Assessment of the response of a Mediterranean-type forest ecosystem to recurrent wildfires and to different restoration practices using Remote Sensing and GIS techniques

P. Christakopoulos, I.Hatzopoulos, K. Kalabokidis
Faculty of Environmental Studies, Aegean University, Lofos Panepistimiou, 81100 Mytilene, Greece, e-mail: phrista@env.aegean.gr
D. Paronis
Institute for Space Applications & Remote Sensing, National Observatory of Athens Vas. Pavlou & Metaxa, 15236 Palaia Penteli, Greece, e-mail: dpar@space.noa.gr
A. Filintas
Department of Farm Machinery & Irrigation, Faculty of Agriculture, T.E.I. of Larissa, 41110 Larissa, Greece, e-mail: filintas@teilar.gr

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ABSTRACT**:** Restoration of Mediterranean-type forest ecosystems is of great importance and a main environmental issue in Greece and other countries of the Mediterranean basin as well. For the effective implementation of proper restoration practices, a thorough knowledge is required as regards post-fire regeneration processes, namely changes that occur in the vegetation composition and the evolution of ecosystem resilience rate, after one or more fire incidents.
The research work presented in the paper, took place at the National Park of Sounio (Greece), where an intensive forest land survey was performed. Forest-ecosystem resilience and vegetation composition was studied under various post-fire regimes by the use of Remote Sensing and GIS techniques. For that purpose, Landsat (TM and ETM+) satellite images spanning a 20-year period were used for the calculation of NDVI time-series. Classification maps depicting the pre- and post-fire situation were also considered.
Results showed that for the single-fire case, high resilience post-fire rates accompanied by minimum changes in the composition of the initial vegetation are established. In the case where a second fire recurs within a time period of 19 years, results showed that severe changes in vegetation composition are induced and also lower resilience rates are finally established. As regards reforestation efficiency, in the latter case, a satisfactory contribution with higher evolutionary vegetation schemes was found.

1. INTRODUCTION

Assessment of the response of Mediterranean-type forest ecosystems to recurrent wildfires is important for the effective implementation of the various restoration practices. According to existing research, restoration of the Mediterranean pines and evergreen-broadleaved seems to be ensured after one fire incident (Papanastasis 1977, Trabaud 1982, Arianoutsou 1984, De Lillis and Testi 1990, Moreno and Oehel 1994, Daskalakou 1996, Thanos et al 1996).

Recurrent wildfires play an important role in the natural regeneration process of the Mediterranean-type forest ecosystems. As pointed out in the relevant literature, natural regeneration of *Pinus halepensis Mill* isn't feasible in the case of recurrent fires within a period 7-15 years (Thanos and Daskalakou 2000). Recurrent wildfires influence also the evolution of the evergreen-broadleaved, since often fire recurrence leads these ecosystems to elimination (Zedler et al 1983).

Ecosystem resilience is another factor which is negatively influenced in a significant way by recurrent fires in the Mediterranean forests (Kazanis and Arianoutsou 2004).

The present work aims to assess the effect of multiple wildfires on the response of various vegetation types by means of remote sensing techniques. The overall ecosystem resilience and the contribution of the reforestation practices are also assessed.

2. DATA AND METHODOLOGY

The study took place in two areas at the National Park of Sounio (*figure1*). The first area (area1) has burned by recurrent wildfires in 1985 & 2000. The second area (area2) has also burned by recurrent wildfires in 1974 & 1993. In the area 2 and after the second fire, reforestation works were implemented.

Six Landsat (TM and ETM+) satellite images (1984, 1987, 1990, 1999, 2002 and 2005) and one IKONOS image (2004) were used. All images were calibrated and corrected geometrically and atmospherically.

In order to study the vegetation evolution after the recurrent wildfires, classification maps were produced from two Landsat satellite images for years 1984, 1999 and the IKONOS image for year 2004 (*figure3*). Supervised classification techniques aided by photo-interpretation of aerial photos and ortho-maps produced by the forest service, were applied. For the 2004 image, suitable training areas were carefully selected during a field campaign.

