# Do fire severity effects on soil change in space and time in the short term? What ash tells us


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## Introduction

Fire severity is an indirect measurement of fire effect on the ecosystem. In absence of real data, difficult to be collected during wildfires, indirect estimations are frequently carried out, as soil organic matter content, soil hydrophobicity, minimum branch diameter, crown scorch, fine fuel combustion, among others [1]. Ash colour is a current method to estimate fire severity. The degree of combustion change ash physical and chemical properties. These changes are an indirect effect of the temperatures reached, which depends also of the plant specie and ecosystem affected [2].

Ash is highly mobile, especially in the immediate period after a fire when can be wind (re)distribute uncountable times in a complex manner, especially in severe wildland fires, where ash is easily transportable due to the intense combustion [3]. Only after the first rainfalls ash can bind onto soil surface, infiltrate or erode. The ash mobility can be a problem to assess the fire severity, since the ash analyzed in an area could be not produced in the same place. However, it is also an opportunity to study the impacts of fire severity (different ash characteristics) on soil cover and understand that the same ash particulate can have implications in different parts of the soil profile and surface. From this point of view fire severity can change in space and time.

The objective of this work is to study the ash colour changes in an experimental plot in the immediate period after a fire.

## Methods

*Study area and sampling*

A wildfire occurred in July 26 of 2010 and affected an area of 100 ha near the urban area of Quinta do Conde, located at 38° 57' N, 09° 05' W and 115 m of altitude (Fiigue1). The geological substrate was composed by Plio-Pleistocene low cementation dunes, and the soils are classified as Podzols [4]. The mean annual temperature is 14.8 ºC and the annual precipitation of 639.2 mm. The burned forest was mainly composed by Pinus pinaster trees. One day and fifteen days after the fire, ash colour was observed visually in four parallel transects with 20 m separated by one meter in a south faced uniform slope with an angle of inclination of 17%. In each transect, ash colour were observed with a resolution of 50 cm. A total of 200 samples were collected per sampling period. This qualitative assessment, do not allow to quantify the degree of fire severity observed in each point. Thus, fire severity was (re)classified. A previous study by Pereira [2] showed that ash produced at low severity has a reddish colour (R), at medium severity, black (B) and dark grey (DG) colour, and at high severity light gray (LG) and white color (W). Also, after high severity fires patches of bare soil (BS) were found, due the high combustion temperatures that consume all the litter. In the present case this is true because in the contiguous area not affected by the fire, continuous thick accumulations of litter were identified. The ash identified was B, DG, LG and W. Some areas were bare. To quantify fire severity effects on soil cover, some indexes were applied, 1 to B, 3 to DG, 5 to LG, 7 to W and 9 to BS (no protection).

