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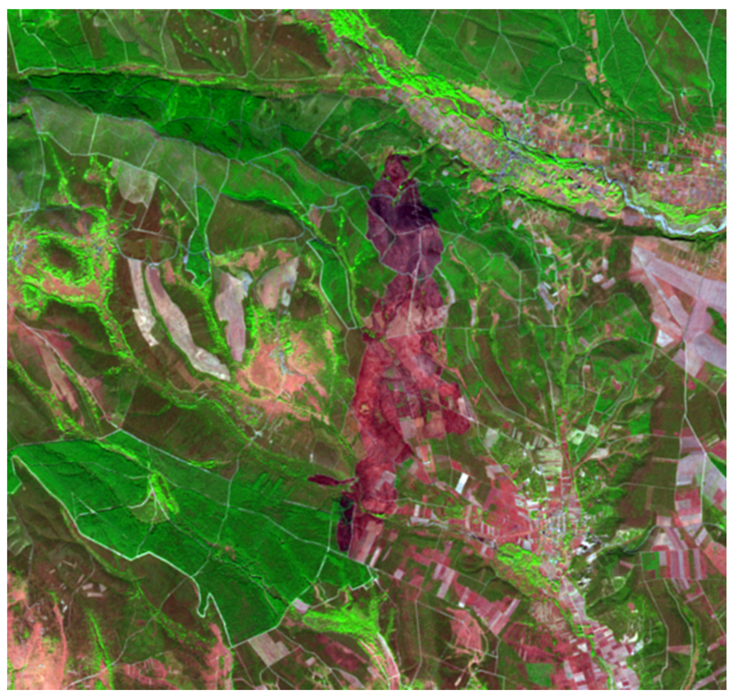
Advances in Remote Sensing and GIS applications in Forest Fire Management

From local to global assessments

Jesus San-Miguel Ayanz, Ioannis Gitas, Andrea Camia, Sandra Oliveira
Editors



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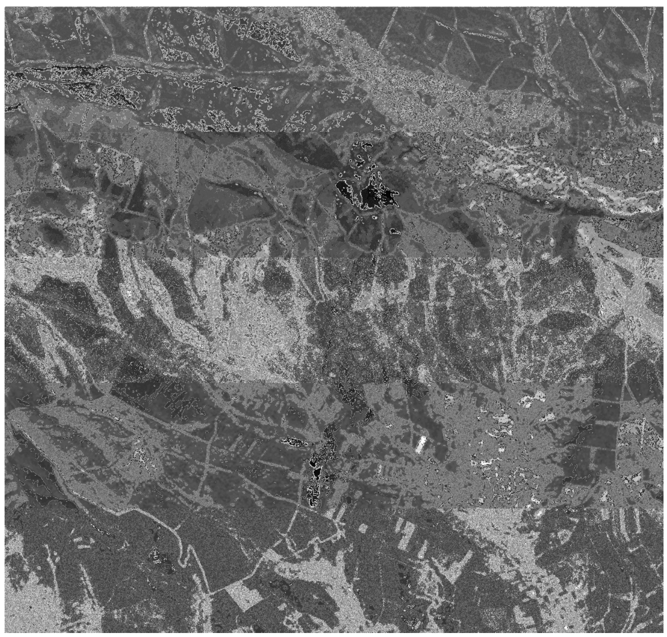

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COMPARATIVE EVALUATION OF RESTORATION PRACTICES APPLIED TO MEDITERRANEAN FOREST ECOSYSTEMS USING REMOTE SENSING AND GIS: NATURAL REGENERATION VERSUS REFORESTATION

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Abstract

The evaluation of the restoration practices applied to burnt Mediterranean forest ecosystems is an essential element of any restoration project and it refers both to the restoration by natural regeneration and by artificial reforestation as well.

The objective of the research was to study the forest post-fire dynamics for the two restoration practices under various fire regimes as regards the frequency of fire breakouts. This work was carried out in Pendeli mountain (Attica, Greece) that has been repeatedly burnt by fires. In-situ measurements were performed in 2008 in one hundred and three burnt surfaces which were identified in the territory. In each surface, all kind of plants (physical regeneration-artificial reforestation) as well as incremental data were measured and were subsequently used for the determination of the total aboveground biomass using suitable allometric equations. The analysis was based on appropriate satellite time-series of a modified Normalized Difference Vegetation Index retrieved from SPOT series satellites which were used for the determination of the forest recovery empirical model.

