Modelling the long term effect of changes in fire frequency on the total area burnt

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Abstract

Wildfires are one of the major problems in Mediterranean countries, and much effort is done by the governments to dissuade people from starting fires. Public campaigns often promote the idea that the more ignitions the larger the surface burnt will be. This reasoning is, however, not so straightforward. This paper addresses the question of how fire frequency relates to the total area burnt by using a model of fire regime that includes variables such as the number of ignitions, fire fighting capacity, fuel accumulation rates, existence of prescribed burning and meteorological variability. This question was addressed by performing three experimental simulations: effect of the number of potential ignitions, the combined effect of the number of ignitions and extinction capacity, and the non random spatial pattern of fire ignitions. Results showed that a larger number ignitions did not have a great effect on the total area burnt but had an effect in the occurrence of large fires, independently of the extinction capacity and of the spatial distribution of ignitions. An explanation for these findings is provided and management implications of these results are briefly discussed.

Key words: annual burnt area, behavioural simulations, fire ignition, fire regime, large fires.

Introduction

In the last decades, there has been 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 also increased in Spain (Moreno et al., 1998), and in the other Mediterranean countries of the European Union (Xanthopoulos 2000, Viegas 2004). However, the increase in the total area burnt is not as sustained as the increase in the fire frequency, but there are periods of low annual area burnt punctuated with years of extraordinary fire activity, like 2003 in Portugal or 1994 in Eastern Spain. Some authors link these two phenomena, and attribute the increase in the area burnt to the increase in the ignition frequency, as a consequence of a higher activity of people in and around forested lands (Moreno et al., 1998; Xanthopoulos, 2000; Keeley et al., 1999).

Fire prevention policies from all over the world promote public campaigns preventing people from starting fires. Examples of these policies are the Smokey bear campaign (Keeley 2001) held in the U.S. since 1944, the Spanish "*Todos contra el fuego* —All against fire" and the Catalan "*Aprop del bosc no juguis amb foc*— Do not play with fire in the woods" (Diputació de Barcelona, 2002). As the main concern everywhere is the area burnt or to be more precise, the area burnt in large, catastrophic fires, rather than the number of fires by itself, it can be inferred from these campaigns that managers are assuming that fewer fires will translate into less area burnt. In this paper we consider large fires as those with a burned area larger than 1000 ha.

However, from a theoretical point of view the above reasoning is not so straightforward, as there are feedbacks than can modify 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 reduced area burn 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.

Here we address the question of how fire frequency relates to the total area burnt by using a model of fire regime. The model incorporates meteorological variability, different rates of fuel accumulation, number of ignitions per year, fire-fighting capacity and prescribed burning. The model successfully reproduced the fire regimes of a variety of Mediterranean regions of Europe and California (Piñol et al., 2005). In this paper we take advantage of the parameterisation of the model obtained for the Coimbra region in Central Portugal and Tarragona in NE Spain (Piñol et al., 2005) to conduct virtual experiments addressed to answer this kind of questions. In particular, we wanted to know whether or not fire frequency relates to the total area burnt and to the total area burnt in large fires. We consider two possible covariates that could affect the relationship between fire frequency and area burnt. The first one is the likely reduction in fire fighting capacity as the number of ignitions increases (the same fighting infrastructure has to be shared among more simultaneous fires). The second one is an irregular or deterministic spatial distribution of ignitions across the landscape, as we have observed in NE Spain (Salvador et al., in press).

Materials and Methods

The model

Here we provide a brief outline of the model; a more detailed description can be found elsewhere (Piñol et al., 2005). In short, the model consists on a grid of 316 x 316 pixels (*ca.* 100 000) covered by vegetation. In the context of the present study one pixel represents one hectare. The terrain within pixel is totally homogeneous except for the vegetation, which is characterized by the age since last fire. There are 11 parameters in the model related to the age of the vegetation, meteorology, number of ignitions, extinction capacity and prescribed fire. The time step of the model is one year, which has particular meteorological conditions (m_y) and a number of potential ignitions (n_i) that occur at random locations on the grid. Each fire event has also its particular meteorological conditions (m_e) that affect the ignitability (I) and the burning intensity (B) with what the vegetation will burn. Each potential ignition will become a fire depending on chance and on the actual ignitability (I_a) of that particular fire event. Once a fire starts, it propagates depending on chance and on the actual burning intensity (B_a) of that particular fire event. Extinction of the fires is represented by three parameters: the time of the fire brigade to arrive to the fire (t_e), the extinction capacity (E), and the reliability of the extinction system, i.e. the possibility that the fire brigade could not extinguish the fire. After having completed the first n_i potential annual ignitions, the age of non-burnt vegetation is increased by one unit and the new ignitability and burning intensity of the pixels is calculated. The age of burnt vegetation is set to zero years for the next time step.

