Volume 11 – No.4 – 2002
REPRINT pp. 186 - 193

POST-FIRE VEGETATION SUCCESSION: THE CASE OF ALEPPO PINE (*PINUS HALEPENSIS* MILLER) FORESTS OF NORTHERN ACHAIA (GREECE).

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POST-FIRE VEGETATION SUCCESSION: THE CASE OF ALEPPO PINE (*PINUS HALEPENSIS* MILLER) FORESTS OF NORTHERN ACHAIA (GREECE).

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SUMMARY

Extensive wildfires affected Northern Achaia in the last decade. The largest proportion of the burnt areas is localized in Aleppo pine (*Pinus halepensis* Miller) forests. Post-fire vegetation succession of two adjacent *Pinus halepensis* forests in this area has been studied. The studied forests lie around Platani and Ziria villages and were burnt during great wildfires in 1989 and 1995, respectively. Floristic diversity and vegetation dynamics were studied in the burnt forests of Platani and Ziria, and also in unburnt stands, during a two year period (1995 - 1997). The data process showed great floristic similarity between the quadrats one and two years after the wildfire. The characteristic plants of these quadrats are annual herbs that belong mostly to the *Leguminosae* and *Compositae* families. Plant diversity is found at a minimum one year after fire, but it increases during the following years and drops again in the unburnt forest. The vegetation of the mature forest is characterized by the dominance of woody perennial species that create a dense understorey beneath the *Pinus halepensis* trees. All plant species of the unburnt forest are already present during the early post-fire years. The observed succession is nothing more than the replacement of small, short-lived plants by large, long-lived ones. This succession pattern matches the "initial floristic composition" model of Egler.

KEYWORDS: *Pinus halepensis*, fire, vegetation succession, post-fire regeneration, mediterranean-type ecosystems, Peloponnisos (Greece), secondary succession.

INTRODUCTION

Wildfires are important ecological events shaping ecosystems of the Mediterranean Basin [1-6], especially in the thermo- and meso-Mediterranean vegetation belts. Mediterranean plants use three strategies to resist fire: (1) Direct or indirect, fire-induced germination of existing seeds, (2) vegetative growth from underground organs and (3) passive fire-tolerance aided by thick bark or growth habits that prevent crown fires.

Aleppo pine (*Pinus halepensis*) forests are widespread in southern, mainland Greece and each year large areas of them burn during the hot, dry summer period.

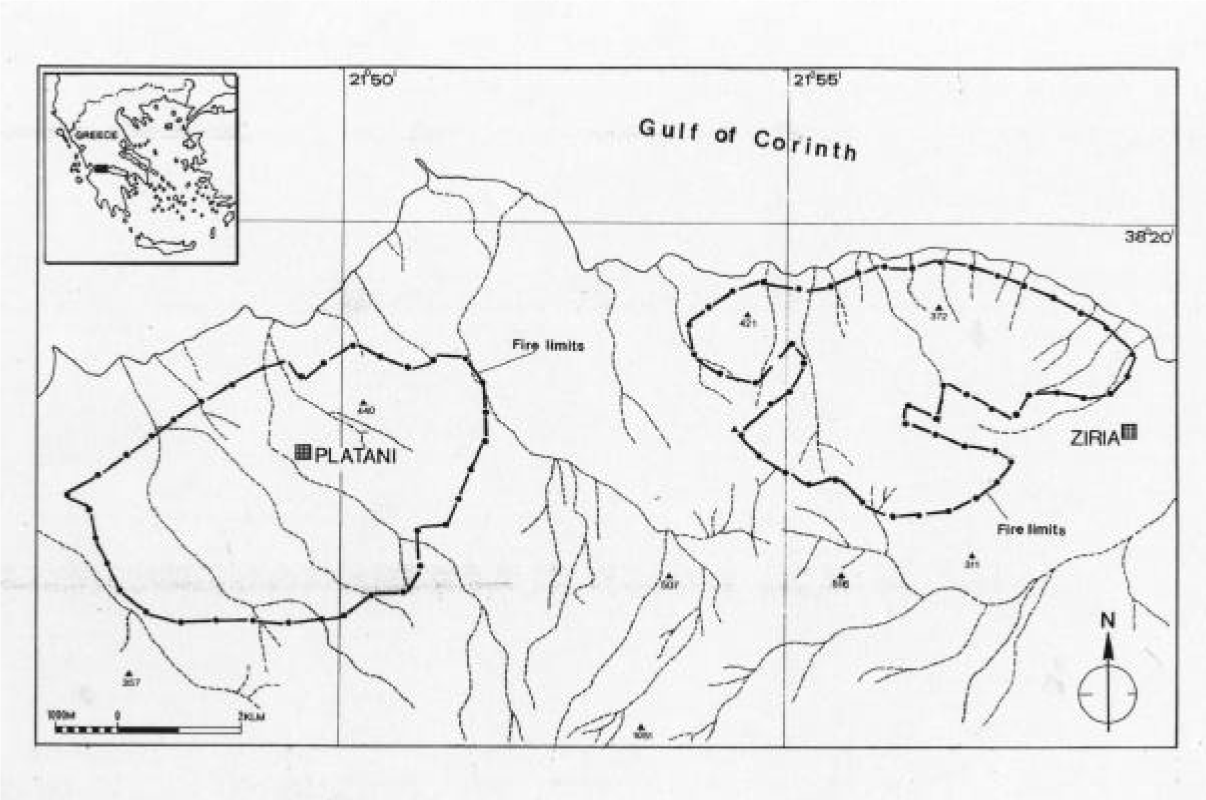
During recent decades various aspects of natural post-fire regeneration have been studied in several Mediterranean ecosystems, including *Pinus halepensis* forests [7-16]. However, as Kazanis & Arianoutsou [14] note, there are presently not enough data available to develop a sound theory of species replacement during post-fire succession in the Mediterranean basin. This paper contributes towards this direction and focuses on the post-fire vegetation succession of two adjacent Aleppo pine (*Pinus halepensis* Miller) forests in Northern Achaia (Peloponnese, South Greece).

