GEOSTATISTOCAL AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) APPLIED TO SPATIAL DISTRIBUTION OF WILDFIRES IN PORTUGAL AND IN PORTUGUESE NATURA 2000 AREAS

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Abstract. *Fire it is a natural element of the ecosystems, but with social and economical negative impacts. To analyse fire impacts on the landscape, Geostatistical and Geographic Information Systems (GIS) techniques are often used. In this work we aim to identify with the mentioned tools, the spatial correlation and pattern of fire occurrences in Portugal and in Natura 2000 areas during the years of 2010 and 2011. The results showed that the number of fires was high in 2011, but the burned area was high in 2010. The spatial correlation and pattern were different and in 2010, the fires were more concentrated in the northwest part of Portugal, meanwhile in 2011, were majority observed in the north and more distributed across the territory. During the studied years, fire affected especially the Nature 2000 areas located in the north of Portugal. In the global context, the number of fires and burned area were not significant in Natura 2000 areas. However, in the surroundings of these areas, there is a high fire activity, that if carried out during the summer season and criminally, can represent a serious threat to nature management and conservation.*

Keywords: *Fire, Ecosystems, Geostatistical, Geographic Information Sytems (GIS), Natura 2000, Portugal.*

INTRODUCTION

Fire is considered global phenomena with important implications on the ecosystems. It is a natural element of the ecosystem and with exception to polar environments, shaped the biomes as we know it today (Bond and Keeley, 2005; Pereira et al., 2010a). Fires are important to worldwide ecosystems, but socially and economically unwanted (Pereira et al., 2012a). However, nowadays it is regarded not as an important ecological dilemma, but an economical and social problem, due the important impacts on human goods. Recently, there is an increase of wildfire occurrence that it is attributed to land use change (e.g rural abandonment) and climate change (Mataix-Solera and Cerdà, 2009). The rural abandonment increased the quantity of fuel in the countryside areas increasing their vulnerability to wildfire occurrence and impacts. In addition, fire suppression policies, gives an additional contribution to this vulnerability (Pereira et al., 2012a). The recent climate change is increasing the intensity and frequency of warm and dry summers (Flannigan et al., 2005; Lavorel et al., 2006). This creates the favourable conditions for the occurrence of tremendous destructive wildfires.

Nature 2000 protected areas management and conservation are one of the priorities of European Union policies (Pereira and Braga, 2009; Pereira et al., 2012a) and much efforts are being done to integrate ecological, economical and social in Nature 2000 areas development (Janssen, 2004; European Commission, 2010). Nature 2000 areas are based in the idea of integration of local communities in territorial planning (Pereira et al., 2012a). Among other questions, the use of fire to landscape management is matter of conflict because land-use planners do not understand the role of fire in the nature as local communities understand it. For these reason at national level, in numerous countries the legislation forbids the use of fire by farmers, creating conflicts and leading to use of fire illegally, often in unsecure conditions, foremost numerous times to uncontrolled wildfires. Previous to be protected areas, many of the ecosystems existent were shaped by fire. These fire suppression policies can change ecosystems functions and sustainability (Shaffer, 2010; White et al., 2011; Pereira et al., 2012a). Recently some efforts are being carried out to return fire to Nature 2000 areas, for landscape restoration, with positive impacts to the ecosystems (Goldammer and Montiel, 2010; Pan Parks, 2011; Pereira et al., 2012b). Natura 2000 areas are frequently visited by summer wildfires, at the same rate of other non protected areas. This induces important social and economical problems in rural communities that depend on agriculture and forests to survive (Rego et al., 2010; Pereira et al., 2012a). This increase is due the reasons above mentioned.

Geostatistical and Geographic Information Systems (GIS) and spatial analysis are often tools used to identify wildfire risk, management, causes, effects (e.g. severity) on landscape, recurrence, regeneration and forecast (Pew and Larsen, 2001; Romero-Calcerrada et al., 2008; Bhandary and Muller, 2009; Kaval, 2009; Poirazidis et al., 2012; Feltman et al., 2012). The uses of these techniques permit quantify the impacts and spatial correlation of wildfires. Thus are excellent tools that synthesise complex information and make them understandable for decision makers.

In this work the is objective apply Geostatistical and GIS methods to identify a) spatial correlation and spatial structure of burned areas in Portugal, b) number and total of burned area in Nature 2000 areas and c) number and burned area in Nature 2000 contiguous areas.

MATERIALS AND METHODS

The data used in this work was from the wildfires occurred in 2010 and 2011 in Portugal. Natura 200 areas was collected in http://www.eea.europa.eu/themes/biodiversity/document-library/natura-2000/natura-2000-network-statistics/area-calculations-2007-to-2009/gis-area-of-natura-2000-network-1 and the data from 2010 and 2011 wildfires in Portugal from http://www.icnf.pt/cn/ICNPortal/vPT2007/.

