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Strategies to prevent forest fires and techniques to reverse degradation processes in burned areas

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ABSTRACT

Forest fires are probably the more deleterious event in forest and range areas in the Mediterranean nowadays. Despite the significant area burned every year, little has been done to develop strategies and techniques for soil and water conservation in burned areas, despite the major impacts on soil erosion and hydrological processes.

The main problem is the fast speed at which soil and water degradation occur right after the fire, in response to the first autumn rainfall events. This limits the opportunities to mitigate the deleterious impacts. This paper presents several ex-ante strategies and techniques, such as the forest planning, prescribed fire and preventive forestry, and several ex-post techniques, such as mulching, seeding, hillslope barriers, creating infiltration opportunities, channel treatments and ecosystem restoration. To be effective and implementable, techniques must be in place as soon as possible, if possible before the first rainfall events, since a significant exportation of ash and soil losses occur after the first rainfall events from burned systems.

The ex-post techniques can mitigate the degradation processes, but due to the fast implementation and to the associated costs, should be implemented in key points within the burned area, driven by the knowledge on how hydrological and erosion processes work in burned areas. The objective is to attain the most cost-effective strategies and techniques that might include the integration of several techniques at various scales, to reduce the output of water, sediments and nutrients, and therefore the degradation of local ecosystems.

1. Introduction

Forest fires are probably the phenomenon with the greatest environmental impacts in Portugal. Hydrological processes and erosion shred a resource that is already degraded for start due to the physical constraints that make them not suitable for agriculture due to the sharp slope angles and the stony, poorly structured shrubland soils that are often used to grow commercial forest crops such as *Eucalyptus globulus* and *Pinus pinaster* (Ferreira et al., 2005a,b).

Forest fires have a severe deleterious impact on very shallow and fragile soils, which results to soil fertility and productivity losses (Shakesby, 2011), and ultimately to the complete erosion of the soil horizons leaving bedrock outcrops exposed to the atmosphere.

In the case of Portugal, no consequent effort has been taken widely to eliminate or mitigate the degradation impacts of wildfires, it is apparent that in face of the loss of productivity capacity and the weakening of ecosystem environmental services, a more assertive attitude towards soil and water conservation in burned areas should be sought after. The strategies and actions to deal with soil erosion and degradation should be rooted on the knowledge gained about the erosion processes and the bio-geo-chemical cycles, to develop optimized solutions for soil and water conservation at the most favourable cost-effect relations (Ferreira et al., 2008a).

The degradation of burned areas presents several specific problems. To start, the size of burned areas makes any intervention covering the entire burned area, prohibitive (Macdonald and Larsen, 2009). The second problem is the extreme haste at which the degradation processes occur. Most of the nutrients are lost in the first months after the fire (Ferreira et al., 2005a; Prats et al., 2014b; Spiegel and Robichaud, 2007).

The processes connectivity at slope level and their impact on the transmission of water and sediments from the slopes to the water courses plays an important role in the degradation of burned areas. The enhanced connectivity/continuity results from the absence of heterogeneity, which is a key aspect when designing ex-ante and ex-post solutions to reduce wildfire impacts on the soil and water

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conservation. The increase in connectivity and consequent transmission of downstream flows between different components of the landscape often exceeds the threshold of generation of catastrophic processes at wider areas (Ferreira et al., 2008a), that can produce important property losses and even the loss of human lives. Thus, the strategies and techniques must promote landscape diversity, essential to construct discontinuities at the micro and meso scales, with the purpose of inducing rupture on the continuity/connectivity of soil and water degradation processes (Ferreira et al., 2008a).

Robichaud et al (2000) provide a qualitative description and evaluation of various techniques used to mitigate the impacts of forest fires. There is now enough research about post-fire mitigation, but not a lot of comparative analysis between treatments (e.g. Albaladejo et al., 2000; Badía and Martí, 2000; Robichaud, 2005; Fox et al., 2006; Robichaud et al., 2006, 2008a,b, 2013a,b,c; Wagenbrenner et al., 2006; Fernández et al, 2011; Hubbert et al., 2012; Prats et al., 2012, 2014b, in press).

Despite the urgency and relevance of studying and developing strategies to reduce soil and water degradation after forest fires, the solutions must be evaluated on a cost/benefit basis (Macdonald and Larsen, 2009). This implies that to be feasible, any solution should be applicable to key locations specifically selected to allow the greatest possible impact in terms of conservation at the lowest possible cost (Fox et al., 2006; Prats et al., 2014a).

