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CHARACTERIZATION OF BIOPHYSICAL VARIABLES IN FOREST FIRES OVER 25 HA IN PENINSULAR SPAIN (1991-2005)

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The incidence of forest fires is influenced by several variables of physical and human environment, which determine the probability of ignition and/or propagation of fire. These variables may be grouped into four broad categories: weather conditions, type and condition of vegetation, topographic variables and human activities (Salas y Chuvieco, 1994).

Considering the physical environment, the extent of burned area is favoured by the conditions of natural factors such as fuel availability, temperature, precipitation, wind and slope. In this paper our purpose is to describe the burned area in relation to some of the biophysical variables. The main objective is the analysis of the distribution of some of these variables in the burned area in peninsular Spain during the period 1991-2005 to determine possible patterns of this phenomenon.

The mapped burned area utilized in this work is a resulting product of visual analysis of both Landsat and SPOT mosaics (1991-1995, 1995-1999, 1999-2000 and 2000-2005). The mapped burned area dataset of forest fires over 25 ha of Peninsular Spain in the period 1991-2005 called BDAQ. The total amount of burned area mapped was about 1.004.502 ha, of which 850168 ha is located within forest area (84.6%) (Verdú y Salas, 2010). The accuracy of this product was validated with data from the National Database of Forest Fires (BDIF) of the General Directorate of Biodiversity, with an agreement close to 73%.

For the selection of biophysical variables descriptive and/or explanatory of forest fires it has been considered all the available variables related to the ignition and/or propagation. These variables are grouped into three main factors: climate, topography and vegetation (fuel).

The climatic variables were obtained from the Climatic Atlas of the Iberian Peninsula (Ninyerola *et al*., 2005) with a spatial resolution of 200 m. The selected variables related to forest fires were winter precipitation and summer highest temperature. The topographic variables were generated from digital terrain model 1:25.000 from the National Geographic Institute. This is a model with a grid size of 25 meters. The selected variables related to forest fires were elevation and slope. The land use was included from the Corine Land Cover maps for the years 1990 and 2000 (Natlan, 2005). These maps have been simplified into 11 thematic classes through reclassification of the original categories: artificial surfaces, non-irrigated areas, other cultivated areas, agro-forestry areas, broad-leaved forest, coniferous, mixed forest, shrubland, pasture, sparsely vegetated areas, and other uses. The vegetation series map of Rivas-Martínez (1987) was also included, which summarizes the characteristics of climate and potential vegetation of Spain. The vegetation series map divided the Iberian Peninsula into two biogeographic regions, the Mediterranean and Eurosiberian.

This work focused on cross-tabulation of forest fire map with the biophysical variables, to obtain the distribution of these variables in the burned area, determining the most common combinations and identifying possible patterns. First, a cross-tabulation of the map of forest fires with each of the selected variables, classified by quintiles the quantitative variables and by categories the qualitative ones, was carried out. This information was compared to those variables distribution over the whole territory using the same quintiles. It has also been used the chi-square statistic (χ^2) to check whether the distribution of the burned area in the various categories of the explanatory variables differed from the distribution of these categories in the whole country, i.e. if observed burned area behaved as expected.

Second, a combined cross-tabulation was performed by a combination of winter precipitation and summer highest temperature with each forest land cover category. Temperature and precipitation determine the spatial distribution of plant formations. These variables, along with the duration of the dry season, are used for the classification of Mediterranean forests developed by the FAO (M'hirit, 1999). In addition, temperature and precipitation affect the availability and flammability of fuels in the ecosystem. The vegetation at a given location is governed by the availability of moisture, which is a function of precipitation (through its effect on water supply) and temperature (through its effect on water evaporation) so that the spatial distribution of vegetation and fire occurrence is closely linked with these variables (Westerling, 2008). By using these combined cross-tabulations the burned area percentage was extracted related to each category as a function of the combination of temperature and precipitation (it was used the same quintiles as for simple cross-tabulation). This information was then compared to those categories distribution for the whole territory.