MATERIALS AND METHODS

Study Area: The study area lies at the foot of Mt. Panachaiko, in the coastal zone between the cities of Patras and Aigio. It has a northern aspect and altitudes ranging from 200–750 m. Substrates are blue marls and sandy clays and are topped with calcareous soils. Climatic conditions follow the typical Mediterranean pattern of mild, rainy winters and hot, dry summers, with a drought period from May to September. The mean annual precipitation is approximately 700 mm and the mean annual air temperature is about 18 ^{0}C.

In August 1989, part of the study area was burnt by a wildfire near the village of Platani. This wildfire burnt an area of 2,020 ha, 610 ha of which were *Pinus halepensis* forest. A second wildfire broke out in July 1995 near the village of Ziria. During this incident, 1,800 ha were burnt, of which 1,550 ha were covered with *Pinus halepensis* forest (Figure 1).

FIGURE 1 - Map of Northern Achaia (The areas burnt during the two wildfires are evident).



Aleppo pine forests in the study area consist of *Pinus halepensis* trees with a tall (sometimes over 4 m), dense understorey of evergreen sclerophyllous shrubs such as *Arbutus unedo*, *A. andrachne*, *Erica arborea*, *Quercus coccifera* and *Phillyrea latifolia*. Low shrubs and herbs such as *Cistus creticus*, *Cistus salviifolius*, *Brachypodium retusum* and *Hypochoeris achyrophorus* grow only in openings and forest margins [17]. With the exception of some sheep and goat grazing in the area of Platani, the forests are not managed.

Field Methods and Data Analysis: During a two-year period (1995 - 1997) thirty representative quadrats of 100 m^2 were taken from burnt and unburnt stands of Allepo pine forest in Platani and Ziria. All plant species in each quadrat were recorded, together with their cover-abundance value, using the seven-step scale of Braun-Blanquet [18]. Six quadrats were taken from the Platani area in 1995 (six years after fire) and the same quadrats were sampled again in 1997 (eight years after fire). From the area of Ziria, six quadrats were taken in 1996 (one year after fire) and were sampled again in 1997 (two years after fire). All quadrats were taken in May; the peak flowering time of these ecosystems.

Plant species not identified *in situ* were collected and later identified in the Herbarium of the University of Patras (UPA). Species nomenclature follows Med-Checklist [19] 1984-1989 and Flora Europaea [20] 1968-1980.

