Forest Ecology and Management 400 (2017) 555–567

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Short-term effects of post-fire salvage logging on runoff and soil erosion

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ARTICLE INFO

Article history:
Received 11 April 2017
Received in revised form 11 June 2017
Accepted 12 June 2017
Available online 28 June 2017

Keywords:
Wildfire
Logging
Skid-trail
Eucalypt
Runoff
Erosion

ABSTRACT

Research has been undertaken on the hydrological and erosional impact of forest fires, but remarkably little work has been conducted on salvage logging operations that often follow them. We assessed the effects of mechanical salvage logging following wildfire on soil physical properties, ground cover, and runoff and erosion response on a eucalypt stand in Portugal. We compared two levels of mechanical disturbance, skid trails by a wheeled forwarder tractor ("skid_low") and skid trails by the same tractor followed by a tracked feller-buncher ("skid_high") with control conditions (no mechanical disturbance). Three plots (16 m^2) by level of soil disturbance were installed after a moderate intensity fire and subsequent logging operations, and monitored during the first post-fire year. In two control and two skid_low plots runoff was also measured.

Soil bulk density was higher with increasing mechanical disturbance. Soil compaction reduced porosity 7–16%, but as the control porosity was 70%, the reduced porosity still was 60–65%. Soil resistance to penetration significantly increased for the most disturbed area, whereas soil shear strength was significantly reduced in the intermediate disturbance level. Mechanical disturbance did not induce significant effects on soil moisture or ground cover. Initial greater coverage by bare soil in the disturbed plots compared to the control was compensated by a more rapid vegetation recovery in those plots.

Annual runoff amount was not higher at the skid-low than at control plots. Absence of runoff difference was due to high soil porosity of 65%, even after tractor trafficking, and a greater surface roughness on the skid_low plots compared to the control. Sediment production increased with increasing soil disturbance. The mean sediment rate was 1.6–3 times greater for the disturbed than the control plots. This increase could be explained by the higher soil compaction and reduced soil shear strength on the mechanically disturbed plots and initial differences in ground cover. Organic matter content of the eroded sediments was higher on the control than the disturbed plots, due to initial higher ash cover on the control plots.

Overall, sediment production was significantly related to rainfall intensity and reduced by vegetation regrowth. Sediment rates tend to decrease with time since the initial fire and logging disturbance, highlighting the importance of a rapid implementation of erosion control measures. Specific management practices are needed to minimize the impacts of logging in burnt soils which are already subject to greater erosion risk and soil degradation.

1. Introduction

Over the past decades, wildfires in Portugal have affected an average of 100,000 ha $year^{-1}$, becoming the most important factor inducing land-use/cover changes (Pereira et al., 2006). This corresponds to a wildfire return interval between as short as 23–52 years and it is not expected to decrease in the foreseeable future, mainly due to climate change (Pereira et al., 2006). Wildfire is considered a major agent of soil erosion and land degradation in the Mediterranean, producing marked changes in hydrological and erosion processes (Shakesby and Doerr, 2006; Shakesby, 2011). Strong post-fire hydrological and erosion response have been reported for the two principal - and fire-prone - forest types in north-central Portugal, i.e. maritime pine and eucalypt plantations (Coelho et al., 2004; Ferreira et al., 2008; Malvar et al., 2011, 2013; Prats et al., 2012, 2014; Shakesby et al., 1996). Besides wildfire itself, post-fire forestry practices such as logging, can contribute to an enhanced hydrological and erosion response in recently burnt areas (Fernández et al., 2007; Martins et al., 2013; Shakesby et al., 1996). In Portugal, logging is the most common forestry operation in recently burnt areas, especially since the principal forest types are commercial plantations. About 10^7 m^3 of timber are harvested every year (INE, 2012) with a considerable

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http://dx.doi.org/10.1016/j.foreco.2017.06.031
0378-1127/

percentage of this figure coming from recently burnt eucalypt and pine stands. Salvage logging or clearcutting, i.e. the extraction of all the timber is the most common harvesting method and is undertaken to recover burnt timber resources, reduce fuel accumulation, control resprouting in the case of the eucalypt plantations, reduce possible insect infestation hazard in the case of maritime pine plantations, and facilitate subsequent reforestation activities (Moreira et al., 2012; Shakesby et al., 1996).

Salvage logging, especially in the U.S.A, has been under debate due to its potential ecological impacts, which may include removal of habitat, introduction of exotic plant species, decrease in seedling stocks, and reduction of vegetation cover and diversity (Lindenmayer and Noss, 2006; Maia et al., 2012; McIver and Starr, 2001). In recently burnt areas, logging occurs on soils that have suffered heating-induced changes and consumption of the litter layer, making them more sensitive to further disturbances (Beschta et al., 2004)and prone to a multiplier effect of logging. This multiplier effect may occur through soil compaction and other disturbance of the topsoil, further enhancing post-fire runoff and soil (fertility) losses, which can directly or indirectly affect not only long-term site productivity but also on-site ecosystem recovery (vegetation, soil biological activity and diversity) and pollution risk of downstream aquatic systems (Campos et al., 2012; Karr et al., 2004; McIver and Starr, 2001). Frequently, intensively managed forest ecosystems need to evaluate socio-economic benefits against ecological impact, but comprehensive management should be based on an understanding of the range of impacts of a disturbance such as salvage logging. The hydrological and erosion possible impacts of post-fire salvage logging, however, have been poorly studied and, in the case of Portugal, have been by and large overlooked.

