Sensitivity of Portuguese Forest Fires to Land Use and Climatic Factors

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Abstract

This work explored the possible relations between the number and extension of fire events in the Portuguese districts and factors such as forest type, population density and climate. The data used consisted in the time series of the number of fires and area burnt by district for 1980 through 2005. The forest area and type of forest trees used was also available such as information about meteorology, demography, topography and road network.

In spite of the gains in fire fighting efficiency the number and extension of fires in Portugal has been rising in recent years. The number of fires was positively related with both the percentage of conifers and the population density in the districts. Topography determined a part of the variation in area burnt. A weak, but significant relation between the climate variables studied and the area burnt was found for the Northern regions. For the Southern regions no significant relation could be detected. Portuguese wildfires are currently the major factor that renders investment in forestry unattractive.

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Introduction

Human-caused fires are the most important threat to forests and wooded area in the Mediterranean basin. The increasing life standards in Western Europe lead to a migration of population from the rural areas to the city centres. Urbanization and the expansion of transportation routes have affected people's relationship to their environment with respect to fires The abandonment of arable areas and disinterest in the forest resource resulted in the expansion of wooded areas and an increase in the amount of fuel loads. Although the main reason for fire increase is probably due to changes in the land use, climate should be considered as a contributing factor. Predictions on climate warning in the Mediterranean Basin indicate an increase in air temperature and a decrease in summer rainfall suggesting a future increment in water deficit. These changes would lead to an increase of ignition probability and fire propagation. Fire is one of the major disturbance agents on global scale, affecting biochemical cycling, playing an important role in atmospheric chemistry and the global carbon cycle (Thonicke. 2003). Nowadays, the rising concerns about climate change changed our view on forests because they play an important role in the global carbon budget. They control the mosaic structure of the forests which in turn controls the amount of carbon stored or released (Harden *et al*. 2000) and regional-scale albedo, both of witch directly feedback to the climate system (Chapin *et al*. 2000).

The extreme fire events recorded in Portugal in recent years are a major threat to the sustainability of the National forest and a challenge to the future management policies. Is therefore important to understand how changes in land use and climate affect the distribution and extension of forest fires.

Portuguese Forests

Portugal is a Mediterranean country with some Atlantic influence near the coast, strongly conditioned by physical, biologic and climatic environmental characteristics. In the Portuguese mainland, forest ecosystems covers one third of the territory and provide a wide range of goods and services. The high economic importance is paralleled by its importance for biological diversity as part of the landscape mosaic. Most of the forests in Portugal have an economic function of providing raw materials to the industry, and are, in many cases, the result of deliberate afforestation/reforestation. Other forests remain less disturbed by deliberate human action and are considered a repository of biological diversity (Santos *et al*. 2002). Private property is 87% of the all forest area and the average size of private forest properties ranges from 2ha in the North, trough 30ha in the centre districts of the country up to 100ha in the South.