The thirty quadrats were divided into five groups: Ziria 1996 (one year after fire), Ziria 1997 (two years after fire), Platani 1995 (six years after fire), Platani 1997 (eight years after fire) and unburnt forest (at least fifty years after fire). Data were analyzed using the detrended correspondence analysis (DCA) ordination method and the numerical classification method of TWINSPAN [21]. To produce life-form spectra, plant species were classified according to Raunkiaer?s life-form categories [22]. The five categories used were Phanerophytes, Chamaephytes, Hemicryptophytes, Geophytes and Therophytes [21, 23, 24]. Data were also analyzed using Shannon's Diversity Index. This index was calculated from the formula [21]:

$$H' = -\sum_{i=1}^{s} p_i \log p_i$$

where s = the species number of each quadrat, and
P_i = the abundance of species *i* as a percentage of total abundance.

The Evenness Index was calculated from the formula:

$$J = \frac{H'}{\log s}$$

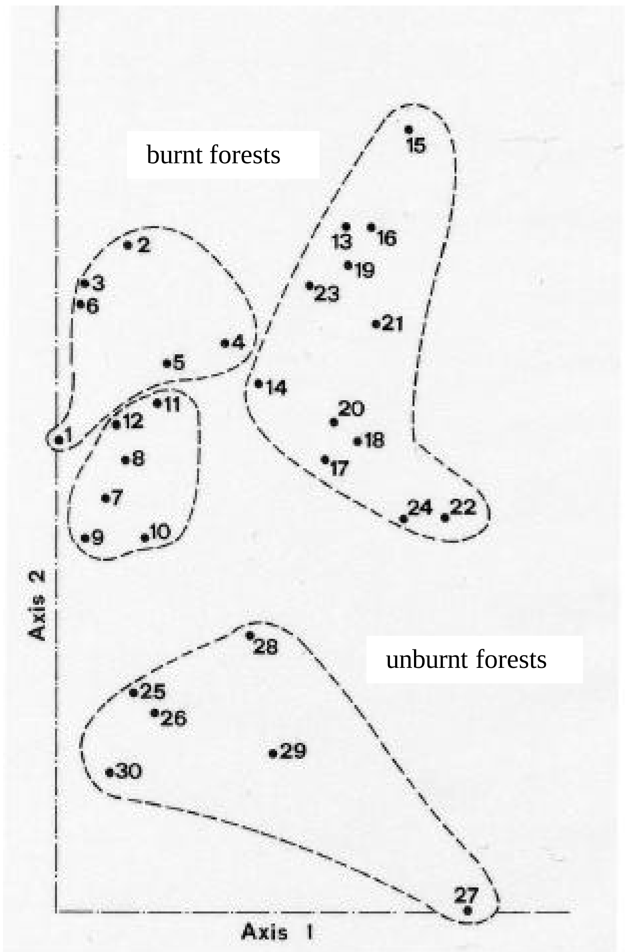
To calculate the above indices, species abundance data were transformed to the decimal scale according to Westhoff & van der Maarel [25].

RESULTS

Numerical Elaboration of Data

The data set consisted of a table containing thirty quadrats and 138 species. The DCA ordination diagram is presented in Figure 2 where quadrats are arranged by similarity of species composition and abundance. It is clear from Figure 2 that the quadrats can be separated into four groups: (1) quadrats from unburnt forest (25-30), (2) quadrats from first and second post-fire seasons (13-18 and 19-24, respectively), (3) quadrats of the sixth post-fire season (1-6), and (4) quadrats of the eighth post-fire season (7-12).

FIGURE 2 - DCA ordination diagram of the thirty quadrats. Quadrats 1-6 correspond to Platani 1995, 7-12 correspond to Platani 1997, 13-18 correspond to Ziria 1996, 19-24 correspond to Ziria 1997 and 25-30 correspond to unburnt forest.



Vegetation samples from the unburnt forest have the least similarity with the other groups. The two quadrat groups of Platani (six and eight years after fire) are clearly separated, although their distance is very small. On the contrary, it is not possible to separate the two quadrat groups of Ziria (one and two years after fire).

Numerical classification was used in order to detect possible species grouping patterns in relation to quadrat distribution. From the 138 species recorded, thirty-six seem to follow a pattern. These species are shown in Table 1. It is significant that no species were found to characterize exclusively the unburnt forest.