The results concluded that reforestation performed on surfaces that were burnt once in the year 1995 was comparable to natural regeneration. In fact, ten years after the fire, it was superior in terms of total biomass. The reforestation made after the year 1995 in areas that were burnt also in 1982, was superior than the corresponding natural regeneration. Those findings were confirmed by the assessment of the degree of natural regeneration of Pinus halepensis Mill in each surface and the measurement of the average value of biomass for year 2008.

Keywords: Restoration, Natural regeneration, Reforestation, Evaluation, SPOT

Introduction

Restoration of burned Mediterranean forest ecosystems with natural regeneration is ensured after a single incident (Trabaud 1982, Daskalakou 1996, Thanos et al. 1996). On the other hand, recurrent wildfires significantly impede or even eliminate the natural regeneration process of those ecosystems. As pointed out in the relevant literature, natural regeneration of *Pinus halepensis Mill* is not possible in the case of multiple fires occurring within a short period of time. For this reason, artificial reforestation is extensively adopted for restoration in Greece and other Mediterranean counties as well. (Christakopoulos et al. 2007).

The evaluation of the restoration practices is an essential element of any restoration project applied to burnt Mediterranean forest ecosystem and it refers both to the restoration by natural regeneration and by artificial reforestation. Benchmarking of the two practices may lead to useful findings, regarding restoration success. Towards this direction, the above-ground biomass is considered as one of the essential ecological indicators of restoration success (Aronson et al. 1993). In the literature, various biomass estimation methods based on allometric equations are found (Blanco and Navarro 2003, Christakopoulos 2010). Alternatively, the assessment of the restoration success can be based on remote sensing indicators, such as the Normalized Difference Vegetation Index (NDVI) (Diaz-Delgado et al. 2002, Gouveia et al. 2010), the SWIR/NIR index (Vogelmann et al. 2009), pRI(Lhermitte et al. 2010), Green Vegetation Cover (Röder et al. 2007) and other indices derived from data acquired by existing sensors (e.g. LANDSAT TM and ETM+, ASTER, IKONOS, SPOT). In general, NDVI exhibits a strong relationship with a number of vegetation characteristics, notably green leaf area index (LAI), green biomass, and fractional absorbed photosynthetically active radiation, FPAR. In particular, and because of its general response to levels of green biomass irrespective of plant species, it has been used to quantify the total vegetation cover. It corresponds well to the levels of the total above-ground biomass, especially during the first stages of post-fire restoration before reaching its saturation level (Anderson et al. 1993).

This paper focuses on the evaluation of restoration success of a burnt forest ecosystem in Greece. The proposed research is based on the determination of an empirical restoration model using the post-fire trends as determined by a modified NDVI index derived from a series of high resolution SPOT multispectral images. The specific model is used in conjunction with estimations of the total above-ground biomass, for the comparative evaluation of the two restoration practices namely natural regeneration and artificial reforestation.

Data and methodology

The study took place in the area of mountain Pendeli near Athens, the capital city of Greece (Figure 1). Some parts of the area have been burnt once in 1995 while some other parts have been burnt by recurrent wildfires in 1982 & 1995. The former have been restored mainly by natural regeneration while a small part has been restored by artificial reforestation. The parts of the area burnt twice have been mainly restored with reforestation.

In-situ measurements were performed during 2008 in 103 burned surfaces (control surfaces) identified in the territory. In each surface, the number of plants (natural regeneration-artificial reforestation) as well as incremental data (height, basal diameter, canopy cover) were measured. Using suitable allometric equations suggested by Blanco and Navarro (2003) and Christakopoulos (2010) the total above-ground biomass was estimated in each area.

An extended set of images comprising twenty high resolution images from SPOT series satellites (SPOT 1, 2, 3, 4) covering the years 1986-2008 and corresponding to summer acquisitions was used. Prior to the analysis, all images were corrected for geometric, topographic and atmospheric effects. For each one of the identified control surfaces, the spatially average values of the Normalized Difference Vegetation Index (NDVI) were determined. Those values were normalized by the average NDVI values of some unburned areas identified in the area. This modified NDVI, called Resilience (R), has proven to be insensitive to factors such as moisture, visibility, and temperature variations (Diaz-Delgado et al. 2002).