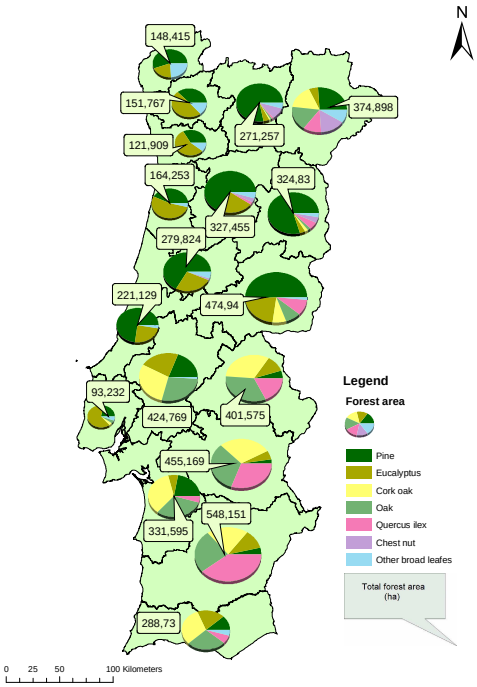


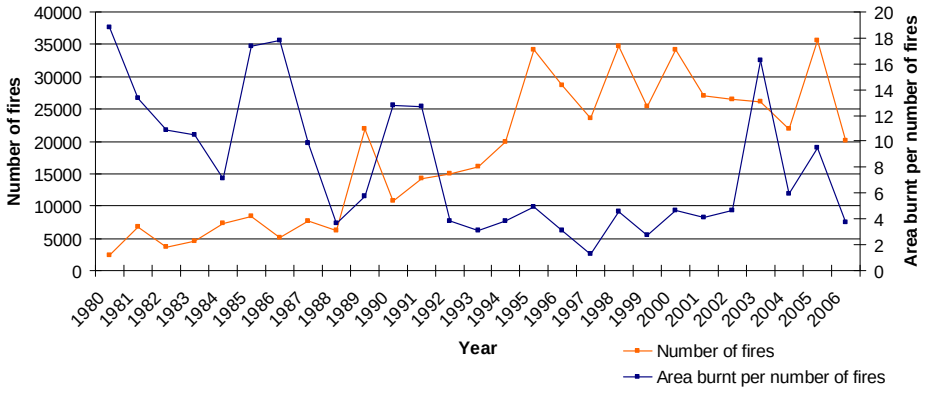
Figure 1 – Fractional composition of the forests by species/species groups. The size of the pie is sorted by total forest area in each district.

We can observe two distinct situations relatively to the tree species used in the Portuguese mainland. In the North Pine and Eucalypts are the two main groups of species used. In some districts Pine accounts for more than half of the total forest area. Eucalypts are widely used in the costal districts in the Northern regions. In the South the most common species are Oaks. Pine and Eucalypts are also planted but in a substantially smaller fraction of the forest area than in the North.

Fire Events

Because of the cool and rainy winters and long dry hot summers, wildfires in the areas of Mediterranean influence are a frequent threat to forest ecosystems and population. The rainy winter provides soil moisture content that provides good vegetation growth; on the other hand, the dry hot summers decrease the water content in plants leading to an increase of the inflammability of the vegetation. These climatic factors coupled with the high fragmentation of ownership of the forest area makes of wildfires are a major cause of land degradation due to their frequent recurrence in the same area.

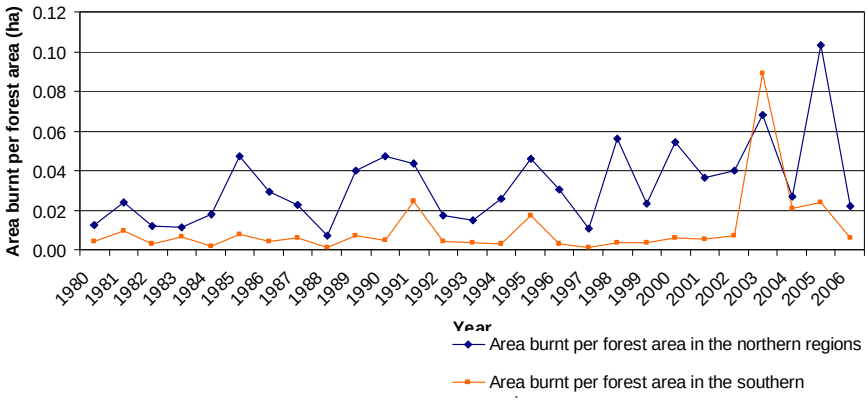
Since the mid 80ies there has been a positive trend both in the number and area of annual fires in the Portuguese mainland. Although the area burnt per fire is decreasing, showing a gain of fire fighting efficiency, extreme fire events have become more frequent leading to an increase of area burnt. So far the reasons for this these trends remain uncertain.



Graphic 1 - Number of fires and average area burnt per fire event

Usually in the Northern regions the area burnt per forest area is higher than those verified in the Southern regions of the country. The only exception so far was the

year of 2003; this was an extreme year of fire events especially in the South. In this particular year, for the first time, the burnt area in the South was higher than the area burnt in the North. On the other hand, in 2005, in the Northern regions, the highest value of burnt area was recorded since 1980.