Life-form Spectra

Life-form spectra for each quadrat group are shown in Figure 3, which shows that percentages of chamaephytes, hemicryptophytes and geophytes remain almost stable, and were not affected by the wildfire. The percentage of phanerophytes remains constant in all burnt areas but increases sharply in the unburnt forest. This is not due to their exclusive occurrence in the unburnt forest, but to the great reduction of therophytes in the nature stand. Therophytes constitute one half of the flora in the first two years after fire, and one third of the flora six to eight years after fire. However, in the unburnt forest they constitute just 12% of the flora.

Therophyte dominance the first post-fire years and their subsequent absence in the mature stages has been observed in many mediterranean-type ecosystems [26-30]. Trabaud [31] ascribes this pattern to the vegetation opening after a fire, the absence of litter, and the increase of nutrients in the upper soil layers. As vegetation cover increases, therophytes reduce in numbers, as their competitive abilities are limited.

Floristic Analysis

The most abundant plant families in the post-fire flora were the *Leguminosae*, *Compositae* and *Graminae*. The *Leguminosae* are of special interest as they seem to flourish after wildfires [32, 33]. In addition, due to their hard-coated seeds and ability to fix atmospheric nitrogen, they may play an important role in the post-fire succession of fire-prone ecosystems.

Figure 4 presents the percentages of the three commonest families in the five quadrat groups. This diagram takes into account only the herbaceous plants of the three families. It is evident that herbaceous *Leguminosae* are most abundant in the post-fire flora. They peak during the first post-fire season and during the following years their percentage stabilizes at around 20%. In the unburnt forest they represent only 5% of the total flora. The *Compositae* have a very small presence the first post-fire year, but increase rapidly in the second post-fire year.

TABLE 1 - Species showing a distribution pattern among the quadrat groups.

Species present in all quadrat groups	Species only present 6 years after fire (Platani 1995)	Species only present 6 and 8 years after fire (Platani 1995, 1997)	Species present 6 and 8 years after fire (Platani 1995, 1997) and in the unburnt forest
Pinus halepensis	*Euphorbia apios*	*Anthyllis vulneraria*	*Pistacia lentiscus*
Arbutus andrachne	*Onobrychis caput-galli*	*Convolvulus elegantissimus*	*Anthyllis hermanniae*
Arbutus unedo	*Polygala monspeliaca*	*Urginea maritima*	*Coridothymus capitatus*
Erica arborea			*Genista acanthoclada*
Phillyrea latifolia			*Sarcopoterium spinosum*
Quercus coccifera			
Cistus creticus			
Cistus salviifolius			
Dorycnium hirsutum			
Brachypodium distachyon			
Brachypodium retusum			
Hypochoeris achyrophorus			

Species only present the first and second years after fire (Ziria 1996, 1997)	Species only present the second year after fire (Ziria 1997)	Species present in all quadrats except the unburnt forest (Ziria 1996, 1997, Platani 1995, 1997)	Species present the first and second year after fire (Ziria 1996, 1997) and in the unburnt forest
Fumaria sp.	*Desmazeria rigida*	*Fumana thymifolia*	*Quercus ilex*
Lactuca serriola		*Trifolium campestre*	
Lotus ornithopodioides			
Sonchus asper			
Trifolium glomeratum			
Trifolium nigrescens			
Vicia hirsuta			
Vicia tetrasperma			

FIGURE 3 - Life-form spectra for the five quadrat groups.