Some descriptive statistics were analysed, mean (m), minimum (min), maximum (max), standard deviation (SD), first quartile (1Q), median (M), third quartile (3Q), skewness (Skew) and kurtosis (Kur). Previous to data spatial modelling data normality was tested with the

Kolmogorv-Smirnov test. Since original data did not respect the Gaussian distribution, a neperian logarithmic (ln) transformation was applied to normalize the data. Modelling data without data checking should be avoided and previous data is necessary in order to not produce errors (Lu et al., 2007). The spatial models were carried out using the transformed data. The spatial autocorrelation was carried out with the Moran's *I* index. The index assess if the variable have a dispersed, random or clustered distribution. If the result of this index is lower than -1.65, the distribution is considered dispersed, between -1.65 and 1.65 have a random distribution, and if it is higher than 1.65, the distribution is clustered. It is calculated according the following formula:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \tag{1}$$

Where z_i is the deviation of an attribute for a feature i from its mean), $w_{i,j}$ is the spatial weight between the feature i and j , n is equal to the number of features and S_0 is the aggregate of all spatial weights. It is calculated according the formula:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \tag{2}$$

Moran's *I* index also calculate the Z-score and the p value in order to assess the significance of the index. Z-score is simply based on standard deviations. If Z-score is very high or very low (negative) and with and with small p values, means that the spatial pattern of the variable is significantly dispersed or clustered. The z-score is calculated according the formula:

$$Z_I = \frac{I - E\,[I]}{\sqrt{V\,[I\}}} \tag{3}$$

Where:

$$E[I] = -\frac{1}{n-1} \tag{4}$$

$$V[I] = E[I^2] - E[I]^2 \tag{5}$$

The spatial pattern of the burned area distribution was assessed with the semi-variogram modelling. The semi-variogram describes de variation, its magnitude and spatial scale (Rodgers and Oliver, 2007). It is calculated according the formula:

$$\gamma(\mathbf{h}) = \frac{1}{2M(\boldsymbol{h})} \sum_{i=1}^{M(h)} \{z(x_i) - z\,(x_i + h)\}2 \tag{6}$$

Where $\gamma(\mathbf{h})$ is the sample semivariance at lag h, the lag is the vector in both distance and direction $z(x_i)$ and $z(x_i + \mathbf{h})$ are the values of $z(x)$ at locations x and x + h, respectively, and $M(\boldsymbol{h})$ is the number of pairs of comparisons separated by a lag h for $i = 1, 2, \dots, M(\boldsymbol{h})$. In this paper it was used the semivariograms were modelled using the least squares regression (Goovaerts et al., 2005). Variable dependence was calculated with the Nug/sill ratio. According to Chien et al. (1997), 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. Statistical, Geostatistical and GIS analysis were carried out with Statistica 7.0 and ArcGIS 10 software for windows.

RESULTS AND DISCUSSION

Burned area in Portugal (2010-2011)

During the years of 2010 and 2011 the majority of the fires occurred in the north and central Portugal, where are located the major *Pinus pinaster* and *Eucalyptus globulos* forests area and higher mountains (Fig 1.). These industrial plantations are very flammable and vulnerable to fire occurrence. Once ignited, spread quickly and affect marginal areas (Pereira and Braga, 2009). In total during 2010 were registered 1991 fire occurrences and in 2011, 3005 (Table 1). In 2010 burned a total of 133944.21 ha and in 2011 76030.27 ha. Despite the high number of fires in 2011, the large burned area occurred in 2010. This is reflected in the average area burned, 67.27 ha in 2010 and 25.30 in 2011.

In both years, data were positively skewed, which means that the majority of the fire occurrences burned a small amount of area. The extremely high Kur is evidence that data was very heterogeneous with high

SD (Table 1). High skewed data is not suitable for modelling (Pereira et al. 2010b), thus data was normalized (ln) in order to reduce the differences and minimize the model errors (Table 1).

Fig.1. Burned area in Portugal in 2010 and 2011.

Table 1. Some descriptive statistics of the burned area in Portugal in 2010 and 2011. Data in hectares.

