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# Effects of mulching and post-fire salvage logging on soil erosion and vegetative regrowth in NW Spain

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ABSTRACT

Mulching is frequently used to reduce runoff and erosion following high-severity wildfires. In commercial forest stands, post-fire salvage logging is common practice, although it can lead to increased erosion losses in recently burned areas. Field research concerning the effects of post-fire salvage logging on sediment production is limited and the effects of clearcutting in areas previously treated by mulching are not known. In this study, 36 experimental plots were established in three experimental sites affected by crown fires that caused moderate-high soil burn severity in the summer of 2013. Immediately after the fire, bark strands mulch was applied in 18 of the plots. Salvage logging took place at the end of the first winter following fire. Post logging treatments were: mulching + salvage logging, no mulching + salvage logging and no mulching + no logging. The objectives of the study were to determine whether mulching mitigates soil erosion caused by fire and salvage logging and also to assess the possible effects of wildfire and salvage logging, with and without mulching, on vegetation recovery. During the six month period lapsed between the wildfire and salvage logging, precipitation was higher than the annual mean in the area, and the average soil loss in the untreated burned soils was 18.5 Mg ha$^{-1}$. In that period, mulching significantly reduced soil loss (84%). In the 18-month period following salvage logging and in the absence of mulch, there was no increase in erosion due to logging (8.7 Mg ha$^{-1}$) compared with the unlogged treatment (7.0 Mg ha$^{-1}$) whereas mulching reduced significantly soil losses even after logging (2.3 Mg ha$^{-1}$). Neither mulching nor salvage logging had any detrimental effects on the regeneration of natural vegetation. Our results showed that the mulching just after a fire can substantially reduce the subsequent erosion due to post-fire salvage logging without any significant adverse effects on vegetative regrowth. In addition, leaving the standing burned trees seemed not to be a feasible management option to reduce post-fire erosion and enhance vegetation recovery in those kind of stands.

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## 1. Introduction

Wildfire is considered one of the most important agents of soil erosion and land degradation in forest ecosystems (Shakesby, 2011), mainly due to increased runoff and erosion rates (Benavides-Solorio and MacDonald, 2005; Spigel and Robichaud, 2007; Fernández et al., 2011; Vega et al., 2015). In forested areas, wildfire typically generates a mosaic of different levels of damage in understory and canopy vegetation layers. In sites affected by moderate fire severity, needle cast occurs when leaves from impacted trees fall, increasing ground cover on burned soil, and thus protecting it from erosion (Pannkuk and Robichaud, 2003; Cerdà and Doerr, 2008; Prats et al., 2012; Robichaud et al., 2013). However, when canopy needles are consumed by fire (crown fire), post-fire soil erosion mainly depends on soil burn severity (Fernández and Vega, 2015). Soil stabilization treatments are crucial for mitigating the post-fire erosion risk (Robichaud et al., 2010; Vega et al., 2013a). Mulching is increasingly used to stabilize soil after fire, by providing cover that reduces raindrop impact, prevents soil sealing, promotes infiltration and slows runoff (Smets et al., 2008). Agricultural straw has traditionally been used for mulching because of its effectiveness in reducing post-fire erosion losses (Wagenbrenner et al., 2006; Fernández et al., 2011; Robichaud et al., 2013; Fernández and Vega, 2014b; Vega et al., 2014, 2015), although there are also some disadvantages associated with its use (e.g. susceptibility to be blown by the wind, rapid loss on steep slopes, risk of introduction of non-native species). In recent years, mulches made from forest residues have also proved their usefulness for mitigating erosion and runoff (Foltz, 2012; Prats et al., 2012; Robichaud et al., 2013; Fernández and Vega, 2014b) although the data available is still limited.

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Salvage logging is carried out after fire to recover some of the value of the wood (Moreira et al., 2012), to reduce the risk of pest infestation (Santolamazza et al., 2011) and to facilitate subsequent reforestation activities (Peterson et al., 2009; Moreira et al., 2012). Increased risk of future fires due to the accumulation of fuel due to fallen burned trees and snags is other reason used to justify post-fire clearcutting (McIver and Ottmar, 2007; Keyser et al., 2009).

The potential ecological effects of post-fire salvage logging are also of concern, although controversial (Beschta et al., 2004; Karr et al., 2004; Lindenmayer et al., 2004; Lindenmayer and Noss, 2006). More specifically, some authors argue that burned soils are sensitive to the increased soil compaction caused by the machinery used in logging operations, which leads to reduced water infiltration and accelerated erosion (Fernández et al., 2007; Wagenbrenner et al., 2015). However, the effects of post-fire salvage logging on sediment yields have been shown to be moderately low (Marques and Mora, 1998; Spanos et al., 2005; Fernández et al., 2007; Wagenbrenner et al., 2015) and the impacts of salvage logging on soil properties and erosion strongly depend on the quantity and treatment of logging slash (Fernández et al., 2004, 2007; Page-Dumroese et al., 2006; Wagenbrenner et al., 2015). Emergency post-fire mulching may therefore be critical for reducing soil erosion, especially after clearcutting in areas affected by crown-fire, where soil is exposed to the action of rainfall and the amounts of logging debris may be low. However, nothing is known about the effects of post-fire mulching applied before salvage logging.