The pace at which the degradation takes place after the fire (Ferreira, 1996; Ferreira et al., 2005a), limits the options available to mitigate the degradation processes, namely those resulting from an increase in runoff, erosion rates and dissolved nutrients exported shortly after the fire. Ferreira et al. (2005a) found that most of the losses occur in the first months after the fire. Once that the window of disturbance used to be maxima immediately after wildfires (Shakesby and Doerr, 2006) the management options to solve the problem can be synthesized at two levels:

a) Before the fire, possibly during the plantation of forest stands, installation of measures and planning the activities to be carried out inside the burnt area, so that the forest fire occurrence does not degenerate into a catastrophic phenomenon.
b) Immediately after the fire, implementation of measures to reduce the transmission of water, sediment and solutes towards the stream channel and downstream, out of the watersheds.

The management of the burned areas will consist of a range of techniques that will be carried out before (ex-ante) and after (ex-post) the fire; i.e., respectively preventive and mitigating strategies.

According to Moreira et al. (2008), land use planning for wildfire prevention has to take into account three main aspects: a) to facilitate forest accessibility, b) to limit wildfire spread by splitting the landscape in small forest units and c) to reduce wildfire severity by carrying out fuel management. Nevertheless, the main preventive strategies to reduce fire incidence and its deleterious effects will be to promote land use diversity, building a landscape mosaic that can reduce the area burned in case of fire outbreak (Ferreira et al., 2010). This philosophy is already evident in the Portuguese Decree-Law No. 124/2006 of 28 June 2006, which establishes the National System for Forest Fire Prevention and Protection. It lays on a set of infrastructures in rural areas, consisting in the creation of networks of fuel managed firebreaks, fuel management plots, creating a landscape mosaic, fuel managed strips along the forest roads and a network of water points, among others. Landscape diversity acquires an enormous importance in the management before the fire, since the variety of landscapes and infrastructures can be planned so as to hamper fire progression, thus reducing the area burned. These discontinuities and infrastructure should be also designed to reduce the hydrological connectivity and lower erosive response.

The emergency of intervention strategies after fire should be addressed first and foremost to soil erosion mitigation, with the objective of reducing the magnitude of hydrological processes and erosion at the scale they are implemented, preventing the degradation processes to act in the first place and preventing the add up of processes that will trigger catastrophic events at wider scales. Among the actions taken to prevent degradation to happen in the first place we will act not only on the source of runoff and erosion, the slopes, but also on the waterlines and roads (Fig. 1).

The rate at which the degradation takes place after the fire (Ferreira, 1996; Ferreira et al., 2005a), limits the options available to intervene the burned areas. In the case of the United States of America (USA), with a long tradition in rehabilitation and restoration, GAO (2006) divided the post-fire treatment activities into emergency stabilization, rehabilitation and restoration, depending on the objectives and timing. Emergency stabilization treatments are conducted as soon as possible after the fire to stabilize hydrological and erosion processes of burned area, protect public health and safety, and reduce the risk of additional damage to valued resources. Rehabilitation and restoration are longer-term activities to repair access and recreation repairing (i.e., roads, bridges) and to mitigate degraded areas that cannot recover to pre-fire conditions on its own (i.e., tree planting, noxious plant reduction, fuel control; in Robichaud et al., 2010).

In the Iberian peninsula context, Vallejo and Moreira (2008) recognized five phases to effectively manage the burned areas: i) Identification of vulnerable areas and values at risk, ii) in situ wildfire impacts assessment, regarding special wildfire severity, iii) emergency interventions, focused mainly in soil erosion control to protect the values at risk, iv) intermedium phase, to analyse the forest response to the interventions during the second–third post-fire years and v) long term recovering phase, in which the forest management plans defined for the burned area must be executed.

2. Ex-ante

2.1. Planning

The landscape is largely the result of the human interaction with the territory. In fact, the 'natural' ecosystems suffered for millennia in the interaction with the human species, the main factors responsible for the shaping of the present forest formation (Shakesby, 2011). However, in Portugal, the introduction of homogeneous and flammable forest plantations and the rural exodus that occurred since the mid-twentieth century increased the homogeneity of the forest ecosystems, leading to increased wildfire susceptibility (Ferreira et al., 2008).

Due to the magnitude that wildfires acquired in Portugal, several strategies were developed in recent years to reduce its occurrence, including a set of tools applied to forest areas that have gradually been changing the management of forest areas. These include the Portuguese Standard for Sustainable Forest Management Systems (PSFMS) and the Forest Intervention Areas (ZIF). These plans allow the identification and classification of fire risk and promote the creation of discontinuities to limit fire progression.

These are thought to improve the forest area management by creating forest management units with a size compatible with local sustainable objectives and actions. In what concerns fire prevention, it does not make sense to use a property scale, since the typical forest property in the north and centre of Portugal is very small (typically < 2 ha). Since fire knows no boundaries, many other land uses apart from the forest itself must be considered, including the entire rural context. There is a need to divide the landscape into smaller units in order to make it less vulnerable to wildfires. This landscape mosaic can be set in place, for example, by maintaining the riparian vegetation around the water lines, by keeping the ridge lines of hills and mountains with a low charge of fuel, by clearing the vegetation around the roads and tracks and by managing the fuel at the firebreaks