Spatial Distribution Patterns of Wildfire Ignitions in Portugal

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Abstract

Burnt area in Portugal increased in the last decades, contrarily to other southern European countries. On the other hand, the number of wildfire ignitions is increasing in Portugal, Spain and Greece, but in Portugal its occurrence density is much higher. Since 2000 Portugal registered an average of about 28,500 fire ignitions every year, and this situation causes an important dispersion of detection and fire fighting resources, contributing to reduce their effectiveness. In order to evaluate the distribution of wildfire ignitions, we analyzed 127,492 fires detected in Portugal during the period 2001-2005 in relation to variables such as population density, proximity to urban areas and road network, land cover types, altitude, causes and final burnt area. Results showed that most part of fire ignitions are concentrated in the north and centre littoral areas, in the most populated municipalities, and were intentionally caused. Although municipalities with more than 100 persons per km^2 only represents 21% of the territory, they concentrated more than 70% of fire ignitions occurring in Portugal, but only about 14% of total burnt area. We verified that 85% of fire ignitions occurred at less than 500 m from urban areas and 98% were within a distance of 2 km. Fire ignitions were also located very close to the main roads (70% at less than 500 m, and 98% at less than 2 km). Most ignitions were located in agricultural and social/urban areas (60% and 25%, respectively), and only 15% in forested or uncultivated areas (8.5% and 6.5%, respectively). We verified that about 80% of ignitions occurred at elevations below 500 meters, and that 85% of fire ignitions originated a burnt area lower than 1 ha, and only 0.3% of them originated large wildfires with 500 hectares or more. These results emphasise the crucial role of human distribution and activity in the spatial distribution of wildfire ignitions, and can be very useful in fire risk management and in prevention strategies implementation.

Keywords: forest fires, wildfire ignitions, spatial distribution, fire risk, GIS, Portugal

Introduction

Forest fires have been increasing in Portugal during last two decades and especially last years, being an agent of landscape changes, and important social, environmental and economic impacts. Contrarily to other southern Mediterranean European countries, where in last decades the average burnt area decreased (Spain, Italy and Greece) or stabilized (France), in Portugal the situation got worst (EC 2005, DGRF 2006). Between 1990 and 2005, about 2.3 million hectares burnt (DGRF 2006), representing about 25% of the country area, and in the recent years of 2003 and 2005 the burnt area reached the highest values since 1980 (750,932 ha). Since

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2000 Portugal registered an average of about 28,500 fire ignitions per year (DGRF 2006). Statistics also shows that the number of wildfire ignitions is increasing in Portugal, Spain and Greece (EC 2005), but in Portugal its number per area unit is much higher, having proportionally more ignitions than the other southern European countries all together. Although the registration methods could differ from one country to another, the situation seems to be quite concerning. This increase of fire occurrences in the last decades is registered even if more resources are being allocated to prevention, vigilance and fire fighting, including management plans, public educational campaigns and the implementation of more restrictive legislation concerning human activities and wildfires.

It is known that most fire ignitions in Portugal are associated to human causes. A recent official report from the Forest Services (DGRF 2006) shows that only 3% of the forest fires successfully investigated between 2000 and 2005 were naturally caused (lightings). It also reports that about 49% of the wildfires were intentionally caused, while 37% were due to negligence and 11% were accidentally caused.

Although the high number of wildfire ignitions in Portugal constitutes a problem in terms of fire detection and fire fighting resources dispersion, few studies concentrated on this subject. The importance of knowing fire ignition characteristics is widely recognized (Vasconcelos and others 2001, Preisler and others 2004, Riva and others 2006, Robin and others 2006; Badia-Perpinyà. and Pallares-Barbera 2006). Fire ignition probability (or ignition risk) is often considered as an important factor, for example used in association with fire propagation risk to produce fire risk cartography (Johnson and Miyanishi 2001, Finney 2005, Roloff and others 2005, Hessburg and others 2006, Jappiot and others 2006). Nevertheless several fire risk maps and fire prevention plans only consider the fire propagation risk, but as it is known that there are no fires without ignitions, it should be given more attention to fire ignitions. The main objective of this work is to analyse the spatial patterns of wildfire ignition in Portugal, contributing to a better knowledge of their occurrence and consequently to improve fire risk management.

Methodology

Study area

The study area is constituted by the entire Portuguese mainland, which covers about 90,000 km^2 in southern Europe (*fig. 2*). Most part of the country is included in the Mediterranean biogeographic region and there is a transition to the Atlantic region in the north. Mean annual temperatures range from about 18ºC in the south to 7ºC at more altitude in the north, and annual precipitation ranges from about 400 mm to 2,800 mm (IA 2003). In general topography is not very rough and the altitudes range from sea level to 2,000 m. About 48% of the country area is used for agriculture and 27% is covered by forests (DGF 2001). The population is estimated in about ten million inhabitants, more concentrated in the north and centre littoral areas (INE 2003).