The few studies assessing the effects of post-fire salvage logging on runoff and sediment losses at the plot scale have found widely varying results. In Israel, Inbar et al. (1997) compared burnt plots (400–500 m^2) with manual and mechanical log clearing and found no differences in runoff generation. Using 300m^2rainfall simulation experiments, in Tasmania, Wilson (1999) measured higher runoff rates as the surface disturbance increased, and this was attributed to the disturbance of the biotic crust that limited runoff at the site. In western USA, Wagenbrenner et al. (2016) using simulated rill experiments, found runoff to increase as plots were disturbed by logging machinery and this was mainly attributed to a decrease in infiltration due to soil compaction. Regarding soil erosion, in some cases salvage logging did not produce significant changes in plot-scale sediment production as compared to unlogged areas (Fernández and Vega, 2016; Fernández et al., 2007; Marques and Mora, 1998; McIver and McNeil, 2006; Spanos et al., 2005; Stabenow et al., 2006). Conversely, other authors have found significantly higher erosion rates in salvage-logged areas as compared to unlogged areas (Inbar et al., 1997; Slesak et al., 2015; Wagenbrenner et al., 2015, 2016; Wilson, 1999).

This apparent discrepancy in the results can be attributed to the variability of the degree of disturbance caused by logging operations. Logging disturbances and their effects are very dependent on site characteristics – such as slope, soil type, natural vegetation recovery, and precipitation patterns – logging system, slash disposal and timing of logging relative to soil moisture conditions and fire occurrence (McIver and Starr, 2001; Wagenbrenner et al., 2015). The use of logging equipment does not affect soils uniformly and the percentage of disturbed soil has been the variable most related with the erosion response (Fernández et al., 2007; Safari et al., 2016; Wilson, 1999).

The main objective of this study was to assess the combined effect of wildfire and subsequent salvage logging on runoff and soil erosion and the role therein of key topsoil properties and ground cover characteristics. To this end, three different levels of soil disturbance due to logging machinery (none, low and high) were compared in a eucalypt forest plantation in north-central Portugal during the first year after the fire. The specific objectives were to quantify the effects of soil disturbance on: (i) soil physical properties and ground cover, (ii) post-fire runoff and erosion response.

2. Material and methods

2.1. Study area and site

This study was conducted near the Semide locality, (40°9′38″N 8°20′14″W-100 m elevation), north-central Portugal, in a forest area that was burnt by a wildfire on 9-10th August 2015, consuming a total of about 751 ha of mainly eucalypt plantations. Salvage logging within the burnt area started as soon as late September 2015, and one of the first eucalypt plantations being logged was selected for this study. In the upper part of the slope, the trees were cut "manually" with a chain-saw and the logs were removed from the slope and piled on a rubber wheeled forwarder tractor. In the bottom part of the slope, both a tracked feller-buncher and the forwarder tractor were used to cut and remove the burnt logs. Based on visual observations, we identified three sub-areas with three levels of disturbance by the logging machinery: (i) control: logs were manually cut and removed with no mechanical disturbance (ii) "skid_low", with skid trails by the forwarder tractor with two passes; (iii) "skid_high", with skid trails resulting from several passes by both the forwarder tractor and the feller-buncher (Fig. 1). The control and skid_low areas were located on the upper part of the slope, whereas the skid_high area was located on the lower part. No slash treatment or removal was done after the logging in any of the sub-areas.

Complete combustion of the litter layer and tree canopies, as well as the predominantly black color of the ash layer, suggested a moderate fire severity, according to simple field indicators proposed by Shakesby and Doerr (2006). The Twig Diameter Index also suggested a moderate burn severity, based on the diameter of the thinnest remaining twigs of each measured shrub in a transect close to the plots (3–5 shrubs × 9 sampling points), with values amounting 0.4 – 0.5, in a range of 0 (unburnt) to 1 (severely burnt) (Maia et al., 2012).

The climate of the study area is Mediterranean with mild winters and warn, dry summers (Csb, according to Köppen). The 22-year average annual rainfall at the nearest rainfall station ('Carapinhal', 7 km south) was 828 mm on average.

Soils were developed from pre-Ordovician schists of the Hesperic Massif (Pereira and Fitzpatrick, 1995). Two soil profiles described in a nearby slope were classified as Epileptic Umbrissol (WRB, 2014). The soil depth was 30 cm and field soil texture was loam. On 0–5 cm soil depth, stone content range was 34–50% (w/w), pH values ranged between 4.6 and 4.8 and organic matter content was 10–23%. Slope percent was 50% and very similar between the plots (Table 1).

2.2. Experimental design and data collection

At the end of September 2015, just after logging, the site was instrumented with nine sediment fence plots (Robichaud and Brown, 2002; Prats et al., 2016a, 2016c) of approximately 2 m wide by 8 m long, with three replicate plots per level of soil disturbance. Additionally, runoff was measured at two of the control plots and two of the skid_low plots. To this end, the design of these four plots was modified by installing a plastic sheet underneath the sediment fence fabric to collect the runoff which was accumulated in 450 L tanks. Few rainfall events (54 mm) occurred between the fire and the installation of the plots.