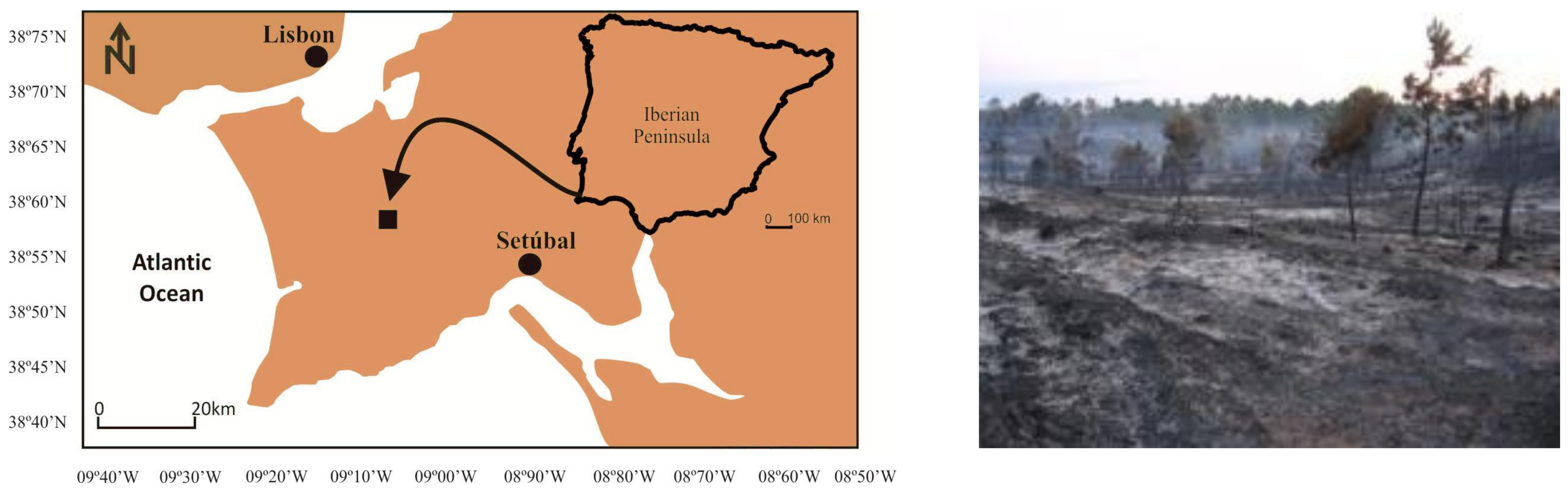


**Figure 1**. Study area.

*Statistical analysis spatial analysis*

Some descriptive analysis were performed, mean (m), Standard deviation (SD) Coefficient of variation (CV%), Skewness (Skew) and Kurtosis (Kur). Differences between sampling periods were observed with the non-parametric Wilcoxon Matched Pairs Test. Spatial autocorrelation of fire severity in each period was assessed with Global Moran's *I* that it is similar to the Pearson correlation coefficient. The index values fall between -1 and +1. Negative correlations shown that, data was spatially dispersed and positive correlations that data was clustered. This index calculates also the Z-value. A positive Z-value represents that samples are clustered and negative that are dispersed. Lower positive and negative values represent a random pattern. Significant differences were considered at a $p<0.05$.

Previous to data modelling, data normality and homogeneity of the variances were tested. Several data transformations were considered, as neperian logarithm, box-cox and square root. However, none of them was able to normalize data. In this case, non-transformed data was always more close of the normality and homogeneity of the variances were higher than the transformed, in all the methods. Thus for semi-variogram modeling and data interpolation we used non transformed data. In order to observe the spatial dependence of the fire severity index it was calculated the nugget/sill ratio. If the ratio is less than 25%, the variable has strong spatial dependence, between 25% and 75%, the variable has moderate spatial dependence, and greater than 75%, the variable shows only weak spatial dependence [5]. In this work data was interpolated with the ordinary kriging method. Statistical analyses were carried out with Statistica 7.0 and interpolation with Surfer 9.0.