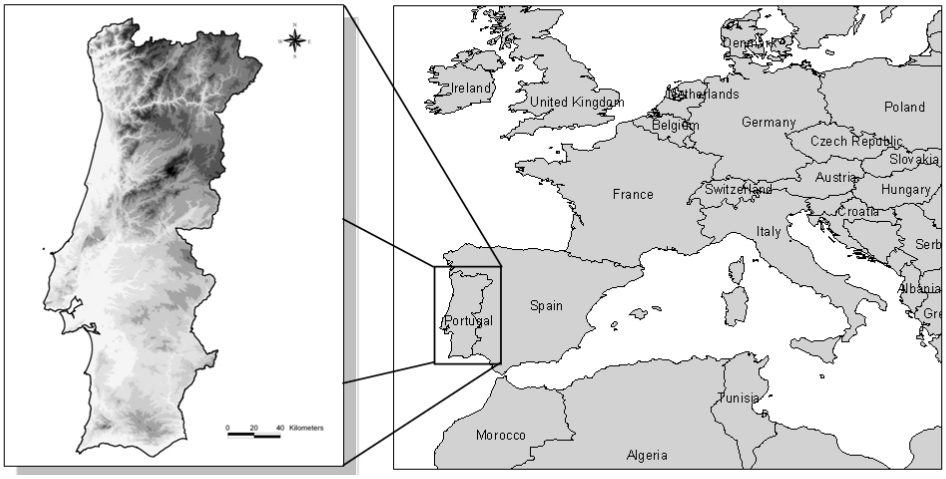

Figure 1 — General location of the Portuguese mainland, with representation of its elevation.

Data preparation

Methodology used resulted from an interactive process in which different approaches were evaluated. Special emphasis was putted on territory characteristics related with human presence and activity. All spatial analysis and cartographic production were made using geographical information systems (GIS).

In order to analyze the spatial distribution and characteristics of fire ignitions we prepared the following digital cartography in a GIS environment:

a) Fire ignitions – we used the official database from the Forest Services, which contained the geographical coordinates and other characteristics (eg. start and end date, burnt area) of all fire ignitions detected in Portugal during a five years period (between 2001 and 2005), to create a vector map with the location of all occurrences (DGRF – database made available by Forest Services, by request);

b) Land cover – we used the Corine Land Cover 2000 cartography in vector format, at scale 1:100,000 (IA 2005). The Portuguese cartography identifies 42 land cover classes which were grouped to five classes: 1) agricultural areas, 2) forests, 3) shrublands and natural grasslands, 4) urban and other artificialized areas, and 5) wetlands and water bodies;

c) Population density map – this map was produced using a database which includes the number of persons present in each parish, from the National Statistic Institute concerning the 2001 National Inventory (INE 2003). This information was assigned to the official municipality map to create the population density map (number of persons per km^2);

d) Distance to urban areas map – to produce this map, we extracted the urban areas from the Land Cover Map COS'90 (IGP 2005) and from Corine Land Cover 2000. The Land Cover Map COS'90 (scale 1:25,000) was used for almost all the Portuguese mainland (about 95%); for the few places where this map was not available we complemented the missing data with the Corine Land Cover 2000; although COS'90 is not as recent as desirable, we opted to use it because it doesn't exist other detailed cartography at national level. Based on this map, we calculated the distance from each location of the national territory to the nearest urban area, producing the desired map (raster format with 10 m spatial resolution);

e) Distance to roads map – to produce this map, we used the Itinerary Military Map from the Portuguese mainland, in vector format at scale 1:500,000 (IGEOE 2005). Based on this map we calculated the distance of each territory location to the nearest road and produced the desired map (raster format with 10 m spatial resolution);

f) Elevation map – we used a free digital elevation model (DTM), in raster format and with 90 m spatial resolution (NASA and others 2004). This map was submitted to several operations, including georeferencing and correction of negative and no data values (by interpolation methods), in order to prepare it for spatial analysis;

g) Portuguese administrative maps – we used a map which defines the official Portuguese administrative borders, as well as the parish limits, both in vector format (IGP 2004).