From the eleven parameters, only five (s_m, n_i, E, t_b, B_{max}) were chosen to vary randomly between a specific range for each one. It was judged unnecessary to allow any variation of the other parameters because their effect was redundant, or could be balanced by the effect of another parameter. The model was parametised in Piñol et al. (2005) using fire statistics of two regions: Tarragona and Coimbra (Table 1). The model was run until 100 parameter sets were considered adequate to reproduce the observed fire regime data. Here we use the same 100 parameter data sets for each data set found there. Each one of this parameter sets is referred as a behavioural parameter set or a behaviour simulation, following the GLUE methodology (Generalized Likelihood Uncertainty Estimation) of Beven and Binley (1992).

As initially the vegetation of all pixels was set to an age of zero years it was necessary to warm-up the model, both during the calibration of the model and during the following experiments. The warming-up period lasted 131-193 years in Tarragona, and 50-77 years in Coimbra. Then, the simulation proceeded further for 4 times the warm-up period: 524-772 more years for Tarragona and 200-308 more years for Coimbra to produce the simulated long term fire statistics for the two regions.

Virtual experiments

1. Analysis of the effect of number of potential ignitions. All behavioural parameter sets were used but changing the value of the number of potential ignitions. Its value was reduced or increased by multiplying the optimized value of n_i by the following factors: 0.50, 0.67, 0.90, 1.0 (i. e., the actual value in the behavioural parameter set), 1.10, 1.33 and 2.00. All the other parameter were maintained at their original values.

Table 1. Main characteristics of the Tarragona and Coimbra regions and of their fire regimes. Only fires of at least 1 ha were considered (summarised from Piñol et al., 2005)

	Tarragona	**Coimbra**
Forested area (ha)	308 376	113 284
Period	1968-1982	1992-2002
Mean number of wildfires (year^{-1} 100 000 forested ha^{-1})	26	38
Mean annual area burnt (ha year^{-1} 100 000 forested ha^{-1})	1 494	3 815
Proportion of area burnt in fires larger than 1 000 ha	0.579	0.609

2. Combined effect of the inverse relationship between the number of ignitions and extinction capacity. We considered as an hypothesis that a higher number of ignitions would be associated to a reduction of the extinction capacity, as less resources would be available per individual fire event. This hypothesis was introduced into the model by considering that the product of both parameters (n_i and E) was a constant value k in each behavioural simulation.

$$n_i \cdot E = k$$

Thus, as n_i was increased or reduced as in experiment #1, E was accordingly changed to satisfy the above relationship. For instance, if a particular simulation doubled the number of potential ignitions n_i, the extinction capacity E was reduced to half of its original value.

3. Irregular spatial pattern of fire ignitions. All the behavioural simulations were conducted again using an irregular or random distribution of the potential ignitions across the x-axis of the virtual landscape. In particular, the probability of ignition of a particular fire (p_i) with coordinates (x, y) chosen randomly were modified in the following way:

$$p_i' = p_i' \cdot e^{-h \cdot x}$$

Where p_i' is the modified probability of ignition, x is the x-axis coordinate value, and h is a parameter that determines the distribution of ignitions across the x-axis. A value of h = 0 makes p_i the same everywhere (as in the behavioural simulations); a high value of h makes that most ignitions occur at lower values of x, that is at the left side of the virtual landscape. This is in accordance with the observed fact of accumulation of fire ignitions in some areas more than others.

In order to make this experiment totally comparable with the behavioural parameter sets, the simulation proceeded until the number of actual ignitions was exactly the same that would have been with no spatial effect. Thus, we will be able to compare the same number of ignitions distributed in different ways along the x-axis, according the value of parameter h.