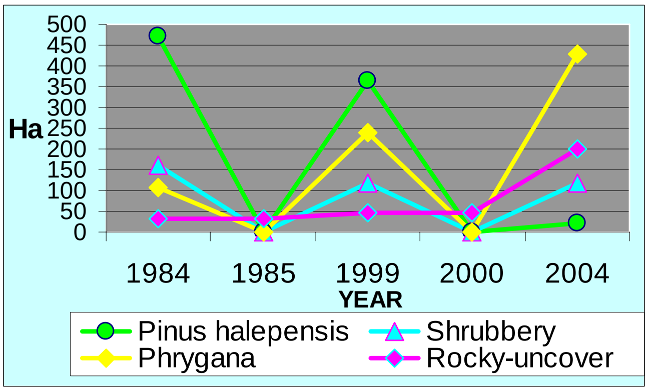
For the estimation of the ecosystem resilience, a parameter which is related to the total vegetation biomass, average NDVI values were calculated for the study areas for the six years under consideration. For each year, a resilience indicator R was computed as the ratio of the average NDVI value of an area that has been burned, to the value of a neighbouring unburned stud. The resilience indicator R has proven to be insensitive to factors such as moisture, visibility, and temperature variations (Diaz-Delgado et al 2002).

3. RESULTS AND DISCUSSION

The evolution of vegetation coverage in the area which was burned twice by recurrent fires in 1985 and 2000 is presented in figure 2:

Figure 1: Areas of study in National Park of Sounio

Figure2: The evolution of vegetation coverage after two recurrent wildfires in 1985 & 2000 (area 1)



As we observe in the graph of figure 1, after the first fire (in 1985), a failure of *Pinus halepensis Mill* natural regeneration occurs, resulting in 1999 to a 28 % decrease of the coverage compared to the value calculated for the 1984 image. This fact could be attributed mainly to the rocky character of study area. After the second fire, that occurs 15 years later (in 2000), we observe that even in 2004 (4 years after the second fire), *Pinus halepensis Mill* is almost eliminated from the area. This could be explained from the fact that the 15-years young *Pinus halepensis Mill*, did not present satisfactory bearing to support natural regeneration for a second time (Thanos and Daskalakou 2000).

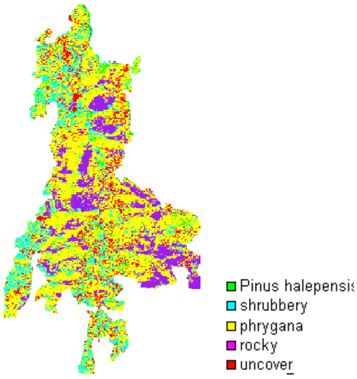
As regards shrubbery, we can remark that they present a stable appearance in the ecosystem, even after the two intense fires that took place in the area. On the other hand, phrygana's cover is increased significantly after the first fire and even more after the second. As a consequence, the extent of rocky-uncovered areas was increased lightly after the first fire but the increase is more intense after second fire.

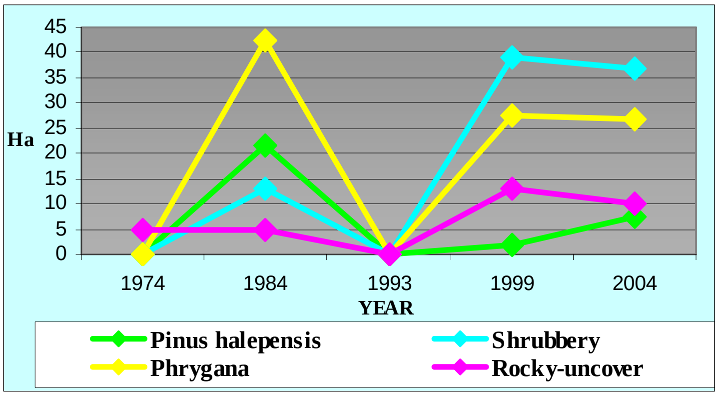
Considering *Pinus halepensis Mill* stands as a higher evolutionary level, shrubbery as a transitional stage and phrygana as inferior stages of the natural evolution, we could conclude that as regards vegetation coverage, after the first wildfire, the higher vegetation schemes were shifted to inferior schemes while the middle class schemes (shrubbery) weren't significantly affected. This trend became more evident after the second fire, where an almost complete **"inversion"** between vegetation schemes of higher evolutionary stages and those of the lower stages, is observed. The only fact that prevents the complete "inversion" after the second fire, is the enhanced presence of phrygana, which could be considered as the last feedback mechanism of the Mediterranean forest ecosystem to total desertification.