Considering the set of quantitative variables, the burned area occurred mainly in areas with high summer temperatures between 25.8 and 30.1 degrees C (54%), winter precipitation between 52 and 413 mm (62%) in areas between 336 and 774 m in elevation (62%), and slopes above 7º (67%). Of these 4 variables, only summer temperature and the slope obtained a statistical value of χ^2 above the critical value, which meant that the distribution of burned area in the ranges used was significantly different from the expected distribution (area susceptible to burn) and, therefore, clearly related to the incidence of forest fires. Although the relationship was not statistically significant with the used quintiles, winter precipitation showed a clear negative relationship with the burned area (Spearman: -0.66). In the case of elevation, the quintiles used did not show either a clear relationship between this variable and the area burned, which could probably be obtained from elevation ranges associated with land use.

Taking into account the categorical variables, the burned area was mainly found in shrubland and coniferous areas (67%) of the supra and mesomediterranean region (53.1%).

Of these two variables, only land cover obtained a χ^2 value above the critical value, a sign that showed that the same distribution was significantly different from the expected distribution. The ecozones showed no significant relationships with the burned area. However, it seemed to show a slight difference between the cold and humid regions (coline, montane and supramediterranean), with lower proportions of burned area than these regions represented for the whole territory, and warmer and drier regions (thermo and mesomediterranean), where the proportion of burned area is higher than that of the entire territory.

Given the combination of climatic variables and land use categories, there was, in general, a greater proportion of burned area in the different formations in areas with higher temperature and less precipitation, although adding a rider depending on the category. The temperature appeared as a more determining factor than precipitation, with a greater proportion of broad-leaved forest, mixed forest and grasslands in areas of lower temperature, while the shrubland and coniferous were found in areas with higher values. This finding suggested that any increases in temperature could cause increases in burned area, as some authors proposed (Piñol *et al*., 1998).

The three main land use covers that better respond to this pattern were the coniferous, shrubland, and sparsely vegetated areas. In all three cases was clearly an increase in the proportion of burned area with respect to the proportion which held in those areas of higher temperature, while decreased for lower temperatures. In the case of coniferous, the proportion of burned area also showed an increase in areas of high temperatures and when rainfall was lower as winter precipitation act as a regulator of soil moisture and was therefore a driver of growth of these formations (Swetnam y Betancourt, 1998) that impacted on how the conifers flammability would be in the fire season (Van Wagner, 1983). In the case of shrubland, the trend with respect to precipitation was reversed since a higher proportion of burned area was located in areas with higher precipitation values. This trend was related to the increased fuel load available at the fire season when winter precipitation was higher, which facilitated the spread and, therefore, the extent of the fire, confirming what other authors have found in Portugal (Viegas, 1994) and in the Western U.S. (Westerling, 2008). The sparsely vegetated areas also exhibited this behaviour, although to a lesser extent. It should be noted that these three formations were the most important in terms of occurrence of forest fires, accounting for 68.5% of the burned area, compared to 31.3% of the total.

The remaining four land covers (broad-leaved forest, mixed forest, agro-forestry areas and pastures), regarding the climatic variables, did not show significant differences between the distribution of burned area and the distribution for the category as a whole. Moreover, it should be noted that these formations were not the most important in relation to the occurrence of forest fires, accounting for just 17.5% of the burned area, compared to 22% of the total.

In conclusion, our findings showed the degree of relationship between the selected biophysical variables and the area burned in peninsular Spain during the period 1991-2005, noting those relationships which were statistically significant. According to the results, land use, summer highest temperatures, and the slope were the biophysical variables more related to the burned area (1991-2005). The most influential categories of land use in the forest fires in the study area were shrubland and coniferous, which were most affected by this phenomenon.

The results suggested that the proportion of burned area increased with increasing temperature, especially in the shrubland and coniferous, while precipitation had a different behaviour depending on vegetation type, with a direct relationship to coniferous (lower content humidity) and inversely related to shrubland (heavier fuel load).

The proposed techniques are shown useful for the characterization of various biophysical variables in forest fires over 25 ha that have occurred in Peninsular Spain between 1991 and 2005. The results may help in determining the area susceptible to burn in a region, under certain assumptions. In addition, the results improved our knowledge of the spatial distribution of forest fires. Having all the input variables spatialized for the whole territory, its implementation is simple and, therefore, operational. Its effectiveness depends on the update of the variables and the change of spatial patterns over time. The use of information obtained by these analytical techniques can be used in defence/prevention planning against forest fires and, to some extent, can determine the influence of these variables in the development of this phenomenon.

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