Results

Experiment 1. The total area burnt slightly increased with the number of ignitions n_i, both in Coimbra and in Tarragona (Fig 1A, 1C). For instance, when the number of ignitions was halved in relation to that of the behavioural set, the total area burnt decreased only by a 4% for both sites. The proportion of area burnt by large fires increased when number of ignitions decreased (Fig. 1B, 1D): when n_i was halved, the proportion of large fires increased from 60.5% to 79.2% in Tarragona, and from 70.2% to 85.6% in Coimbra.

Experiment 2. Very similar results were found when the extinction capacity E was modified in order to keep the product $n_i \cdot E$ constant (Fig. 2). The area burnt also

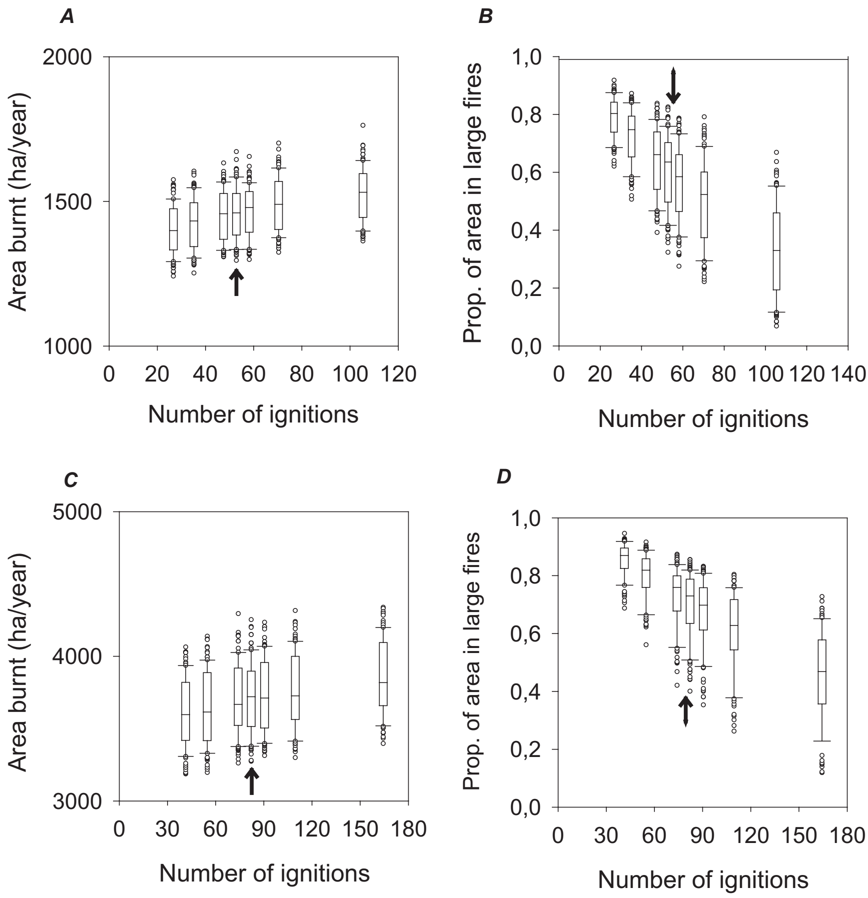

Figure 1. Effect of the number of ignitions on the area burnt (A, C) and on the proportion of large fires (B, D) in Tarragona (A, B) and Coimbra (C, D). Arrows indicate the position of the behavioural parameter sets.

showed, for both sites, a slight variation when n_i varied (around a 5% decrease when n_i was halved and 6% increase when n_i was doubled in relation to the values of the behavioural sets). The proportion of area burnt in large fires also increased when the number of ignitions decreased: when n_i was halved, the proportion of large fires increased from 60.9% to 87.0% in Tarragona, and from 70.6% to 89.6% in Coimbra.