## Main results and conclussions

- Immediately after the fire the majority of the ash identified was LG and a great part of the plot was uncovered, showing that fire had a high severity (Fig 2A). Fifteen days after the fire the area with BS increased, as the mean fire severity index (6.05 to 6.45), showing that during this period, wind had (re)distributed the ash and therefore the fire severity effects and the potential estimation of fire severity through ash colour (no rainfall occurred between the measurement periods). Despite this redistribution, the CV% remains the same and no significant differences between fire severity index were observed (Wilcoxon Matched Pairs Test p=0.084) (Fig 2A and B).
- The Global Moran's I shown that one day after the fire the spatial autocorrelation was 0.13 and not significant at a p<0.05, indicating that fire severity had a random distribution. Fifteen days after the fire the spatial correlation was 0.35, and significant at a p<0.05, that represents an important modification of the spatial distribution and fire severity (Table 1). The Z-score also increases importantly, confirming the previous hypothesis. These results highlight to the necessity of spatial statistical analysis that detect changes, not identified by traditional statistical analysis (paired comparison tests and CV%) as it will be observed in semi-variogram parameters in the Table 2.
- One day after the fire the best-fitted model was the Exponential and a Nug/sill ratio of 76.46% that represents a weak spatial dependency and a random distribution. Fifteen days after the fire, the best-fitted model was the Gaussian and the Nug/sill ratio was 44.40% showing a moderate spatial dependency and a lower spatial variability of fire severity. The coefficient of determination (R2) was also higher fifteen days after the fire were higher fifteen days after the fire, indicating that the spatial correlation was high in the second measurement, as observed previously with the Global Moran I index.
- The nugget effect represents the error of the variance that can be attributed to the small scale variance, outliers or reduced number of samples. In this study, the number of samples was representative of the studied area, the outliers were not possible to minimize (even after several data transformations) and the small scale variability of fire severity is an intrinsic characteristic of burned areas, where combustion conditions change very quick due different fuel conditions (e.g moisture, type, density, package, connectivity, etc.).
- In this study the outliers were not removed because is of major importance to be analyzed and were attributed to the heterogeneous burning conditions. One day after the fire the small scale variability of fire severity was higher than fifteen days after, as shown the high nugget effect. The reduction of the small scale variability is due the ash (re)distribution and homogenization of areas with a determined severity index. Here, there was an increase of the BS areas, which means that soil became unprotected in some patches across the plot. In other areas ash was deposited by the wind as it is represented in the figure 3A and B.
- One day after the fire the small scale variability of fire severity was observed in some areas of the northwest, central and south of the plot. There is no spatial pattern and the map of fire severity confirms the previous spatial autocorrelation and semi-variogram analyzes. Fifteen days after the fire it is observed that fire severity effects on soil cover is more "patched". In some areas at south and north, ash was removed and in others accumulated as in southeast and in the central-north part of the plot (Figure 3A and B).
- However, this ash mobility is very complex to evaluate and in this stage further studies are needed to have better understanding of ash dynamic after the fire. In ash studies there are many uncertainties that further studies need to be focused. One of the most important is the fact that after the fire, wind and water can mix ash produced at different severities, producing ash with a new colour and different severity from the previous ones. This can be a source of error in this work that has to be accurate in the future. New methodologies are being developed to have a better picture of ash mobility.