Graphic 2 - Area burnt per forest area in the Northern and Southern regions

Although the forest area for both regions is more or less the same, the regions in the South tend to present much lower values of burnt area. In some extent, this distinction can be explained by the different values of forest biomass found for both North and Southern regions. Northern regions present higher values of forest biomass leading to high fuel loads and therefore higher values of burnt area.

In Portugal, recent extreme fire events raised concerns on population security, fire fighting policies and biodiversity conservation issues. Fire frequency is a powerful selection force when the life time of tree species exceeds fire return interval (Fernandes *et al.* 2005), the species that are unable to survive or reproduce after fire will eventually be extinct. Fire return for some Portuguese areas is short (20 years), clearly unsuitable for the forest to support a large number of communities.

The complexity of fires ignition and spreading patterns makes them a demanding, but also fascinating, subject of study. Therefore, many questions arise when we search the answers for the particular characteristics of fire events in Portugal.

Which factors (social, land-use, climatic, management) can explain this increase in the fire number, area burnt and shift in the regional distribution observed in the Portuguese mainland? Are there any factors “working” together towards an increase of fire area and number? Are there factors not yet considered in previous analysis?

Methods

The information used involved data on population density, forest area, type of forest, Portuguese road network and the mainland digital elevation model. All of this information was based in Geographic Information System files such as ESRI grids and Shapefiles. GIS operations were made on the original set of data in order to obtain secondary information such as road and population density or a map for the slopes. These operations were preformed using the tools *spatial analyst* and *raster calculator* available in ArcGis 9.1 software.

The fires statistics were obtained from the Portuguese forest services and were available from 1980 to 2005 concerning the number of fires and area burnt by district; the records for the ignition causes are only available since 2002. These records provided information for all the Portuguese districts and presented a wide range of ignition sources, after analysing the ignition sources they were grouped into nine classes; natural, renewal of the pastures, recklessness, controlled fires, intentional, economic activities, vandalism, recreation activities and unknown.

Climate data, namely precipitation and temperature, from Portuguese weather stations was also used in the analysis. Climate indices were calculated for the summer season (JJA) such as, average temperature and precipitation, number of days without precipitation and also the number of ten consecutive days without precipitation. The statistical analysis performed was district based using the statistical software R.

Results

Ignition sources

The data about the ignition sources was only available since 2002. At the district levels often a high percentage of the ignition sources are unknown. In some districts the percentage of unknown ignition sources is very high, namely in the districts of Oporto, Leiria and Portalegre, all with percentages of unknown reaching more that 75% of the total ignition sources.

Some ignition sources reflect the land use in some districts; for example, in the North-Eastern districts of Vila Real, Bragança and Guarda fires originated by the renewal of the pastures represent a significant percentage of the ignition sources. Intentionally lit fires are also a common feature in the entire Portuguese mainland, in some districts intentional fires reach 50% of all the ignition sources.

