Geomorphology 270 (2016) 172–183

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Annual runoff and erosion in a recently burn Mediterranean forest – The effects of plowing and time-since-fire

D.C.S. Vieira [a,*], M.C. Malvar [a], C. Fernández [b], D. Serpa [a], J.J. Keizer [a]

[a] Centre for Environmental and Marine Studies (CESAM), Dept. Environment and Planning, U. Aveiro, 3810-193 Aveiro, Portugal
[b] Centro de Investigación Forestal de Lourizán, Consellería do Medio Rural e do Mar, Xunta de Galicia, PO Box 127, 36080 Pontevedra, Spain

ARTICLE INFO

Article history:
Received 10 April 2016
Received in revised form 28 June 2016
Accepted 29 June 2016
Available online 19 July 2016

Keywords:
Wildfire
Runoff
Soil erosion
Land management
Plowing
Time-since-fire
Window of disturbance

ABSTRACT

The impacts of forest fires on runoff and soil erosion have been assessed by many studies, so the effects of fires on the hydrological and geomorphological processes of burnt forest areas, globally and in the Mediterranean region, are well established. Few studies, however, have assessed post-fire runoff and erosion on large time scales. In addition, a limited number of studies are available that consider the effect of pre-fire land management practices on post-fire runoff and erosion.

This study evaluated annual runoff and sediment losses, at micro plot scale, for 4 years after a wildfire in three eucalypt plantations with different pre-fire land management practices (i.e., plowed and unplowed). During the four years following the fire, runoff amounts and coefficients at the downslope plowed (1257 mm, 26%) and contour plowed eucalypt sites (1915 mm, 40%) were higher than at the unplowed site (865 mm, 14%). Sediment losses over the 4 years of study were also consistently higher at the two plowed sites (respectively, 0.47 and 0.83 Mg ha^{-1} y^{-1} at the downslope and contour plowed eucalypt site) than at the unplowed site (0.11 Mg ha^{-1} y^{-1}). Aside from pre-fire land management, time-since-fire also seemed to significantly affect post-fire annual runoff and erosion. In general, annual runoff amounts and erosion rates followed the rainfall pattern. Runoff amounts presented a peak during the third year of monitoring while erosion rates reached their maximum one year earlier, in the second year. Runoff coefficients increased over the 4 years of monitoring, in disagreement to the window of disturbance post-fire recovery model, but sediment concentrations decreased over the study period.

When compared with other long-term post-fire studies and with studies evaluating the effects of pre- and post-fire management practices, the results of the present work suggest that an ecosystem's recovery after fire is highly dependent on the background of disturbances of each site, as runoff and erosion values were higher at the plowed sites than at the unplowed site.

1. Introduction

Wildfires are a natural phenomenon in regions with a Mediterranean-type climate (Naveh, 1990). However, the current fire regime in southern Europe is unprecedented when compared to the natural fire cycle strongly reflecting human activity either from intentional or unintentional fire ignition (Veléz, 2009) or to land use changes, namely land abandonment and introduction of highly flammable trees, such as pine and eucalypt (Moreira et al., 2009; Shakesby, 2011). On average, wildfires consume 500,000 ha/y of land in southern Europe (San-Miguel and Camia, 2009), 100,000 ha of which burn in Portugal alone (Pereira et al., 2006a). Despite the existence of prevention measures, fire activity is not expected to decline in Portugal in the near future not only because of the continuous use of highly flammable tree species by the economically important paper pulp industry, but also because of the climate change projections that foresee an increase in the frequency of fire-prone meteorological conditions (Pereira et al., 2006b; Harding et al., 2009; Carvalho et al., 2010).