Experiment 3. An increase in the proportion of ignitions in the left-hand side of the virtual map (high value of h) hardly affected the annual area burnt (Fig. 3A; a decrease of 7% was found when h was increased from 0 to 0.05). On the con-

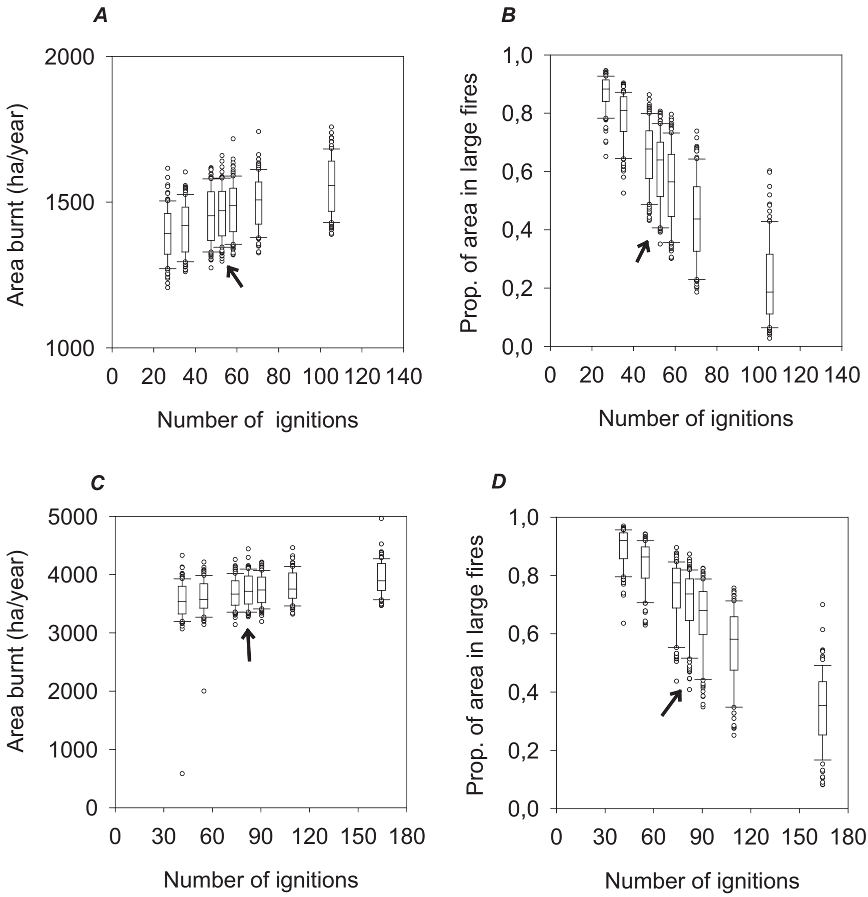

Figure 2. Effect of the number of ignitions on the area burnt (A, C) and on the proportion of large fires (B, D) in Tarragona (A, B) and Coimbra (C, D). Arrows indicate the position behavioural parameter sets. In this set of simulations the product of the number of ignitions (n_i) and extinction capacity (E) was kept constant for each behavioural simulation.

trary, the proportion of large fires clearly increased under the same circumstances (Fig. 3B; an increase of 19.4% was observed when h changed from 0 to 0.05).

Discussion

Our results contradicted the popular belief that reducing the fire frequency would accordingly reduce the total area burnt, but showed that the number of ignitions had very little effect on the total area burnt (Fig. 1A, 1C, 2A, 2C). This result completed those of Piñol et al., (2005) that showed that a variable extinction capacity and different degrees of prescribed burning also had a very slight effect on the total area burnt, but it affected the proportion of large fires. So, according to the model, it seems that the total area burnt will be more or less the same despite any effort to reduce it by reducing the number of ignitions, extinguishing fires or by using prescribed burning. This annual area burnt appears to be determined by the characteristics of the vegetation (maximum biomass and rate of the accumulation of biomass) and by the meteorological characteristics (average and standard deviation of the meteorological conditions).