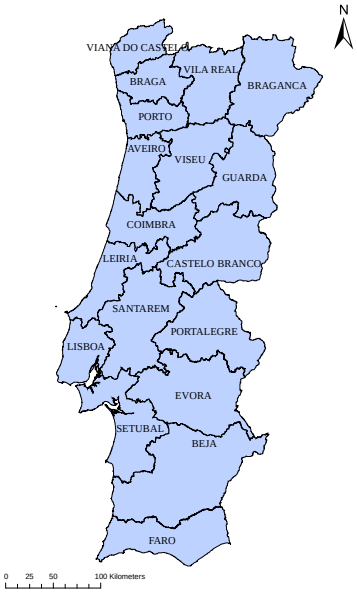


Figure 2 - Portuguese districts

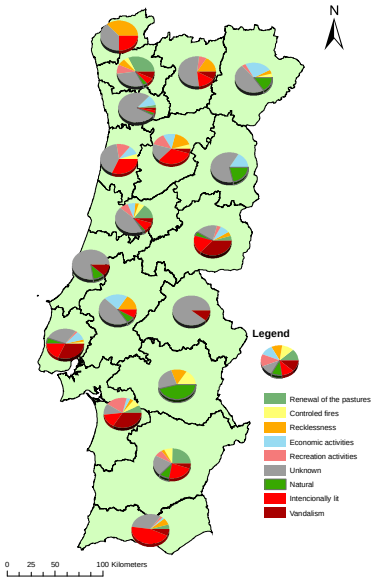


Figure 3 - Ignition sources for fires above 100ha (2002-2005)

The ignition sources of recreation activities are mainly due to hunting incidents, so, it is logical that they appear more in the Northern districts (were hunting is a common activity) than in the South. On the other hand, fires caused by economic activities seem to be more frequent expression in the Southern regions. The lack of a longer record on ignition sources renders any further analysis on this subject difficult.

Area burnt

By analysing the total area burnt in each district per total forested area we obtain a general overview about the Portuguese situation concerning the area of burnt forest.

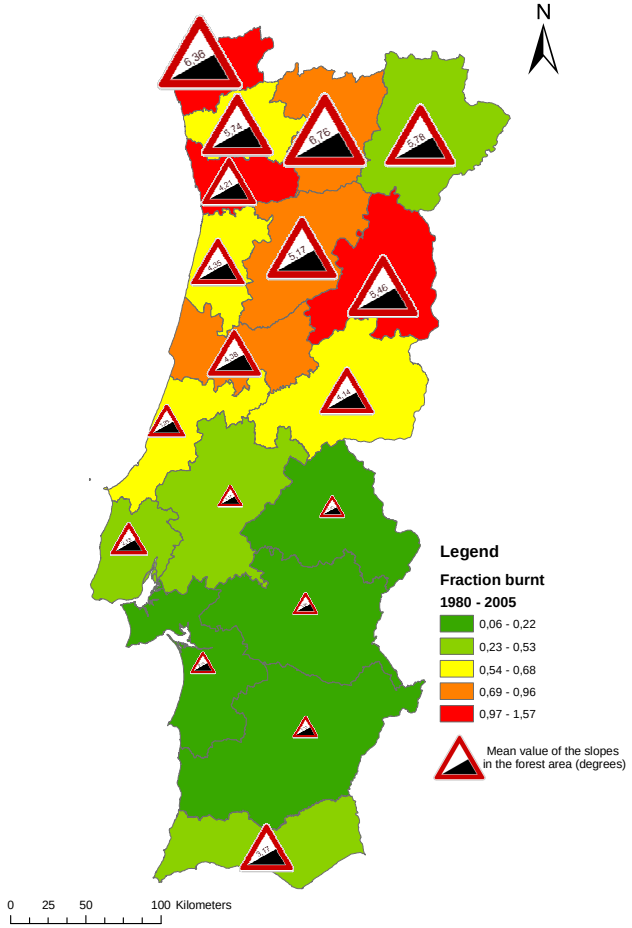
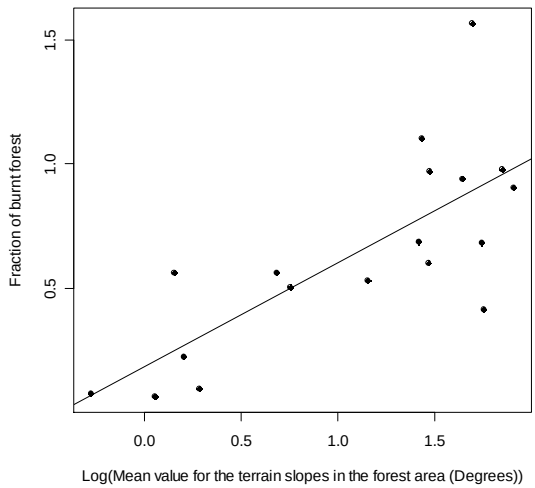