	N	m	min	max	SD	1Q	M	3Q	Skew	Kur
2010	1991	67.27	1	5613.8	330.36	1.43	3.14	21.34	10.95	145.81
2011	3005	25.30	0.0001	2723.8	114.35	0.35	1.691	7.66	11.71	194.73
2010 (ln)	1991	1.86	0	8.63	1.84	0.36	1.14	3.06	1.08	3.35
2011 (ln)	3005	0.46	-6.90	7.90	2.56	-1.06	0.52	2.03	-0.23	3.27

The results of Moran's *I* index showed that in both cases the z-score was higher than 1.65, which means that in both years the burned areas localization occurred in a specific area of Portugal. The *p* value is lower in 2011 than in 2010, and this indicates that fires were more concentrated in the space in 2011. The modelled semivariogram is different in 2010 and 2011, which means that the spatial pattern of burned area is different. In the first year the Gaussian model is the best-fitted in the experimental semi-variogram, meanwhile, in 2011 the exponential model is the most accurate (Fig. 2a and b, Table 2). The fires occurred in 2010, where mainly observed in the northwest area, whereas, in 2011 were more frequent in the north area (Fig 1). This can explain the different semi-variogram pattern. The range was higher in 2010 than in 2011 and this shows that the spatial correlation was higher in the 2011 and the spatial dependence less. This can also be observed with the Nug/Sill ratio, 39.23% in 2010 and 68.61 in 2011 respectively. This shows that fires in 2011 were more spread across the territory.

Table 2. Results of Moran's *I* spatial autocorrelation.

	2010	2011
Moran's *I* index	0.031	0.038
Expected index	-0.0005	-0.0003
Variance	0.00008	0.00028
z-score	3.490	2.336
p-value	0.0004	0.019

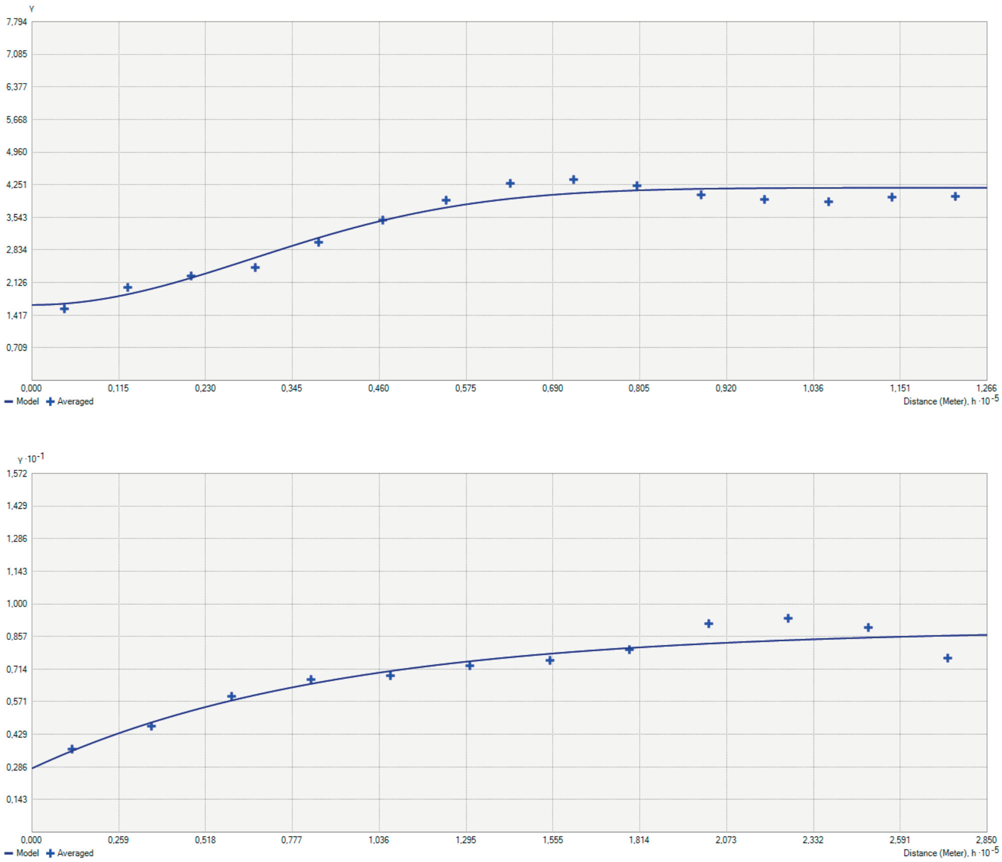

Fig. 2. Experimental semi-variogram for the burned area for a) 2010 and b) 2011.

Table 3. Modelled semi-variogram characteristics for the burned area in Portugal

	Model	Nugget effect	Range (m)	Partial Sill	Nug/Sill
2010	Gaussian	1.640	71.30	2.54	39.23
2011	Exponential	2.79	267.75	6.10	68.61

Fires in nature 2000 areas in Portugal (2010-2011)

In Portugal (Continent + Azores + Madeira + Desert Islands) NATURA 2000 PA covers a terrestrial area of 18.717 km^2, 20.3% of the all territory area. In total (Terrestrial + Marine), Portugal have 138 classified sites, in an area of 20.182 km^2 (Tab. 2). In Portugal Continental there are 99 NATURA 2000 sites, divided in 60 Sites of Community Importance (SCI) and 39 SPA across an area of 1.979.519 ha (20.5%) of all territory and a marine surface of 105.308.5 ha (Pereira and Braga, 2009) (Fig 3a). During the year of 2010 occurred 250 fires that burned a total of 62415.75 ha, whereas in 2011 it was registered 347 fires that burned 24172.60 ha. The majority of these areas affected the Nature 2000 located in the northwest of Portugal (Alvao/Marao, Peneda Geres, Serra da Estrela, Montemuro, Serra da Arada and Serra da Arga).