Figure 4 depicts the evolution of the vegetation coverage in the area which was burned twice by recurrent fires (1974 and 1993) and has been reforested after the second fire:

Figure 3: Classification map of area1(IKONOS 2004)

Figure 4: The evolution of vegetation coverage after two recurrent wildfires in 1974 & 1993(area 2)

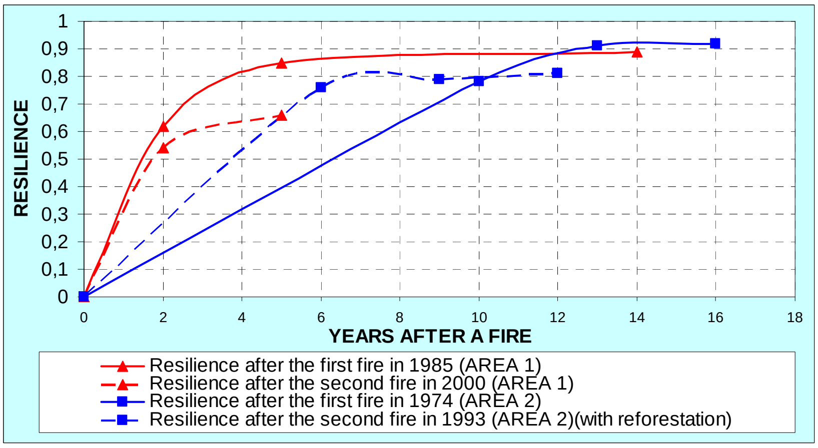




It is remarkable that after the second fire in 1993 and the reforestation followed the fire, an important increase of the shrubbery coverage is observed. This can be possibly attributed to the fact that the *Pinus halepensis Mill* reforestation in conjunction with the shrubbery that sprout, cannot be distinguished by means of multi-spectral classification techniques due to the mixing of the spectral classes. It can also be observed that the coverage of phrygana decreased six years after the first fire due to the reforestation process. The contribution of the reforestation process is apparent in the graph for years 1993-2004, where the observed gradual increase of the *Pinus halepensis Mill* is followed by a parallel decrease of all other cover types. It would be of interest to monitor the evolution of the trend in the future.

Average values for the resilience factor R was calculated for the two cases of recurring wildfires from Landsat images for years 1984,1987,1990, 1999, 2002 and 2005. In figure 5 the plot of the average R values as a function of the number of years after a fire, is presented:

Figure5 : Resilience trends after recurrent wildfires



In the case of a 15-year time interval between the two fires (red line), the resilience recovery rate after the second fire is smaller than the respective rate after the first fire. This can be attributed to the limited regeneration capability of the Pinus *halepensis Mill.* This observation was also pointed out by Kazanis and Arianoutsou (2004) in their study concerning the effects of recurring wildfires following a floristic approach in the same region. Diaz-Delgado et al (2002) presented similar results for recurring wildfires occurring at a time interval of 11 years in their study which was based on the analysis of satellite observations.

In the second case (blue line), recurrent wildfires had occurred at a time interval of 19 years and reforestation was implemented during the first 6 years after the second fire. For the period 1-6 years after the second fire (in which the reforestation activities took place), a resilience rate value of 13% is observed. This value is higher than the respective rate (7%) after the first fire. For the period 6-12 years after the second fire, a similar rate is not evident. As a consequence, the overall resilience (0.81) 12 years after the second fire is lower then the respective value (0.91) after the first fire. Although a higher overall resilience rate would be expected after the second fire, due to the contribution of the reforestation activities, such a behavior is not confirmed. This lag in the resilience values could be possibly attributed to other factors such as the deterioration of the soil quality and to soil erosion effects.

4. CONCLUSION

Wildfires occurring for the first time on the ecosystem under examination did not lead to severe changes on the vegetation composition. Moreover, the ecosystem's resilience rate, concerning the total aboveground biomass extent, was found to be rather fast in the studied areas.

The re-occurrence of wildfires at time-intervals of fifteen and nineteen years induced severe changes on the vegetation composition causing the dominance of the lower-level forms (phrygana) and leading the ecosystem on the verge of desertification.

The enforcement of the restoration process by reforestation practices, nineteen years after the first occurrence of wildfires, contributed to the fast enrichment with vegetation types of higher evolutionary levels (*Pinus halepensis Mill*) as well as to overall enforcement of the ecosystem resilience, during the first years of the reforestation implementation.

The presence of phrygana in certain zones, that were burnt twice (in years 1985 and 2000) makes the implementation of reforestation practices necessary.

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