Figure 4- Area burnt per forest area (1980 – 2005)

Once again the situation in the North differs from the situation in the South. Generally the Northern regions present higher fractions of burnt area; towards the South the fractions become smaller. The Southern district of Algarve present the highest fraction of area burnt among the Southern regions. This is due to the extreme fire event that took place in the year of 2003. We can also see that Guarda and Porto are the districts where the situation is more problematic. Regarding the Guarda district this result can also be easily traced back to the occurrence of the 2005 extreme fire events. Analysing the average slopes within the forested area in each district some correlation of the fraction of area burnt with the topography emerges.



Graphic 3 - Relation between fractions of forest burnt and mean value of the terrain slopes in the forest areas

The fraction of burnt forest area presents a significant positive relation with the mean value for the slopes in the forest area of each district. The amount of explained variability reaches 0.5483.

The rate of fire spread is a primary descriptor of fire behaviour (Paulo A. 2000), spread rate increases significantly with increasing slope values (Santoni *et al*. 1998) playing a crucial down role to achieve effectiveness on wildfire control.

Stiffer slopes generate more difficulties to the fire fighters operations, in some extent; higher slopes can increase the time gap between the moment fires are spotted to the moment fire fighters reach the fire front, leading to higher values of burnt forest.

Number of fires

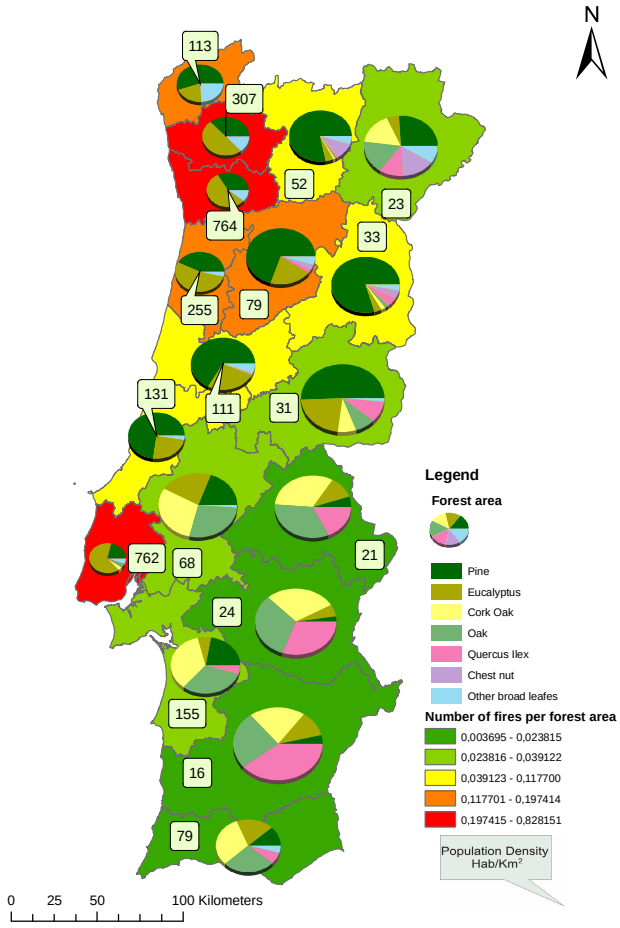
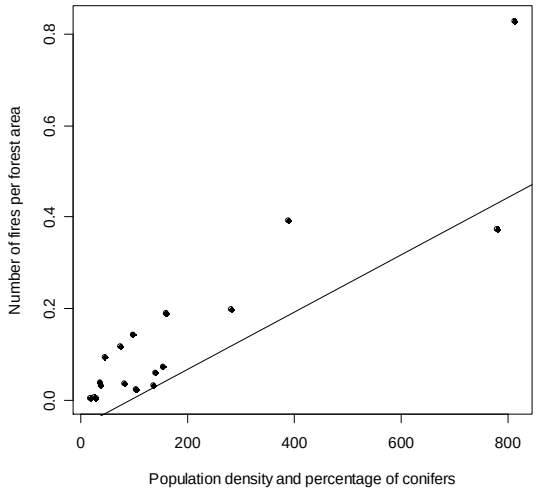


Figure 5 – Number of fires per forest area (1980-2005), percentage of tree species by forest area and population density. The size of the pie is sorted by total forest area in each district.