The analysis of the satellite time-series showed that the post-fire response can be approximated via a logistic or sigmoid curve (Figure 2) expressed in general as $f(x)=a\cdot[(1+b\cdot\exp(-c\cdot x)]^{-1}$. Using the above mentioned curves, four different scenarios were examined in terms of frequency of fire occurrence and the restoration practice applied: a) Fire in year 1995-natural regeneration, b) Fire in year 1995-artificial reforestation, c) Fires in years 1982 and 1995-natural regeneration and d) Fires in years 1982 and 1995- artificial reforestation.

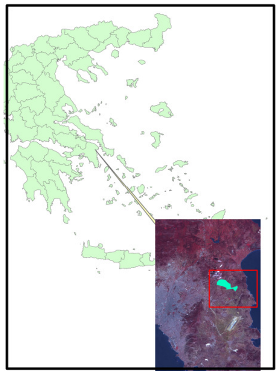

Figure 1. Areas of study in Pendeli mountain

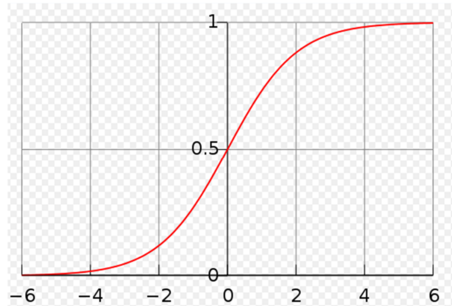

Figure2. The general form of the logistic or sigmoid curve adopted

Results and discussion

Single-fire (1995)

In Figures 3 and 4 the graphs of the temporal evolution of the modified NDVI index (R) (in blue) and its post-fire logistic curves (in red) for natural regeneration and artificial reforestation are shown for the case of a single-fire occurred in 1995. The comparative graph of the post-fire trends is shown in Figure 5 reveals that soon after the fire, the curve of natural regeneration (in blue) is higher than the respective curve of reforestation (in green). This happens because in general, the areas restored with reforestation present low levels of natural regeneration. As it can be inferred from the slope of the two curves, reforestation is growing slightly faster than natural regeneration. As a result, at the tenth year, the two curves cross each other. From this point on though, a decrease of natural regeneration speed is observed. The average above-ground biomass values estimated from the allometric equations for year 2008 as given in Figure 5, are in agreement with the above findings. More precisely, the biomass estimates for reforestation (18.376 ton/Ha) and natural regeneration (17.709 ton/Ha) indicate a higher performance of the former by 4%.

