The recurrence interval of forest fires in Cabeço da Vaca (Cabreira Mountain—northwest of Portugal)

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ABSTRACT

The recurrence of forest fires is degrading an important part of the Portuguese natural heritage namely its forest and soils.

In this paper we present the case study of Cabeço da Vaca (Cabreira Mountain—northwest Portugal), where in recent decades, particularly in the 70s, there was a significant increase in the number of forest fires and in the areas scorched annually. There is thus a turning point between a period when fire was an integral part of the ecosystems and when fire has become a serious threat to woodland management and development (Bento Gonçalves, 2006).

Starting with a thorough characterization of forest fires and based on the mapping of scorched areas between 1990 and 2006, we have proceeded to identify the annual pattern of maximum recurrence and the definition of the return interval in Cabeço da Vaca, producing thus a valuable document to support management and forestry development in general.

1. Introduction

Portugal has a warm temperate climate, mostly Mediterranean, characterized by hot, dry summers and fresh, wet winters. Areas of rugged terrain are common and the natural vegetation is typically evergreen, resistant to drought and fire-prone.

Wildfires are one of the most important agents of land cover change in Portugal (Pereira and Santos, 2003; Nunes et al., 2005).

It is clear that in the Mediterranean basin, fires are a natural phenomenon, they have occurred for millennia and plants have revealed the capacity to cope with them (Pausas et al., 2008). In this framework, forest fires should not be considered an ecological disaster but rather a part of the natural process. However, some studies suggest that current fire regimes may cause disasters by inducing abrupt changes in the community (Kazanis and Arianotsou, 2004; Rodrigo et al., 2004; de Luís et al., 2006; Arnan et al., 2007) or important soil losses (Marquês and Mora, 1992; de Luís et al., 2005).

Large wildfires are relatively recent in the Mediterranean basin; therefore, people perceive them as catastrophic events with the media amplifying this perception (Pausas et al., 2008).

Recent decades have seen a noticeable increase in the number of wildfires in the Mediterranean countries (Xanthopoulos, 2000, Viegas, 1998, 2004, Moreno et al., 1998, Piñol et al., 1998, Pausas, 2004). The total area burnt has also increased in some Mediterranean countries of the European Union (Xanthopoulos, 2000, Viegas, 2004). However, the increase in the total area burnt does not correlate with the increase in the frequency of forest fires, but there are periods of low annual area burnt corresponding with years of extraordinary fire activity, such as 2003 in Portugal or 1994 in Eastern Spain. Some authors link these two phenomena and attribute the increase in the area scorched to the increase in the ignition frequency due to a higher activity of people in and around forests and woodlands (Moreno et al., 1998; Xanthopoulos, 2000; Keeley et al., 1999).

However, from a theoretical point of view the above reasoning is not so straightforward, for there are feedbacks than can refute the logic behind the simple reasoning of 'more ignitions mean more area burnt'. For instance, every fire reduces the amount of available fuel for future fires and, thus, a higher fire frequency would lead to a reduction of burnable land in the future. It is not clear at all which of these two opposing processes would dominate and, consequently, whether or not a higher fire frequency will increase the total area burnt (Oliveiras et al., 2005).

Two main causes have been proposed as catalysts of the fire regime in the Mediterranean-type ecosystems: fuel build-up and weather conditions. If fuel build-up is the main cause, then areas recently burned will not burn again until some years later. Contrarily, if weather is the main cause, then all areas will burn irrespective of their age (Salvador et al., 2005).
There is an ongoing debate on the effect of forest fire suppression policies on the size of fires in areas with Mediterranean climate (Salvador et al., 2005). One point of view holds that the systematic extinction of all reported wildfires allows a build-up of fuel (fuel load and an increased fraction of dead materials) that may in the future produce very large fires in periods of adverse weather (Minnich, 1983, 2001; Minnich and Chou, 1997). Moreover, the effect of fire suppression policies on total surface burned and in return periods would be negligible: with no suppression, there would be frequent and small fires, while fire suppression would lead to fewer large fires.

This view assumes that the fire regime is only controlled by fuel and that ignition probability is uniform throughout the territory (Salvador et al., 2005).

Some authors view implies that large fires would be fuel driven (Minnich, 1983), where Keeley, among other authors (Keeley et al., 1999; Keeley and Fotheringham, 2001; Moritz, 1997; Moritz et al., 2004), advocates for large fires being mostly wind/weather driven.

In this paper we propose to start with an analytical approach to fire occurrence patterns in relation to previous fire events.

Using the Cabeço da Vaca (Cabeira Mountain—northwest Portugal) region as a case study, we use maps of the scorched areas for the 1996–2006 time period, provided on-line by AFN, to analyze the frequency of forest fires, along with its annual spatial patterns. Subsequently, we try to define and understand the maximum recurrence patterns that characterize this region, comparing it with its national counterparts.