Furthermore, reducing the number of ignitions had the perverse effect of increasing the proportion of area burnt in large fires (Fig. 1B, 1D, 2C, 2D): there were less fires, but these were larger. This effect was similar to that of increasing the fire fighting capacity and was the opposite of increasing the use of prescribed fire (Piñol et al., 2005). These results can be easily interpreted under the hypothesis that the main determinant of the fire regime is the accumulation of fuel in the vegetation. Processes that allow the natural accumulation of fuel, like reducing the number of ignitions or increasing the fire fighting capacity, permit the

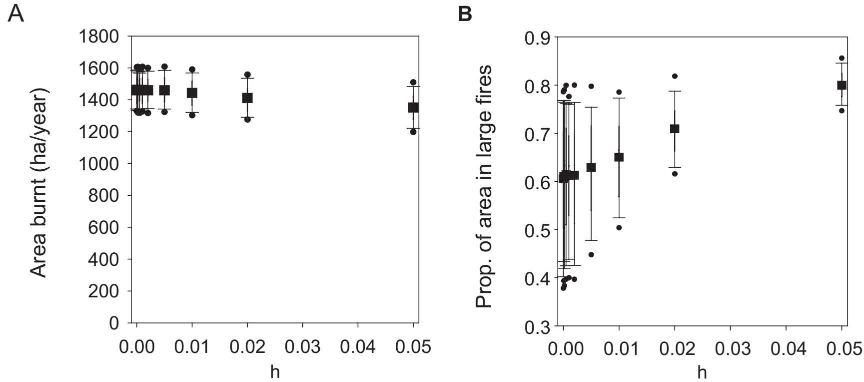

Figure 3. Effect of the irregular spatial distribution of ignitions points along the x-axis on the total area burnt (A) and on the proportion of area burnt on large fires (B) in Tarragona. A high value of the h parameter indicates a concentration of ignitions in the left-hand side of the virtual landscape; a value of h=0 indicates the same probability of ignition along the x-axis.

creation of continuous areas with a high fuel load, which will burn under adverse meteorological conditions and produce large fires. On the contrary, processes that eliminate patches of fuel, like a high number of ignitions, non-fire suppression, or prescribed burning, create a patchy mosaic in the vegetation that can behave as fuel-breaks under some circumstances, and reduce the extension of some fires that, otherwise, would become large fires.

The effect that the irregular spatial distribution of the points of ignition had on increasing the proportion of large fires (Figure 3B) can be also attributed to the formation of a large area of uniform vegetation in the region with a decreased fire frequency. From time to time an ignition will hit (or progress from the other region) this area and create a large fire.

Our simulations are in accordance with the ideas of Minnich (1983, 2001). He maintains that is the accumulation of high fuel loads over large areas the main reason behind the occurrence of large fires. His conclusions were derived from the comparison of the fire regime of Southern California (SC, USA) and Northern Baja California (NBC, Mexico). Both regions shared a similar vegetation and climate, but differed in their respective fire-fighting policies: SC had a general fire-suppression policy, whereas in NBC wildfires were allowed to burn freely. Minnich (1983) and Minnich and Chou (1997) showed that both SC and NBC had a similar mean annual area burnt (1.4% of the territory per year), but differed in the proportion of large fires, as there were many more in SC than in NBC.

Minnich's findings have been heavily criticized by other authors (Keeley et al., 1999; Moritz, 2003; Moritz et al., 2004) who maintain that large fires in Mediterranean areas occur under periods of very adverse weather, like Santa Ana winds in California. Under extreme weather conditions all kind of vegetation burns anyway, so there is not any help from artificially reducing the fuel load in the vegetation. At this moment, the debate among the fuel and the weather hypothesis behind large fires is far form being over. In fact, our model gave support to the importance of fuel accumulation to produce large fires, but failed to support another of the Minnich's main hypothesis, the so-called paradox of the extinction. This hypothesis states that large fires are a modern artefact induced by fire-suppression, but our model produced large fires in all circumstances, even without fire-suppression (Piñol et al., 2005).

The results and conclusions of our modelling exercise have to be considered together with those of Piñol et al. (2005). In conjunction, they suggest that current policies in all Mediterranean countries, based only in reducing the number of ignitions by suppressing fires, will not reduce the extension of the area burnt in large, catastrophic fires. Fire –fighters can extinguish most of the fires, but when there is one out of the extinction capacity, it burns larger areas than when fire –exclusion policies were not as powerful as today. Fire –exclusion policies have to be inevitably complemented with fuel-reduction techniques and fire prevention management of the forest. Strategic areas with different fuel loads would probably help in the extinction of large wildfires and might help to prevent catastrophic events to occur as frequently as they have been occurring in the Mediterranean basin in the last 20 years.

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