Post-fire salvage logging has been reported to have detrimental effects on seedling stocking and on vegetation cover and diversity (Donato et al., 2006; Castro et al., 2011; Leverkus et al., 2014; Morgan et al., 2015), although moderate to null effects on natural regeneration after wildfire and salvage logging have also been reported (Spanos et al., 2005; Fernández et al., 2008; Vega et al., 2008, 2010; Peterson and Dodson, 2016). Mulching may also affect vegetation recovery in some cases (Kruse et al., 2004; Dodson and Peterson, 2010; Fernández and Vega, 2014b), but the possible effects of the interaction between mulching and salvage logging on the vegetation response are uncertain.

In summary, although the pros and cons of salvage logging have been debated for years, little has been resolved (Peterson et al., 2009). In NW Spain where more than 50% of timber in Spain is harvested, the forest area burned makes up around 30% of total burned area in Spain during the last ten years and where the highest post-fire soil losses in the whole country have been recorded (Cerdá and Mataix-Solera, 2009) this issue remains critical.

The objectives of the study were to determine whether mulching mitigates soil erosion caused by fire and salvage logging and also to analyse the possible effects of wildfire and salvage logging, with and without mulching, on vegetation recovery. We hypothesized that: (a) application of eucalypt bark strands mulch would reduce soil losses both after fire and after salvage logging and (b) salvage logging and mulching would affect vegetation regeneration.

## 2. Materials and methods

### 2.1. Study sites

The study was carried out in the area affected by the *Oia-O Rosal* wildfire (Pontevedra, NW Spain), which began on 26 August 2013 and was extinguished on 28 August. At the time of ignition, the air temperature was 22 °C, relative humidity, 49%, and wind velocity (at a height of 10 m), 33 km h$^{-1}$ (NNE), with gusts of 51 km h$^{-1}$. The most recent precipitation had occurred 19 days before the fire. The Canadian FWI index (Forest Fire Weather index) was within the 98th percentile of the values for the period 2006–2012. The Drought Code and Duff Moisture Code indexes were also within the 95th and 98th percentiles respectively, reflecting low moisture contents in the lower duff and surface soil. Under these conditions, the fire spread rapidly in N-S and N-SE directions exhibiting spotting and crown fire runs. The wildfire burned 1824 ha of forest land, mainly comprising *Pinus pinaster* Ait. of pole size (52%), *Eucalyptus globulus* Labill. (36%), *Pinus radiata* D. Don. and patches of deciduous tree stands. The understory is dominated by dry heathland (mainly *Ulex* sp., *Erica* sp. and *Pterospartum tridentatum* (L.) Willk.).

Three sites covered by *P. pinaster* and affected by crown fire (tree mortality was 100%) were selected for study immediately after the fire (Fig. 1). Distance between sites varied from 600 to 1800 m. Elevation ranged between 125 and 325 m and aspect was W-SW. The mean tree density was about 850–1200 trees ha$^{-1}$, basal area, 19–37 m$^2$ ha$^{-1}$, and height, 14–18 m. Serotiny was not observed in the affected stands.

The climate in the area is oceanic. The average rainfall is about 1572 mm year$^{-1}$ (35 years long mean; 470 m elevation), with a dry period of two months in the summer. 70% of the annual precipitation is concentrated in the period October-April. The mean annual temperature is 14.5 °C. The soils were developed on micaschist, and classified as Alumi-umbric Regosols (FAO, 1998). Soil texture was sandy-loam.

### 2.2. Experimental design

Immediately after the wildfire, twelve experimental plots (20 × 4 m each) were established with their longest dimension along the maximum slope in each of the three experimental sites, yielding a total of 36 plots in the study area. Mean stoniness was 23%. Plot slope varied between 22 and 55%.

The upper borders of erosion plots were delimited by geotextile fabric fixed to posts, and trenched to prevent external inputs from runoff or erosion. Sediment fences (Robichaud and Brown, 2002) were erected in the downhill portion of the plots to enable periodic collection of sediments. The geotextile fabrics were removed immediately before harvesting and re-installed just after it. A few days after the fire and before any rainfall, two transects were placed in each plot parallel to the longest dimension of the plot. Soil burn severity was assessed in 20 cm × 20 cm quadrats placed at thirty systematically selected points along transects and a numerical value was assigned to each quadrat following the modification of the soil burn severity index proposed by Vega et al. (2013b) and a numerical value was assigned as follows: 0. Unburnt soil; 1. Burnt litter layer (Oi layer) but limited duff (Oe + Oa layers) consumption; 2. Oa layer totally charred and covering mineral soil, possibly some ash deposition; 3. Soil organic layer (Oi + Oe + Oa) completely consumed (bare soil) but soil organic matter not consumed and surface soil intact, some ash deposition; 4. Soil organic layer completely consumed, soil organic matter in the Ah horizon partially consumed and soil structure altered within a soil thickness less than 1 cm. Noticeable ash deposition; 5. As 4, but with the thickness of affected soil equal to or more than 1 cm; and 6, as 4 or 5 and colour altered (reddish). According to this method, a mean value was obtained for each plot, ranging from 2.6 to 3.5 (moderate-high), and the mean value was 3.0.

Mulching and control treatments were assigned at random to six replicate plots per treatment in each site. The mulch consisted of eucalypt bark strands, a by-product of *E. globulus* timber processing (Fig. 2). The bark strands were spread manually on the plots at a rate of 11 Mg ha$^{-1}$ (dry weight). That dose was three times the used by Fernández and Vega (2014b) to achieve a burned soil cover higher than 80%. Initial mulch cover and depth were 87% and 3 cm, respectively. No mulch was applied to the control plots.

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