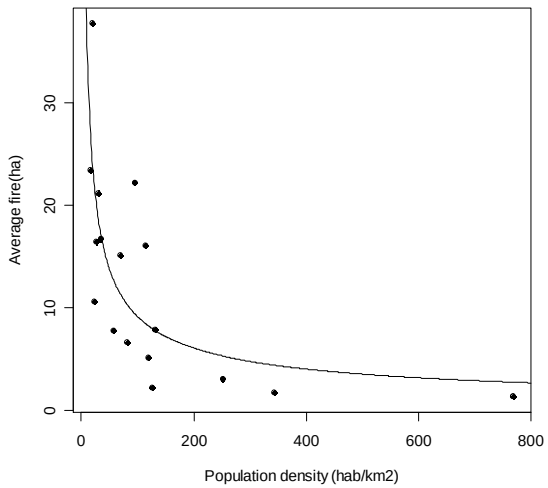
Where the population density is higher usually the number of fires per forest area presents also high values (see Fig. 5). One of the early conclusions we can obtain from the analysis of this map is that high number of fires do not necessarily occur in the districts with higher total forested area. In the Southern regions, in spite of their high value of forested area, lower numbers of fires are observed.



Graphic 4 - Relation between number of fires per forest area and both population density and percentage of conifers in each District.

The number of fires per forest area presents a strong relation with both the percentage of conifers and the population's density in the districts; the multiple regression leads to a value of 0.8786 of explained variability. This result is not surprising since 85 to 97% of the fires are human-caused (Moreno *et al.* 1998; Shvidenko *et al.* 1998). Arsoning as been an important element in the wildfire problem in the Mediterranean, for example, as many as 95% of the fires in 1989 could have been deliberately set (Goldammer *et al.* 1990). Similar fractions of human-caused fires would be found for Portugal if we don't take in account the unknown sources for the total ignition sources.

We take the average area burnt per forest fire as an indicator for the fire fighting efficiency. Like before, once we have this information we can try to assess what factors can explain the differences of efficiency in the fire fighting activities.



Graphic 5 - Relation between the areal extent of an average fire and the population density in each District

The tendency is for a decrease in the average size of the fires as the population density gets higher. The time from the moment that a fire is detected to the moment that intervention by the fire fighters starts is crucial to the future extension and severity of a forest fire. A fast detection prevents fires from reaching a high areal extent. We hypothesize that in districts with high population density the probability of an early detection is higher, leading to a quick response of the fire fighters and therefore to a lower value of forest area burnt.

Hence, population density seems to play a double role. On one hand higher population density leads to a higher number of fires, but on the other hand, it is usually associated with a quick response of the fire fighters and therefore a reduction on the aeral extent of an average fire.

Another type of information obtained was the map of the road density in the Portuguese mainland. The road density usually carries the same information than the population density. Therefore the results obtained using road density or population density are pretty much the same. The correlation between road density and population density is of 0.7796. The lowest population densities verified in Portugal are not low enough for us to notice the effect of the road network.

Climatic factors

The Mediterranean climate is characterized by a long summer arid period, during witch temperature is high and rainfall is almost absent (Thornthwaite. 1933). Future climate scenarios predict changes in rainfall amount and distribution (Bradley *et al*. 1987) and a general increase of global temperature. Fire risk is strongly related to the climatic conditions; therefore, any changes in climate will have repercussions on extension and intensity of fire events.