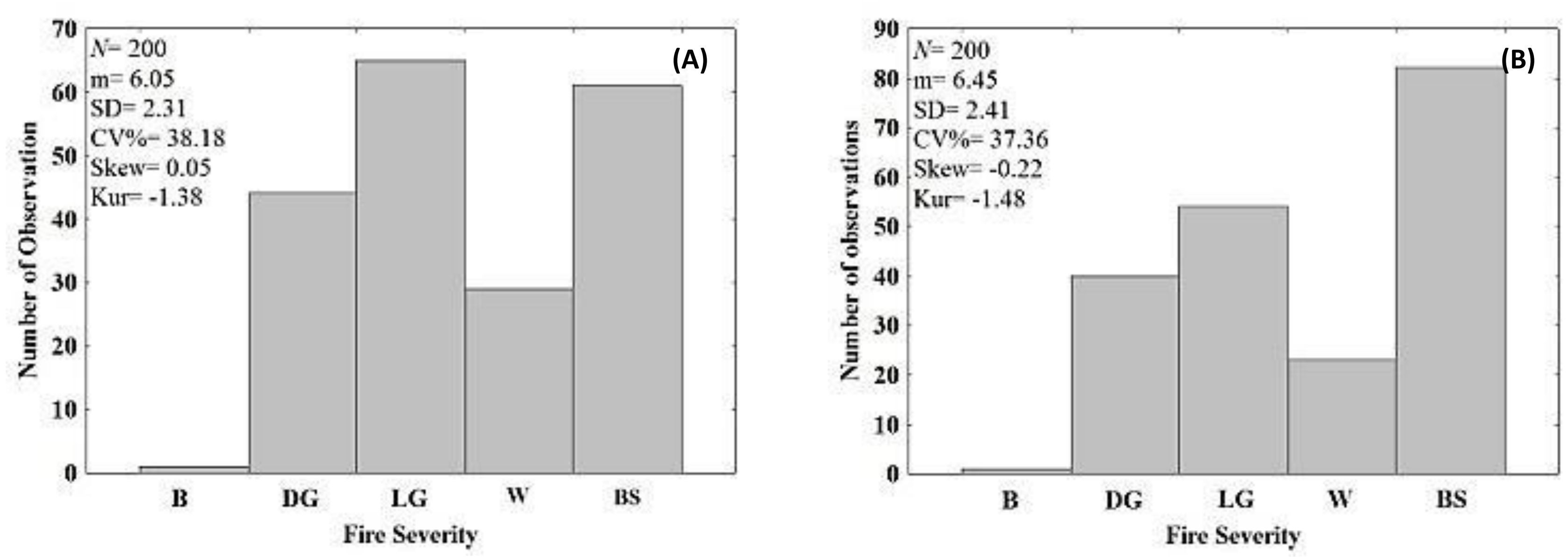


**Figure 2.** Distribution of ash color a) one day after the fire b) fifteen days after the fire

**Table 1.** Results of Global Moran's *I* spatial autocorrelation test.

| | One day after | Fifteen days after |
|---|---|---|
| **Moran's Index:** | 0.13 | 0.35 |
| **z-score:** | 1.92 | 5.03 |
| **p-value:** | 0.06 | 0.0001 |

**Table 2.** Best fitted semi-variogram models of fire severity and corresponding parameters.

| Day | Model | Nugget effect | Partial sill | Sill | Nug/sill ratio (%) | Range (cm) | $R^2$ |
|---|---|---|---|---|---|---|---|
| **1 day** | Exponential | 4.45 | 1.15 | 5.60 | 79.46 | 100 | 0.52 |
| **15 days** | Gaussian | 2.66 | 3.33 | 5.99 | 44.40 | 160 | 0.71 |

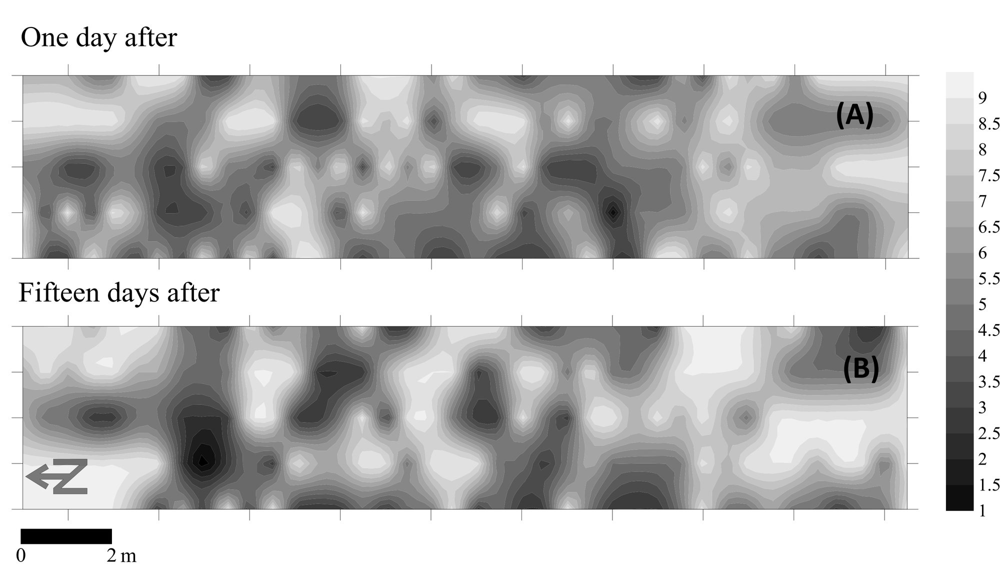


**Figure 3.** Distribution of ash colour a) one day after the fire b) fifteen days after the fire

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