Assessing the effects of wildfires on forest ecosystems allows for a better understanding of the on- and off-site impacts of wildfires, which is essential for defining post-fire management practices, especially in areas with a high risk of erosion (Vieira et al., 2014). According to the work of Shakesby and Doerr (2006) and Shakesby (2011) in this region, the first post-fire rainstorms usually cause enhanced runoff and erosion in burned areas. This effect is commonly attributed to the partial or complete combustion of vegetation and litter, together with fire-induced changes in soil properties such as, a reduction in aggregate stability (e.g., Varela et al., 2010; Mataix-Solera et al., 2011) and an increase in soil water repellency (SWR; e.g., Scott et al., 1998), a phenomenon that has been widely reported in burned forest soils (e.g., Wells, 1981, Vega and Díaz-Fierros, 1987; Prosser, 1990; Walsh et al., 1994; Keizer

* Corresponding author.
E-mail address: dianac.s.vieira@ua.pt (D.C.S. Vieira).

http://dx.doi.org/10.1016/j.geomorph.2016.06.042
0169-555X/

et al., 2008). In Portugal, increased runoff and erosion have been reported for the two principal forest types in the country, i.e. maritime pine and eucalypt plantations (e.g., Shakesby et al., 1994; Ferreira et al., 1997; Coelho et al., 2004;) particularly in the first year after the fire. This post-fire enhanced hydrological and erosive response, however, tends to decrease as vegetation recovers (Prosser and Williams, 1998).

In addition to the fire, post-fire land management practices, (e.g., plowing, terracing, clearcutting and logging) are also known to influence runoff and erosion in Portuguese woodlands (Shakesby et al., 1993, 2002; Terry, 1996; Fernández et al., 2004, 2007; Martins et al., 2013). These management practices, which are commonly used in preparation for new eucalypt plantations, often involve ground preparations or the use of heavy machinery that can have significant impacts on topsoil, leading to similar, or even greater, hydrological and erosive responses than those triggered by the fire itself (Shakesby et al., 2002; Fernández et al., 2007; Martins et al., 2013). When these disturbances are executed between subsequent fires, the negative impacts of fires tend to be magnified (Shakesby, 2011; Vieira, 2015). In fact, according to Shakesby (2011), the significance of post-fire erosion in Mediterranean fire-prone areas can only be accurately assessed if land management practices and their respective effects are considered. However, in Portugal, only limited research has examined the effects of pre-fire land management operations on post-fire runoff and erosion (Malvar et al., 2011, 2016).

Despite the history of environmental disturbances, post-fire erosion rates in the Mediterranean region are lower than those reported elsewhere (Emmerich and Cox, 1992). Such low erosion rates have been mainly attributed to the low depth and high stone content of Mediterranean soils (Cerdan et al., 2010). The abundance of stones, in particular, is thought to limit the extent or continuity of water repellent soils so that infiltration is higher than in areas with less stone cover (Urbanek and Shakesby, 2009). The armoring of soil surface by stones is also known to limit the availability of sediment for transport (Shakesby, 2011) and to increase surface roughness (Kutiel et al., 1995), promoting infiltration and limiting water availability for overland flow generation and soil erosion. These thin and highly stony Mediterranean soils are mainly a consequence of land degradation caused by a long history of anthropogenic impacts such as deforestation, intensive agriculture, land misuse, and rural abandonment (Dunjó et al., 2004). However, the typically low soil formation rates in the region are also likely to contribute to the existence of poorly structured soils (Cerdà, 2001; López-Bermúdez, 2002).

Fires increase the risk of degradation of the already shallow and poor Mediterranean soils (Shakesby and Doerr, 2006; Shakesby, 2011). However to fully understand the magnitude of this risk, more studies are needed on the long-term effects of wildfires on the hydrological and erosive response of forest areas. So far, few studies have monitored erosion rates beyond the first and second year after fire (Benavides-Solorio and MacDonald, 2001; Shakesby, 2011), and even fewer have monitored runoff beyond the second year (e.g., Mayor et al., 2007, Noske et al., 2016). Most of the existing studies have shown that post-fire erosion during the period of the window of disturbance takes the form of a peak lasting one to two years, followed by a decline of varying degrees until returning back to pre-fire conditions (e.g., Helvey, 1980; Robichaud and Waldrop, 1994; Inbar et al., 1998; Noske et al., 2016). Key factors determining the shape of the response include burn severity, fire recurrence, post-fire land management operations, and recovery of the vegetation (Shakesby et al., 1996; MacDonald and Larsen, 2009; Wittenberg and Inbar, 2009; Martins et al., 2013; Vieira et al., 2015).