The database with the wildfire ignitions detected in Portugal during the period 2001-2005 was prepared to the analysis, by removing all the records with incorrect data (eg. fires with incorrect coordinates, without date and hour of detection, with simultaneously coincident coordinates, date and hour, duplicated identification codes), and merging different records concerning the same fire (simultaneously updating respective dates and burnt areas). After these procedures, from an initial number of 137,204 ignition points, 127,492 remained in the database for analysis. Additionally an equal number of points (127,492) were randomly generated within the whole country (average density of 1.4 points per km^2), representing the distribution we should expect if fire ignitions occurred in a random way, or non-ignition points to be used in a logistic regression analysis. Ignition and non-ignition points constituted the new fire ignition variable, coded in a numeric binary format (1 - presence of ignition; 0 - absence of ignition), and were overlayed with all the other variable maps in order to create a new database with the information from all layers. In order to analyse fire causes we used a sub-set of the global database with 4,587 ignitions investigated by the Portuguese Forest Services for which causes were successfully determined, and classified in three main categories: 1) intentional, 2) negligence/accidental, and 3) natural.

Data analysis

First we made a frequency analysis of all variables used to characterize the wildfire ignition population. Than a binary logistic regression (Hosmer and Lemeshow 1989) was used to determine separately the influence of each variable on fire ignition probability. The significance of each variable was tested through a univariate model, by using the likelihood-ratio χ^2 statistic. Model performance was assessed through the likelihood ratio statistic and by calculating the area under the receiver operating characteristics (ROC) curve (Saveland and Neueschwander 1990, Pearce and Ferrier 2000). Land cover and fire cause were analysed as categorical variables and the others as continuous. All analyses were carried out using the SPSS software (SPSS 2004).

Results

Most part of fire ignitions occurred during the period 2001-2005 were concentrated in the north and centre littoral areas (*fig. 3*), mainly in Porto, Braga, Lisboa and Aveiro districts.

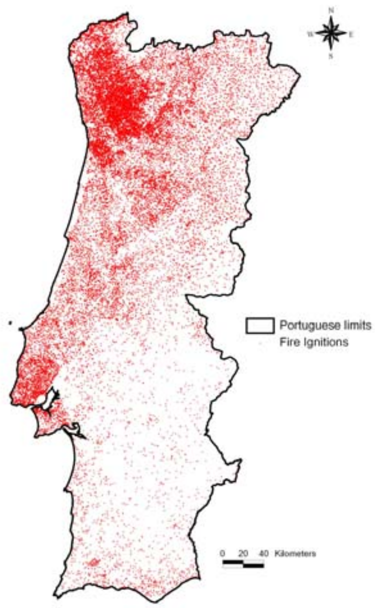

Figure 3 — Fire ignitions distribution in Portugal (period 2001-2005).

Using the univariate regression analysis, we verified that all the variables considered were highly significantly related to fire ignition occurrence ($p<0.001$). The most important variable affecting fire ignitions distribution was *distance to urban areas*. *Land cover type* ranked second, followed by *distance to main roads* and by *population density*. Correlation between variables (Pearson correlation coefficient) was relatively low, and the most correlated were distance to urban areas and distance to roads ($r=0.59$; $p<0.001$).

Distance to urban areas and *distance to main roads* were negatively correlated with fire ignition probability, meaning a decreasing fire occurrence frequency at increasing distances to roads or urban areas (*figs.4, 5*). About 85% of fire ignitions occurred at less than 500 m from urban areas and 98% were within a distance of 2 km. Fire ignitions were also located very close to the main roads, with 70% at less than 500 m distance, and 98% at less than 2 km.