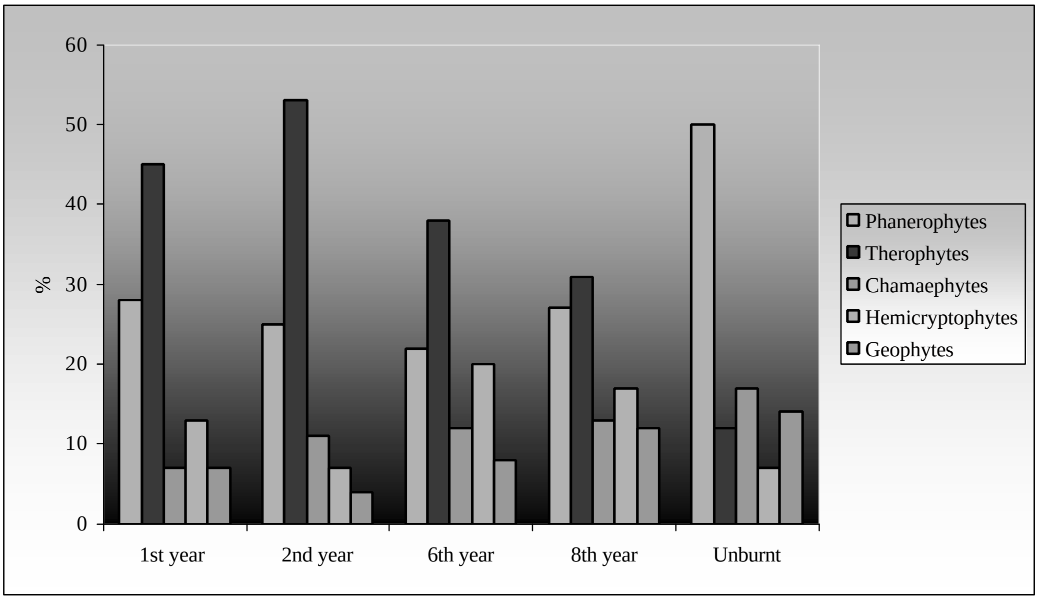


FIGURE 4 - Percentages of the three commonest families in the five quadrat groups.

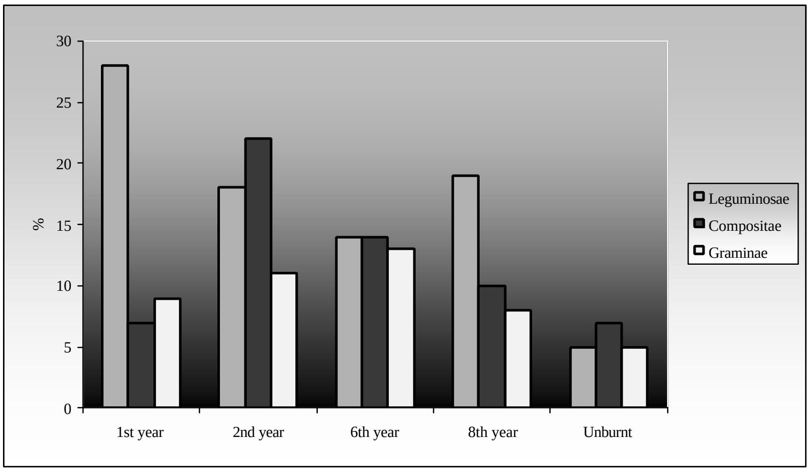


FIGURE 5 - Number of species recorded in the five quadrat groups.

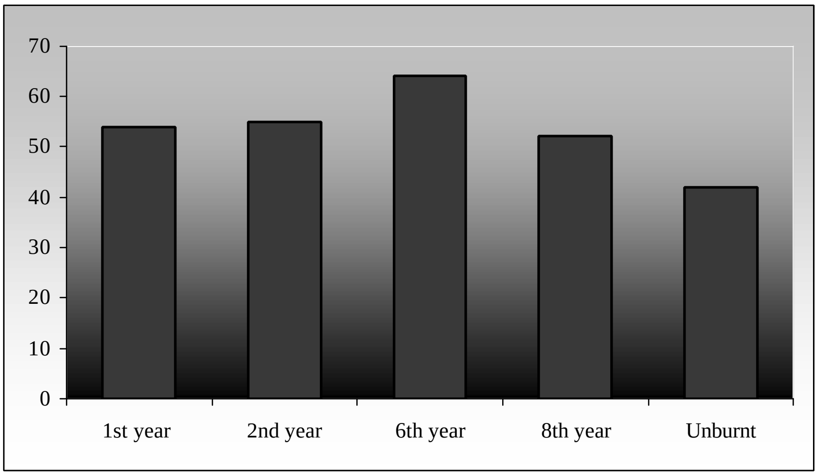


FIGURE 6 - Shannon's Diversity Index for the five quadrat groups.