The main aim of the present study was to assess the long-term (4 years) effects of fires on runoff and sediment losses in three eucalypt forest areas with different backgrounds of disturbances (i.e. wildfires and plowing operations). The specific objectives of this study were to evaluate the effects of (i) pre-fire land management practices, namely no plowing, downslope plowing, and contour plowing and, (ii) time-since-fire, on the hydrological and erosive response of burnt forest areas. Long-term measurements of runoff and erosion were also used for comparing the annual responses with the existing models of the window of disturbance (Prosser and Williams, 1998; Wittenberg and Inbar, 2009), in order to evaluate which model was most representative of the study area and to assess the state of recovery of the area 4 years after the fire.

2. Materials and methods

2.1. Study area and study sites

This study was carried out in a completely burned 11 ha catchment located near the Colmeal village (40°08′46″N, 7°59′50″W), in the municipality of Góis, central Portugal (Fig. 1A). This catchment was burned on 27 August 2008. Within the burnt area, three hillslopes with commercial eucalypt plantations of different ages were selected for their contrasting pre-fire land management practices - i.e. no plowing (U site), downslope plowing (DP site), and contour plowing (CP site; Fig. 1B). According to simple field indicators (i.e. tree canopy and woody debris consumption, litter combustion, ash colour, and mineral soil), the three sites appeared to have experienced a low-to-moderate burn severity since tree canopies and most of the logs were only partially consumed, the litter layer was fully consumed, the ash was black, and the mineral soil was not changed (Hungerford, 1996; DeBano et al., 1998). The 'Twig Diameter Index' (TDI), calculated based on the diameter of the three thinnest remaining twigs of each measured shrub (10 per site), also confirmed the existence of a moderate severity fire since an intermediate value (0.5) was found in an index that typically varies from 0 (unburned) to 1 (severely burned; Maia et al., 2012).

The climate of the study area can be characterized as humid meso-thermal (Köppen, Csb), with prolonged dry and warm summers. Mean annual temperature at the nearest climate station (GÓIS (13I/01G), SNIRH, 2012) is 12 °C. Mean annual precipitation at the nearest rainfall station (10 km) is, on average, 1133 mm (GÓIS (13I/01G), SNIRH, 2012).

The study area lies over pre-Ordovician schists and greywackes (Ferreira, 1978; Pimentel, 1994), which have given rise to shallow soils typically mapped as Humic Cambisols (Cardoso et al., 1971, 1973). However, according to soil profile descriptions carried out at the end of the monitoring period (2012), the soils in the study area were found to range from Humic Cambisols to Haplic Umbrisols at the DP and CP sites, and from Haplic Umbrisols to Umbric Regosols at the unplowed (U) site (Table 1). The A horizon of all three study sites had a rather coarse, sandy loam texture (sand >70%) and a high stone content (40–46%; Table 1).

Soil profile descriptions were also used to define the timeline of earlier disturbances at the study sites (Fig. 2). The presence of ash and charcoal particles below the A horizon indicated that all study sites had been affected by a previous fire and were then plowed afterward (Fig. 2). According to the existing burnt-area maps (ICNF, 2014), this previous fire had occurred in 1990. The depth of the buried ash and charcoal particles suggested that this past plowing was done to considerably greater depth at the DP site (50–60 cm) than at the U and CP sites (20–30 cm). The buried ash and charcoal particles did not form a clear layer at the CP site, probably caused by a subsequent plowing in 2002 (pers. comm. by land managing organization). When selecting the study sites, signs of plowing were not visible at the U site, while signs were visible at the CP site (along contour lines) as well as at the DP site (downslope direction). Contrast in micro topography was quantified at the end of the monitoring period by measuring the downslope random roughness (RR) of all micro-plots, as further detailed in Section 2.2. The RR of the U plots was markedly lower than that of the DP plots and of the CP plots, averaging 1.12, 1.53, and 2.00 cm, respectively (Table 1). During the monitoring period, only the CP site was intervened by management