For the Portuguese mainland an increase in both minimum and maximum temperatures is expected in the context of future climate changes, precipitation is also likely to change with a decrease in annual precipitation in most of the country. During the winter season, total precipitation increases to 120%-150% of the reference value with the highest increase expected in the South and costal zones. The remaining seasons are expected to be characterized by a loss of precipitation (Santos *et al*. SIAM Project, 2002). The main fire season does usually occur in the summer months (JJA); a reduction of precipitation in these months will have serious repercussions on the number and extension of wildfires. The apparent gains of precipitation in the winter will provide good soil moisture content in the spring; models also expect that increasing CO_2 concentrations will enhance vegetation production that will provide a trend for higher fire loads.

Due to the high seasonal and geographic variability of climate in the Portuguese mainland, assessing its relation with the fires events becomes a difficult task. In the Northern regions a weak, but significant relation between the climate variables analysed (precipitation and temperature in the summer season JJA) and the area burnt was found (see Table1). While for the Southern regions no significant relation could be detected.

Table 1 – *R^2-values for the relation between burn area and the climate variables studied (temperature and precipitation) in both Northern and Southern regions.*

	R2		
North Districts	Vila Real 0,326	Bragança 0,657	Porto 0,712
South Districts	Faro 0,036	Castelo Branco 0,067	Beja 0,087

Climate station data were not available for all the districts; a more complete evaluation of this apparent difference between Northern and Southern regions in climate susceptibility is needed.

Conclusions

The trend for increased number of fires and the recent extreme fire events are a major concern to the sustainability of the Portuguese forests. The tree species used in the different regions of the country affects the distribution of the number of fires. Population density plays the main role in both fire number and fire fighting efficiency. Topography determines some of the extension of the area burnt with the higher values located in the districts with stiffer slopes. Southern regions seem to be less susceptible to fires, apparently due to a combination of factors such as tree species, smooth topography low forest biomass and low population density. In spite of the gains in fire efficiency Portuguese wildfires are currently the major factor that makes forest investment unattractive.

Acknowledgements

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References

Bradley, R.S., (1987) Diaz, H.F., Eischeid, J.K., Jones, P.D., Kelly, P.M., Goodess, C.M., Precipitation fluctuations over Northern Hemisphere land areas since the mid 19th century. Science 237, 171–175.

Chapin, F.S., McGuire, A.D., Randerson, J., Pielke Sr., R.,Baldocchi, D., Hobbie, S.E., Roulet, N., Eugster, W., Kasischke, E., Rastetter, E.B., Zimov, S.A., Running, S.W., 2000. Arctic and boreal ecosystems of western North America as components of the climate system. Global Change Biology 6 (Suppl. 1), 1–13.

Fernandes, P., (2005), The fire ecology of maritime pine, Silva Lusitana 13(2): 233 – 248

Goldammer. J.G., (1990). Fire in the tropical biota. Ecosystem processes and global challenges. Ecological Studies 84, Springer-Verlag, Berlin-Heidelberg-New York, 497.

Harden, J.W., Trumbore, S.E., Stocks, B.J., Hirsch, A., Gower, S.T., O'Neill, K.P., Kasischke, E.S., 2000. The role of fire in the boreal carbon budget. Global Change Biology 6, 174–184.

Moreno, J.M., Vásquez A., Velez R., (1998) Recent History of Forest Fires in Spain. In: Large Forest Fires (Moreno JM ed) pp.159-185 Backhuys Publishers, Leiden.

Paulo, A., (2001), Fire spread prediction in shrub fuels in Portugal, Forest Ecology and Management 144, 67-74

Santoni, P.A., (1998), Modelling of two-dimensional flame spread across a sloping fuel bed. Fire Safety Journal 31,201-225

Santos, F.D., (2002) Forbes K., Moita R., SIAM Project, Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures, Gradiva, Lisbon, Portugal.

Shvidenko, A., Nilsson S., Stolbovoi V., Wendt D (1998) Background Information for Carbon analysis of Russian Forest Sectors. IIASA

Thonicke, K., (2003), Fire Disturbance and Vegetation Dynamics – Analysis and Models.

Thornthwaite, C.W., (1933)., The climates of the earth. Geographical Review, 23, 433– 440.