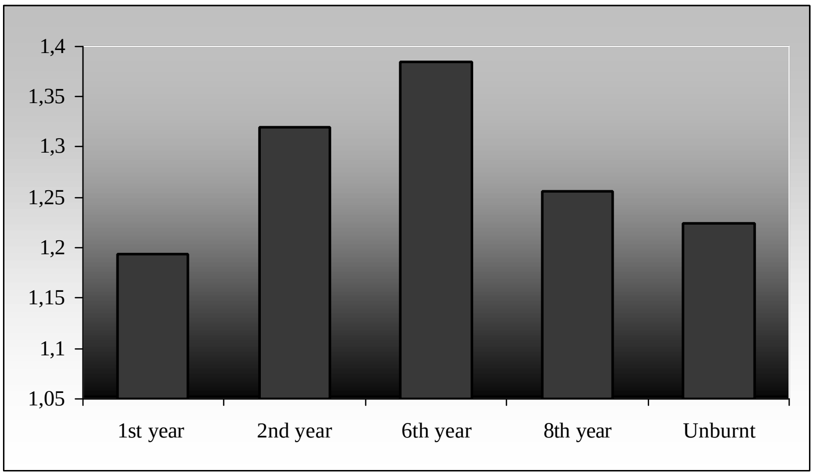
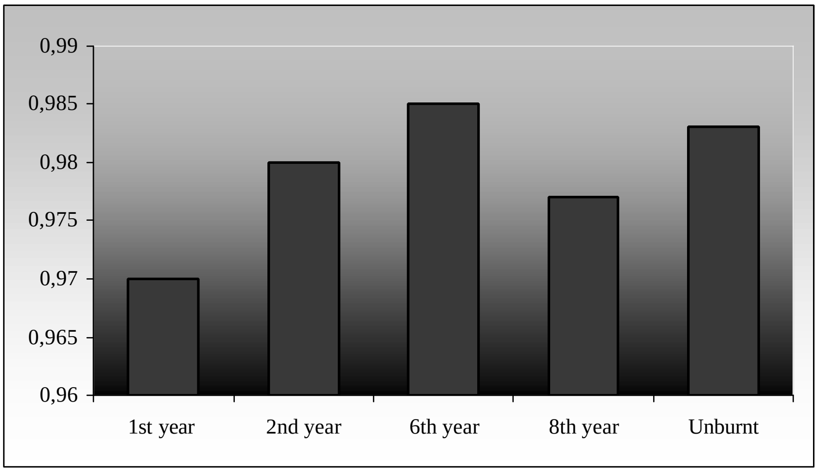


FIGURE 7 - Evenness Index for the five quadrat groups.



All three families show an increased species number after the wildfire. One possible explanation for the increased numbers of *Leguminosae* in the first post-fire year is that seeds of this family plants have hard coats and are impermeable to water [34, 35]. This enables soil seed banks to form and seeds germinate immediately after fire, after undergoing thermal treatment. On the contrary, most *Compositae* species are anemochorous, having small, light seeds with pappus-like structures. Presumably, these seeds are short-lived [36]. Therefore, recolonization of the burnt area occurs exclusively by seeds reaching the area after the fire and this accounts for their increased presence in the second post-fire year.

Diversity and Evenness

Figure 5 shows the number of species recorded in each quadrat group. According to the general, post-fire succession pattern of mediterranean-type ecosystems, the maximum number of species is usually observed one to three years after fire [37]. Our results do not follow this pattern, as the maximum number of species was recorded six years after fire. This fact could be one of the synchronic method deficits.

Shannon's diversity index incorporates species number and relative abundance. Figure 6 shows that the first post-fire year quadrat group has the lowest diversity, and not the unburnt forest group as expected. This can be explained by the more uniform species distribution in quadrats from the unburnt forest (Figure 7). The quadrat group with the highest diversity is that of Platani 1995 (6 years after fire).

DISCUSSION AND CONCLUSION

After fire plants appear rapidly and colonize the bare ground. The first two years after fire, herbaceous annuals make up 50% of the burnt forest total flora. Most of these plants occur usually in open areas (road margins, abandoned fields etc.). Typical examples of these herbaceous annuals are *Fumaria* sp., *Lactuca serriola*, *Sonchus* spp., *Trifolium* spp., *Vicia* spp., etc. Populations of these plants are small and sparse the first year after fire. The largest part of the vegetation cover derives from resprouting shrubs of *Arbutus* spp., *Erica arborea*, *Phillyrea latifolia*, *Quercus coccifera* etc., and from the obligate seeders *Cistus creticus* and *Cistus salviifolius.* Germination of *Cistus* spp. seeds is promoted by fire heat [38-40] and plants of this genus dominate Mediterranean landscapes during post-fire years. Total vegetation cover ranges between 30-60% during the first post-fire season. The second season, annual plant populations are much larger and, combined with the increase in size of other plants, total vegetation cover rises to 60-85%.