In 2010 12% and in 2011 11.58% of the fires occurred in Nature 2000 areas. In comparison to the total of burned area, in 2010 4.56% and in 2011 only 1.76% affected Nature 2000 areas. The results shown that in these years fire did not damage substantially Nature 2000 areas (Fig. 3b). The number and burned area in the 5 km buffer area were also assessed and are represented in the figure 3c. In some cases the fires can be the same. In the situation they were removed from the analysis. In this area it were identified in 2010, 677 fire occurrences (34% of the total number of occurrences) and in 2011, 988 (32.61% of the total number of occurrences). The burned area in 2010 was 65716.74 ha (4.79% of total burned area) and in 2012 was of 35439.14 (2.58% of total burned area). This suggests that in the areas surrounding Natura 2000 areas, there are a high number of fire occurrences and burned area that it is related with human activity. These activities and fire, when criminally used, can be a threat to protected areas management and conservation. A great number of fires in the buffer area of protected areas were also observed in other previous studies (Roman-Cuesta and Martinez-Vilalta, 2006; Wittemyer et al., 2008; Palumbo et al. 2010) and it is consider a threat to nature protection, that is attributed to increasing human pressure.

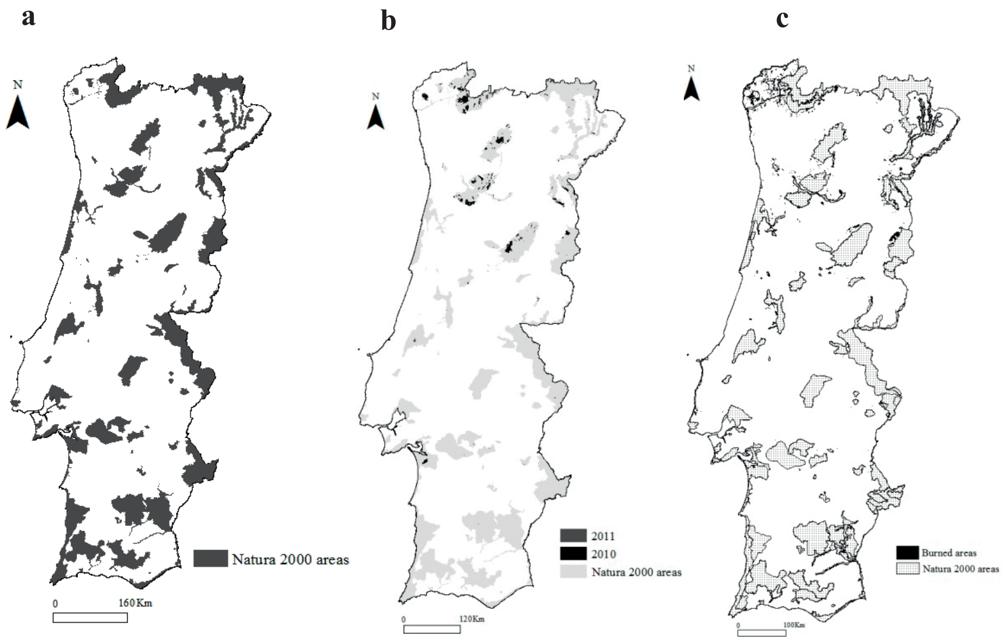

Fig. 3. a) Nature 2000 areas distribution in Portugal, b) burned area in Nature 2000 areas in 2010 and 2011 and c) burned areas in a 5 km perimeter of Natura 2000 areas.

CONCLUSIONS

Geostatistical and GIS techniques are useful to understand spatial patterns of fire occurrences during the years of 2010 and 2011. The number of fires was high in 2011, but the burned area was high in 2010. The spatial patterns observed in both years were different, as identified by the Moran *I* index and semivariogram modelling. During the studied years fire events, were especially observed in the Nature 2000 areas located at centre and north of Portugal. Approximately 10% of the total fires occurred in Natura 2000 areas. Despite of the low % of fire occurrences in the Portuguese Natura 2000 areas, in the buffer areas of these areas, fire activity is increasing, and if are a criminal practice during summer season, should be consider a serious threat to Natura 2000 management and conservation.

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