Fire severity effects on vegetation recovery after fire. The *Bigues i Riells* wildfire case study.

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INTRODUCTION

Fire effects on plants and soil vary as a consequence of fire intensity and residence time of fire (Pérez and Moreno, 1998). The maximum temperatures reached determine fire intensity and it is thought as one of the most important parameters for fire regime description (Whelan, 1995). Exposure time may be different depending on fuel load and meteorological and topographical conditions (Fahnestock and Hare, 1964). Plant productivity and its biological potential will be of relevance when regeneration takes place after disturbance (Christensen 1993; Grubb, 1977).

Fire severity can be defined as a descriptive term that integrates the physical, chemical and biological changes induced by fire (White *et al.*, 1996). Such a variable, commonly quoted as categorical, can aid to evaluate fire effects on plants after fire. The combination of some parameters, such as fuel humidity or fuel load, with fire intensity and exposure time will determine the final plant damage or the so-called fire severity.

This paper shows a local case study of interactions between fire severity and plant regeneration after fire. For that purpose a categorical map of plant damage, carried out on the field, was employed together with a time series of satellite images in order to monitor every different fire severity category along time before and after a wildfire occurred in July 1994 close to Barcelona (NE of Spain).

MATERIAL AND METHODS

The field fire severity map was carried out between January and March of 1995. Severity categories were based on interpretation criteria that were established on the field by observation according to the fire intensity model developed by Moreno and Oechel (1989). This model considers the remaining number of fine branches on woody plants after fire. Such severity categories intend to include the whole damage variability found on the burned area. A total amount of seven fire severity categories was finally distinguished and assigned, in addition to the unburned area:

1. Ground fire
2. Canopy partially green (green leaves)
3. Burned trees with remaining burned leaves
4. Burned trees with fine branches across the whole trunk
5. Burned trees with fine branches only on top of the trunk
6. Burned trees without fine branches
7. Burned trees that only keep the trunk

Every class was recognised through extensive sampling on the field by distinguishing uniform and homogeneous patches. Once visually delimited, each patch was drawn on a 1:5000 topographical map built from a flight in 1986 by the *Institut Cartogràfic de Catalunya* (ICC). A total amount of 12 sheets were used in this phase of the fire severity mapping.

In addition to a temporal series of Landsat MSS images (spatial resolution 59 x 79 m) from 1975 until 1993, we also used 9 images from Landsat TM (spatial resolution 30 x 30 m) covering the 1994-1997 period. Dates of selected images were the following: 05/05/1994 (60 days before fire), 17/07/1994 (13 days after fire), 01/05/1995 (301 days after fire), 24/05/1995 (324 days after fire), 03/05/1996 (669 days after fire), 20/06/1996 (717 days after fire), 23/08/1996 (781 days after fire), 11/04/1997 (1012 days after fire) and 11/09/1997 (1165 days after fire).

From the MSS scenes, 10 were finally selected to be analysed, the oldest image being captured on 4/04/1991 (1180 days before the fire). These images were used in order to recognise the pre-fire phenological variations for a time span similar to the post-fire one. In this case, MSS scenes were resampled to 30 m by bicubic interpolation. For every image and damage category, the NDVI (Normalised Difference Vegetation Index) was calculated. Near infrared and red bands (3 and 4 for TM: 0.63-0.69 μm and 0.76-0.90 μm respectively; 5 and 6 for MSS: 0.6-0.7 μm and 0.7-0.8 μm respectively) were selected to calculate the NDVI.

All the images were radiometric and geometrically corrected using the Palà and Pons (1995) and Pons and Solé-Sugrañes (1994) models respectively.

Additionally, a Digital Terrain Model and a Digital Climatic Atlas were employed to check the relevance of topography and climate on plant recovery as well as on fire severity. Similarly, to analyse interactions with forestry parameters, forest inventory data was extracted for plots located inside the burned area and sampled before fire.

RESULTS

A visual analysis enabled to validate the use of satellite images in spectral discrimination of fire severity classes established from the fire severity field map. The spectral variables considered were so-called *damage* (subtraction of NDVI values of the selected area between the image acquired immediately after fire and the one obtained immediately before fire) and *recovery* (subtraction of the sum of all the NDVI pre-fire values and the sum of all the post-fire values).

Fire severity and regeneration: main trend of the whole burned area

Main trend of regeneration indicated a good recovery 3 years after fire, although pre-fire NDVI levels have not been attained. A good relationship was found between severity classes on the terrain and *damage* variable. Nevertheless, *recovery* variable was not so well related to these severity classes, indicating the possible interactions with other parameters.

Severity and regeneration by dominant species

Communities dominated by *Pinus nigra* showed the highest fire severity class and the worst post-fire regeneration. We also found a significant relationship between *recovery* and *damage* when analyzed by dominant species or land cover.

Forest parameters

Only the amount of litterfall ($t \cdot ha^{-1}$) was positively correlated with *damage* (forward stepwise regression summary: $r^2 = 0.22$, $p < 0.17$, $n = 34$, $\beta = 0.41$, $p_\beta = 0.04$).

Concerning the regeneration, variable *recovery* was negatively correlated to the basal area ($m^2 \cdot ha^{-1}$) and positively to the total wood production amount ($m^3 \cdot ha^{-1} \cdot year^{-1}$) (forward stepwise regression summary: $r^2 = 0.30$, $n = 34$; $p = 0.06$, $\beta = -1.52$, $p_\beta = 0.01$ and $\beta = 0.86$, $p_\beta = 0.03$, respectively).

Climate and topography

Spatial overlay between climate, topography, dominant species or cover and severity categories produced an amount of 8942 plots composed by one or more pixels.

Annual mean rainfall and altitude were negatively correlated to *damage* while slope was positively related (forward stepwise regression summary: $r^2 = 0.04$, $p < 0.001$, $n = 8942$; rainfall, $\beta = -0.19$, $p < 0.001$; altitude, $\beta = -0.03$, $p < 0.002$; slope, $\beta = 0.28$, $p < 0.006$).

Recovery was negatively correlated to rainfall and altitude (forward stepwise regression summary: $r^2 = 0.13$, $p < 0.001$, $n = 8942$; rainfall, $\beta = -0.34$, $p < 0.001$; altitude, $\beta = -0.10$, $p < 0.001$). Results show once again the significant, although weak, relationship between *damage* and *recovery* ($r^2 = 0.34$, $p < 0.001$, $n = 8942$). Such interaction is also present when analyzed for each dominant species or for land cover.

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