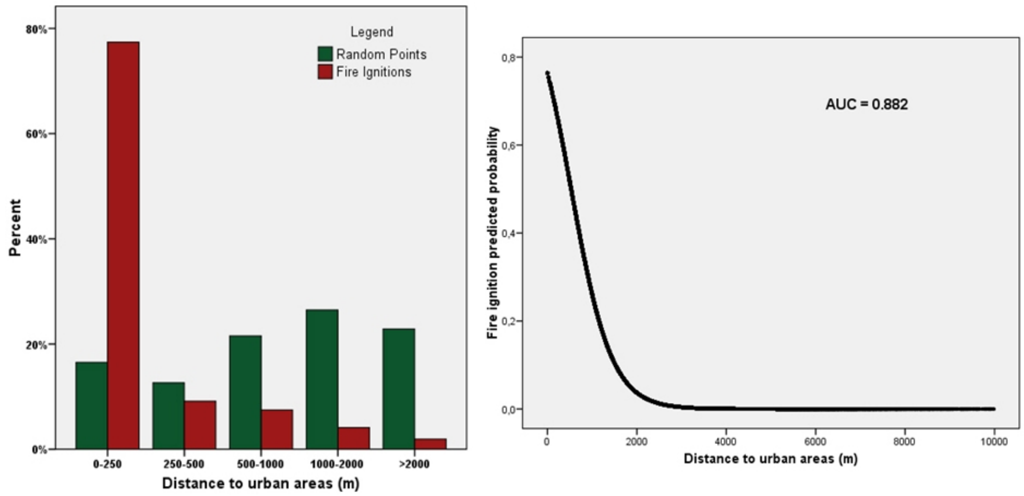

Figure 4 — Fire ignitions in relation to distance to artificial/urban areas. Left: Percentage of random points and fire ignitions observed in each class; Right: Fire ignition probability based on the univariate model (model performance evaluated by the area under the ROC curve - AUC).

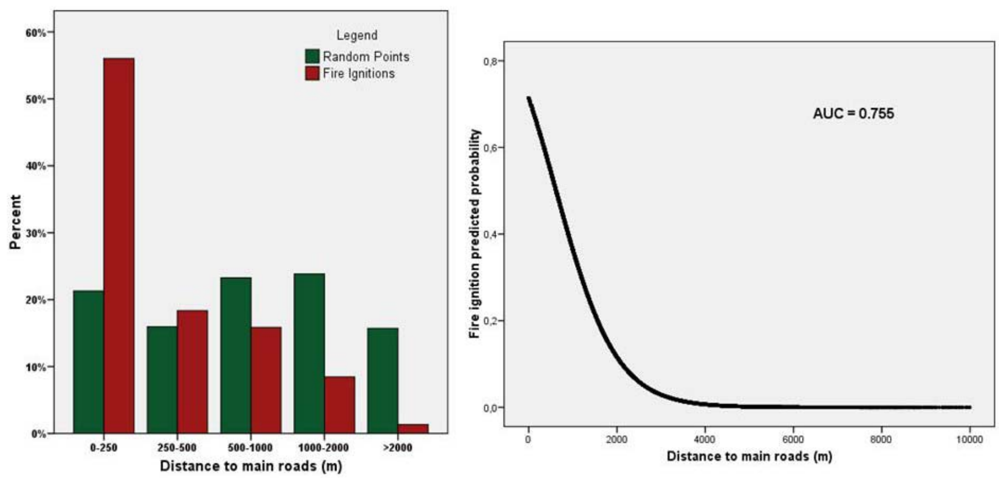

Figure 5 — Fire ignitions in relation to distance to main roads network. Left: Percentage of random points and fire ignitions observed in each class; Right: Fire ignition probability based on the univariate model (model performance evaluated by the area under the ROC curve - AUC).

On the other hand *population density* variable was positively correlated with fire ignition probability (*fig. 6*). Although municipalities with more than 100 persons/km^2 only represent 21% of the territory, they concentrated more than 70% of fire ignitions occurring in Portugal.

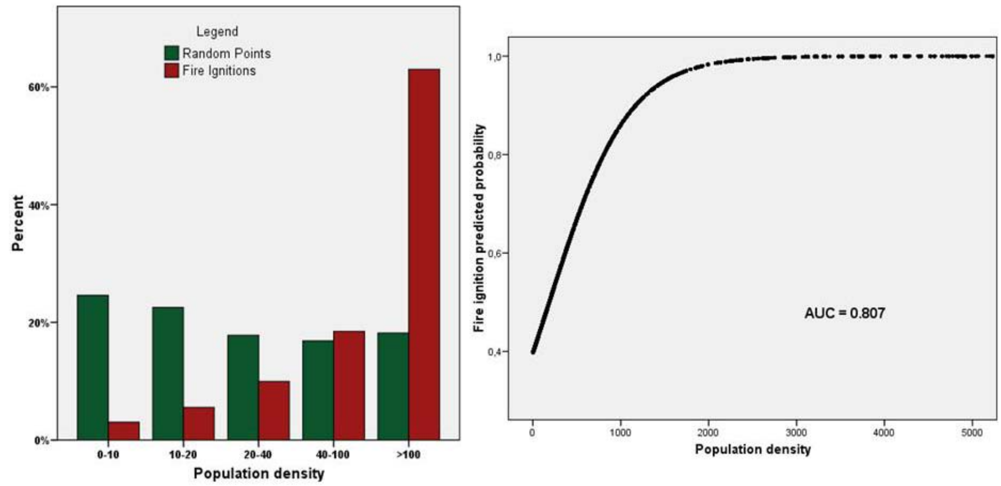

Figure 6 — Fire ignitions in relation to population density (persons/km^2). Left: Percentage of random points and fire ignitions observed in each class; Right: Fire ignition probability based on the univariate model (model performance evaluated by the area under the ROC curve - AUC).