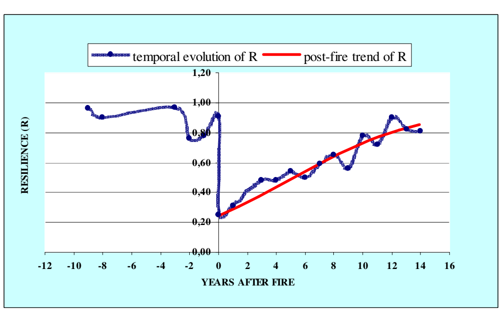

Figure 3. Evolution of R after one fire (1995) and natural regeneration

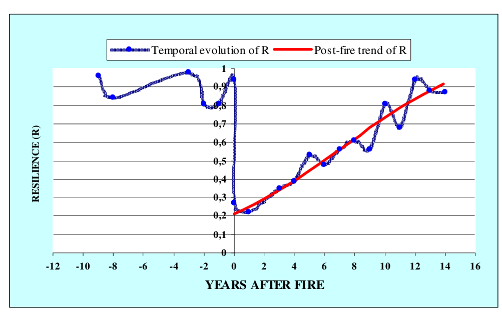

Figure 4. Evolution of R after one fire (1995) and artificial reforestation

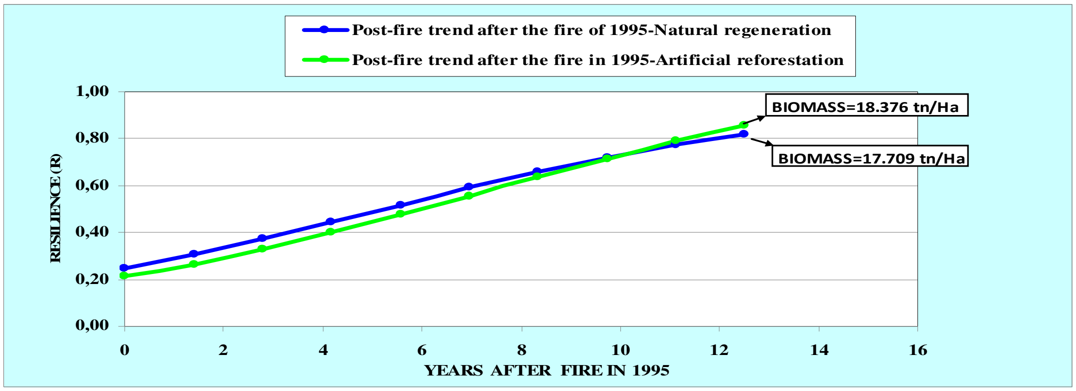

Figure 5. Post-fire trends after one fire in 1995. Natural regeneration versus Reforestation

Recurrent fires (1982, 1995)

Figure 6 depicts the temporal evolution of R as a function of time elapsed from the last fire incident (in 1995) in the case of two recurrent fires, for the two restoration practices.

As it is observed, the reforestation curve (in green) presents higher slope throughout the entire period than the natural regeneration curve (in blue), a fact indicating the higher restoration speed with reforestation. It is characteristic that although the two sample areas present almost identical values immediately after the second fire (R≈0.25) and thus similar initial conditions, the value of R for artificial regeneration is higher by approximately 20% (R≈0.90 and R≈0.75 respectively). The average above-ground biomass values for the areas with natural regeneration and reforestation in the year 2008 are respectively 19.638 ton/Ha and 17.798 ton/Ha, a difference equal to around 10%. According to Christakopoulos (2010), the plant density for natural regeneration of *Pinus halepensis Mill* for the specific case, is moderate (600 plants /Ha) while the relevant density of artificial reforestation is high (about 1400 plants/Ha). Thus, also in the specific case of two recurrent wildfires, artificial reforestation is superior to natural regeneration in terms of total above-ground biomass.

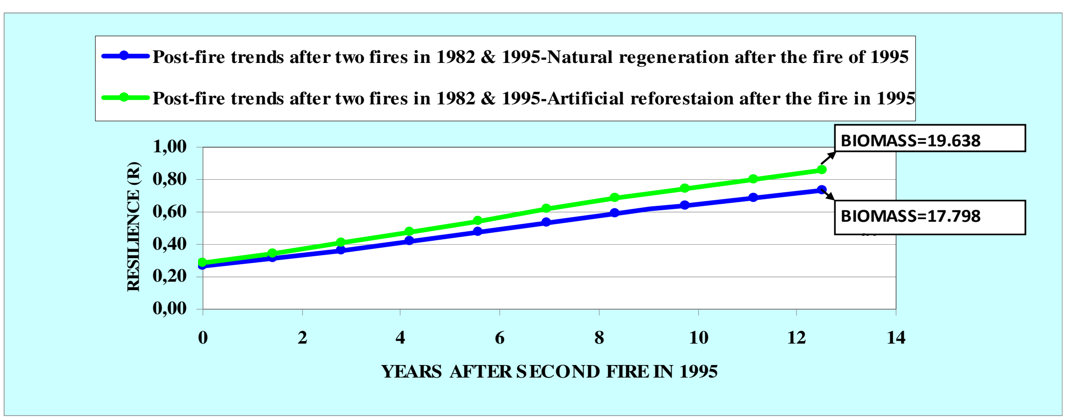

Figure 6. Post-fire trends after the two fires in 1982 and 1995. Natural regeneration versus Reforestation

Conclusion

In the specific work, appropriate sigmoid curves were fitted to the time-series of a Resilience (R) index derived from SPOT high resolution multispectral images to study the post-fire response of a Mediterranean forest ecosystem. The analysis, showed that for the specific cases examined, the post-fire response depends on the restoration practice applied. Reforestation in Pendeli mountain after one incident of fire in 1995 was slightly superior than restoration with natural regeneration while in the case of two fire incidents (in 1982 and 1995), restoration with reforestation was significantly superior to restoration with natural regeneration. The trends identified by the analysis of the satellite time-series were consistent with estimations of the total above-ground biomass made in 2008.

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