2. Materials and methods

2.1. Site tested

The Cabeço de Vaca study area is located in the Cabeira Mountain range, in the municipality of Vieira do Minho\(^1\) in north-eastern Portugal (Fig. 1). In Vieira do Minho, the lowest elevations are found in the West, mounting as we travel Eastward. The highest point presents an altitude of 1262 m, while the lowest merely reaches 60 m, at the valley of Cavado river in the far west (Fig. 2). This range of elevations will be reflected in accentuated local gaps, registering frequent deep slopes inclinations, mainly in the north and east of the municipality, where the higher altitudes of the mountain are distributed.

One of the most notable features of the north-eastern region, especially in the Cabeira Mountain, is the high level of precipitation. Although no weather stations exist in the area, the municipality of Vieira do Minho possesses four rain stations which allow us to analyze the average annual rainfall—i.e., Brancelhe, Guilhofrei, Salamonde, and Zebral (Table 1).

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\(^1\) Since the 1991 census, the municipality of Vieira do Minho saw its population decrease from 15,775 to 14,724 individuals (2001), corresponding to a total negative change of 7%. It presents a negative trend of population dynamics, marked by low birth rates and aging population. In 1900, Vieira do Minho registered 14,904 inhabitants. The years that followed were of population growth that although momentarily interrupted between 1911 and 1920 by cyclical factors, reaches its peak in 1950, when it registered 19,259 inhabitants. The period with higher growth rates were achieved during the 30s and 50s. Since then the trend reverses itself and there is a declining population. The increase of 5.5% between 1970 and 2001 is unable to mean a reversing of the trend which began to delineate in the 50s. Between 1981 and 1991/2001 the decrease was of 12% and 6.6%, respectively. Over the past 50 years, the municipality of Vieira do Minho lost 4535 of its inhabitants, reaching the lowest in the census of 2001, with 14,724 inhabitants.
From the records we can verify that in Zebral there is a high value of annual average precipitation (3071.1 mm) and a prominent number of days registering rainfall (142), mainly due to the stations higher altitude (775 m). The Salamonde post (550 m) presents records of annual average precipitation of about 2281.9 mm. For its part, in Guilhofrei, located at 350 m of altitude, the rainfall is smaller (2705.7 mm), although the number of rainy days is relatively high (134). In the Brancelhe station precipitation levels are even more reduced (2118.7 mm), along with the number of days of precipitation (116). Nevertheless, all four rain stations record high levels of annual average precipitation and number of days with rain.

The municipality of Vieira do Minho is dominated by wildlands (86%), with 12% of the area occupied by croplands. For its part, Cabeço da Vaca is composed by wildlands in 88% of its area, while only 8% are croplands.

Shrubs are the dominant kind of vegetation in the Cabreira Mountain due to agricultural abandonment and lack of livestock management representing about 50% of the total area (Soares and Coord, 2000).

The most common type of shrub across the mountain is dominated by species such as furze (Ulex europaeus) and several species of tree heath (Erica arborea). They appear in places where the original forest is degraded, where damp conditions are low and the soils are relatively shallow. Also frequent in this area are the broom (Cytisus scoparius), the gorse (Chamaespartium tridentatum), and fœtus (Pteridium aquilinum). The presence of fœtus (Pteridium aquilinum) as the dominant species is common to regions where wildfires and grazing exert excessive pressure on the vegetation.

### 2.2. Methodology

In order to achieve our goal we have mapped the forest fires that occurred between 1990 and 2006 and the year in which they occur in the municipality of Vieira do Minho (Fig. 3).

The data on forest fires (1990–2006) applied are from the web page of the Autoridade Florestal Nacional (AFN). The cartographic information was subsequently manipulated and analyzed with GIS software, specifically ESRI's ArcGIS 9.2.

With the use of the GIS software we were able to use the available information to generate a map of forest fire recurrences by implementing a modeling process. Accordingly, with ArcGIS 9.2, the information relating to the occurrences of fires had to be organized by individual “layers”, containing the year of their incidence. Next, the aforementioned information was converted to raster and was codified according to the existence or not of scorched areas—e.g., “0” for non-scorched areas and “1” for the areas scorched by fires. After all the raster data are converted they were combined into a final raster output which summarized all the previous information. Subsequently it is then possible to create a legend that reveals the patterns of wildfire recurrence—i.e., “0” (non-scorched areas), “1” (scorched areas once), “2” (scorched areas twice), “3” (scorched areas three times), “4” (scorched areas four times), and “5” (scorched areas five times). The final result allows us to visualize the scorched areas and the pattern of recurrence throughout the years.

### 3. Results

Using the data obtained from the AFN, the year of 1998 stands out, introducing a considerable statistical deviation in the sample. However, it is possible to identify a significant correlation
Fig. 3. Forest fires (1990–2006) in the municipality of Vieira do Minho.
Source: www.afn.min-agricultura.pt.

Fig. 4. Number of forest fires and burnt area in Cabeço da Vaca (1990–2006).
Source: www.afn.min-agricultura.pt.
between the increase in the number of wildfires and the increase
in the area scorched annually after the year of 2000 (Fig. 4).

By treating the data from AFN\(^2\) we have identified the
recurrence degree (fires that occurred more than once in the
same area) and frequency (Fig. 5). Consequently, at Cabeço da
Vaca the maximum number of forest fires in the same area is 5,
resulting in a maximum recurrence degree of 4. However, in the
municipality of Vieira do Minho, these rates climb to 7 and 6,
respectively. At the national level, using the same data and the
same time period, the maximum number of fires in the same area
is 8 and the maximum recurrence degree is 7.