Concerning fire ignitions distribution by land cover classes (*fig. 7*), about 60% were located in agricultural areas; within those ignitions, the majority occurred in heterogeneous agriculture (81%), annual crops (10%) and permanent crops (8%). About 25% of ignitions occurred in artificial/urban areas, which often includes a dense mosaic of mixed urban with other land covers, including mainly agriculture but it can also include some small fragments of woodlands and shrublands; in those areas (which only covers 2.7% of the country) the occurrence of fire ignitions were nine times larger than if ignitions occurred in a random way through the territory. On the other hand the forested areas, covering about 27% of the country, only registered 8.5% of fire ignitions, most of them in mixed and coniferous forests (80%). A similar situation was observed in uncultivated areas (including shrublands and natural grasslands) which cover about 19% of the land and registered 6.2% of ignitions.

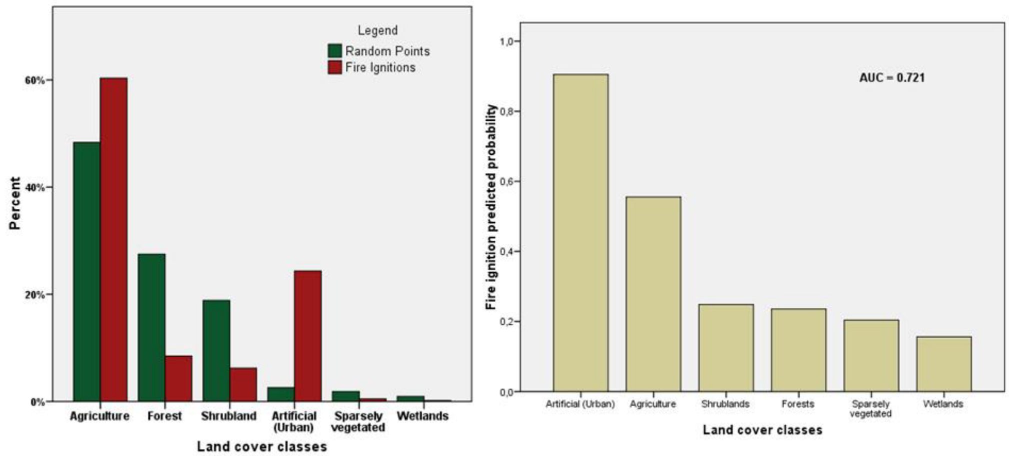

Figure 7 — Fire ignitions in relation to land cover classes. Left: Percentage of random points and fire ignitions observed in each class; Right: Fire ignition probability based on the univariate model (model performance evaluated by the area under the ROC curve - AUC).

It is important to notice that about 85% of fire ignitions originated a burnt area lower than 1 ha and 95% burnt less than 5 ha. In fact only 0,3% of ignitions analyzed originated large wildfires which burnt 500 ha or more. Regarding topography, we verified that 80% of ignitions occurred at elevations below 500 m and 98% below 1000 m.

The analysis of fire causes showed that 50% were intentionally ignited, 47% were due to negligence and only 3% had natural causes (lightings). Fire causes were not independent of land cover type (χ^2=35.85; $p<0.001$); major differences were observed in forested areas, where the majority of fires (58%) were intentionally caused, while 37% were caused by negligence or accident. Concerning wildfires which burnt more than 500 ha (208 cases), we also verified that the majority (53%) were intentionally caused. Fires due to negligence and accidental causes were more frequent in the south of the country and in the interior areas of north and centre, while intentionally caused fires were more frequent in north and centre littoral areas.

Conclusions

Portugal has one of the highest fire occurrence densities in southern Europe. As in many countries fire ignitions are highly related with human presence and activity, in the present study we analyzed fire ignition occurrence in relation to some natural and anthropogenic variables, but giving special emphasis to the last ones.

The high number of wildfire ignitions in Portugal constitutes a problem in terms of fire detection and fire fighting resources dispersion and consequently it is very important to know their characteristics and spatial distribution patterns to improve fire risk management.

We concluded that fire ignition occurrence in Portugal is strongly correlated to variables such as proximity to urban areas, proximity to main roads, land cover, and population density. The ability to predict the locations with higher or lower ignition risk constitutes an important factor in order to improve and optimize prevention activities, as well as vigilance and fire fighting management. Results obtained can now be used in a multivariate model to predict fire ignition occurrence probability, and to produce a map of fire ignition risk for the entire Portuguese mainland.

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