Density of *Pinus halepensis* seedlings varies greatly. Indicative measures taken in three of the quadrats during the first post-fire season showed a density of 0.67 to 35 seedlings per m^2. Similar measures taken in Platani 1995 (six years after fire), showed a seedling density of 0.2 to $35/m^2$. However while seedling height did not exceed 10cm the first post-fire season, six years later it ranged from 20 to 150 cm. If no fire breaks out in the next fifteen years, it seems that by then the pine forest will have regenerated fully.

Numerical analysis showed that in the first two years after fire, differences in vegetation composition and structure are very small. Some differences are seen when we compare vegetation of the first two post-fire years with that of six to eight years after fire. This is due to the decrease of annuals, the increase of woody plants, and the more complex vegetation structure. Vegetation of the unburnt forest has least similarity with the other groups. Mature *Pinus halepensis* forest is dominated by woody perennial species that form a dense, impenetrable vegetation beneath which very few herbaceous species grow. The most important species of the unburnt forest are already present from the first post-fire years. This leads us to the question of which vegetation succession pattern is followed in *Pinus halepensis* forests of Northern Achaia.

From our study it seems that all species of the succession process are present from the initial stages. These species grow and reproduce, and the final resulting vegetation (if a fifty-year old forest can be considered as such) is the result of their growth habits, life span and life history differences. As time passes and plants grow to their full size, the initial combination of herbs, shrubs and trees results in a forest where trees and tall shrubs dominate and herbs and low shrubs grow only in forest margins and openings.

Many patterns of ecological succession have been described worldwide but it is doubtful whether one model or theory can explain all cases of succession [41, 42]. Several researchers have used different terms to describe secondary succession in post-fire communities of the Mediterranean Basin. For example, Christensen [43] believes that post-fire maquis succession is best described by the "tolerance" model of Connell & Slatyer [44]. Moravec [12] who studied post-fire regeneration of Algerian *Pinus halepensis* forests, reached results similar to ours. He described post-fire regeneration as a cyclic forest growth process and rejected the term secondary succession since most dominating plants resprout after the fire. Roy & Sonie [45] use the term "autosuccession" to describe the post-fire vegetation dynamics of a *Cistus* spp. garrigue. This term was first used by Hanes [26] in order to distinguish "a self-replacing vegetation like chaparral from those types that must be preceded by distinct seral stages". Trabaud [37] reviewed many papers relative to post-fire vegetation dynamics in Mediterranean European countries, and concluded that most researchers agree that succession follows the "initial floristic composition model" of Egler [46] or the "inhibition" model of Connell & Slatyer [44]. Whelan [47] states that, especially for fire-prone ecosystems, we should not accept the implementation of a theoretical pattern on the actual succession process. However, Stiling [48] points out that components of different models may coexist in each succession case.

In the case of *Pinus halepensis* forests in Northern Achaia, we conclude that the vegetation succession pattern follows the "initial floristic composition" model proposed by Egler [46] to explain vegetation succession in abandoned fields. As Crawley [24] describes "the observed succession of species is nothing more than the replacement of small, short-lived plants by large, long-lived ones". However, we do not rule out the possible occurrence of processes predicted by other models. For instance, if the role of the herbaceous *Leguminosae* (or other herbaceous plants that abound in the first post-fire stages) is proved critical for soil nitrogen enrichment and protection from surface erosion, then the "facilitation" model of Connell & Slatyer [44] would be partly valid. This model predicts that the initial species of the series modify the environment and render it suitable for species of the next stage.

ACKNOWLEDGEMENTS

We would like to thank Sandy Coles and Panagiotis Labropoulos for assistance in the manuscript preparation.

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Received for publication: November 30, 2001
Accepted for publication: February 13, 2002

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FEB/ Vol 11/ No 4/ 2002 – pages 186 - 193