Throughout the years we can verify a decreasing tendency for
the time necessary for the repetition of another fire in the same
area (Ferreira Leite et al., 2010), allowing for an identification of a
correlation of 94\% between the maximum recurrence degree and
the time evolution.

The fires that happened by the second time in the same area
(1st recurrence) took 5 years to occur; to those that took place by
the third time (2nd recurrence) the average time was less, 4.6
years; and for the areas that have registered a fourth incident (3rd
recurrence) we verified an aggravation of the average time
diminution about 3 years (2.8). (Fig. 6)

In a total area of 8259.9 ha, 3225.94 have been scorched by
wildfires at least once (39.05\% of the study area). Of these areas,
1428.71 ha have been scorched more than on one occasion.

\(^2\) The cartography used in the present study was provided on-line by AFN and
results from Landsat satellite images. In the initial years, 1990–92, the minimum
scorched area mapped was 25 ha. In the following years – 1993–94 – the
minimum area mapped was 15 and 5 ha since 1995, leading to difficulty in
comparing rigorously the total areas in the proposed time span.

Therefore, 44.28\% of the scorched areas reveal at least one
recurrence, while 16.82\% (542.89 ha) of the areas have been
scorched three times, and 5.05\% (163.07 ha) have been scorched
at least four times. Records show that 6.61 ha revealed a fourth
recurrence. As a result, only 5034 ha, corresponding to 60.94\% of
the total study area of the Cabeço da Vaca did not record any
wildfires between 1990 and 2006 (Tables 2 and 3).
In the municipality of Vieira do Minho the scorched area corresponds to 37.79% of the total area, while that value is only 19.37% at the national level (Table 3).

When comparing the percentage of areas burnt only one time, we verify that in Portugal the value is 74.30%, while in the respective study area it is only 55.71%. When considering areas burnt only two, three and four times, the Cabeço da Vaca region reveals higher rates than the national level.

4. Discussion

It is widely accepted that in the ecological conditions of the country, forest fires are inevitable because of the large accumulation of fuel that is the ideal catalyst of wildfires, which often becomes uncontrollable by the action of the wind.

The 70s and 80s were periods of transition between the reality of fire that existed in the first half of the twentieth century, in which the use of fire was one of the management tools of wild spaces and the current reality, where, from the 90s onward, forest fires started to be part of our wild spaces (Bento Gonçalves, 2006).

It was the year of 1975, with a total area of 2207.2 haectares scorched in Vieira do Minho, which marked a major turning point between a period in which fires were part of the ecosystem, cohabiting almost in a natural way with the people and the present period in which fires have become a serious threat. (Fig. 7).

More recently, since the year of 1995 there has never existed a year when there were less than 100 occurrences and the scorched areas have continued to be very variable with the year of 1998 standing out for negatively reasons. (Fig. 7).

The location of the areas where recurrence occurred at least twice does not reveal any relevant risk for the larger forested areas. There seems to exist a pattern that identifies forest areas with mountain characteristics and can be attributed to fires associated with pressure for cattle grazing and eventual hunting-related conflicts.

In the municipality of Vieira do Minho, the changes initiated in the 60s, particularly the social and demographic changes3, led to a disruption of traditional agrarian systems of production4 that have

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3 In Portugal, the rural exodus that began in the 1950s and augmented considerably in the next decade led to the abandonment of agricultural fields, villages, and hamlets, contributing to a low demographic density in the hinterland.

4 In relation to the distribution of individuals by sectors of economic activity, the municipality of Vieira do Minho registered a significant change between 1981 and 2001, with the primary sector (agriculture) dropping from 50% to only 8%, while the secondary and tertiary sectors verified an important boost from 28% and 22% to 46% and 46%, correspondingly.

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**Table 2**

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<th>Portugal</th>
<th>Vieira do Minho</th>
<th>Cabeço da Vaca</th>
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<tr>
<td>Burned area (ha)</td>
<td>Burned area (%)</td>
<td>Burned area (ha)</td>
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**Table 3**

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<td>Burned area (%)</td>
<td>Burned area (ha)</td>
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greatly contributed to the change in the reality of wildfires in this area.

The lack of labor led to agricultural abandonment and adaptive ways that were reflected in the number of livestock, particularly in the change of grazing type (going to dominate the grazing free) and sharp increase in the permanence of livestock in mountain pastures. These transformations of the agrarian systems of traditional production have had a direct impact on mountain areas, notably due to the reduction in the growth of vegetation control by predation of livestock, the marked reduction or disappearance of farming and a significant decrease of firewood. The sum of these actions ultimately results in the accumulation of fuel.

The accumulation of fuels in Cabeço da Vaca (warm temperate climate with very wet winters) by reducing predation of livestock, farming activities, need for firewood and controlled burning, coupled with the rugged topography reinforces the occurrence of fires.

In short, large fires are relatively recent in this region, but areas recently burned do not burn again until some years later, implying that large fires would be fuel driven.

Acknowledgments

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References