibited mainly in the first post-fire years and decreases with age. Accordingly, the biomass that corresponds to these shrubs approaches pre-fire levels within the first years after the disturbance.

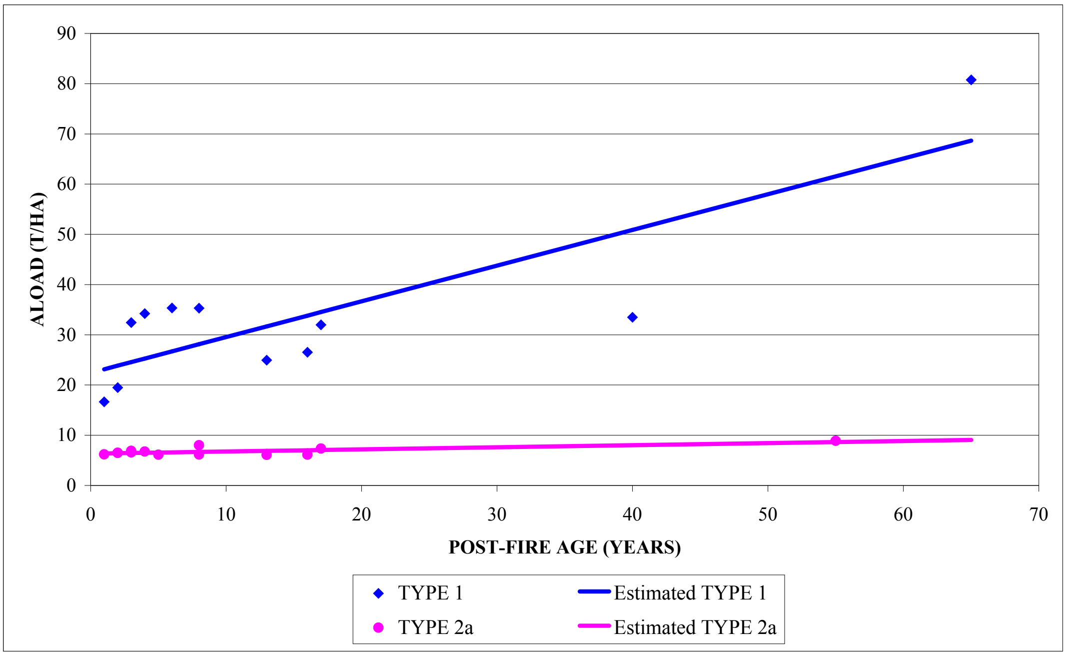

Figure 7. Estimated active fuel load (ALOAD) for stands of type 1 and type 2a.

It is this fact that makes stand type a factor of prime importance towards the understanding of fuel dynamics across heterogeneous landscapes. This is reflected in the value of the standardized coefficients for TYPE and AGE for equations (3) and (4): their values are equal to –0.782 and 0.333 respectively, for both equations.

Equations (5) and (6) indicate that the average rate of fuel accumulation with AGE in the undestorey of *Pinus halepensis* forests is very different for the corresponding stand types. An "active" fuel load of 0.711 t/ha is added every year, on the average, to the understorey of type 1 forest stands, while the corresponding rate is 0.042 t/ha per year for type 2 stands. This leads to relatively quick fuel load accumulation in type 1 stands.

Equations (3) – (7) may be non-linear outside the range of ages sampled here (<65 years). However, the early fuel load accumulation makes type 1 stands vulnerable to fire much earlier and subsequently understorey fuel management efforts, at least in critical areas, must start accordingly. On the other hand, fuel management needs in type 2 stands are much lower and may come much later in the age of the stand.

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