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Effects of post-fire wood management strategies on vegetation recovery and land surface temperature (LST) estimated from Landsat images

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ABSTRACT

The study contributes remote sensing data to the discussion about effects of post-fire wood management strategies on forest regeneration. Land surface temperature (LST) and Normalized Differenced Vegetation Index (NDVI), estimated from Landsat-8 images are used as indicators of *Pinus halepensis* ecosystem recovery after 2008 fire in areas of three post-fire treatments: (1) salvage logging with wood extraction from the site on skidders in suspended position (SL); (2) snag shredding in situ leaving wood debris in place (SS) performed two years after the event; and (3) non-intervention control areas (CL) where all snags were left standing. Six years after the fire NDVI values ~0.5 estimated from satellite images and field radiometry indicate considerable vegetation recovery due to efficient regeneration traits developed by the dominant plant species. However, two years after management activities in part of the burnt area, the effect of SL and SS on ecosystem recovery is observed in terms of both LST and NDVI. Statistically significant differences are detected between the intervened areas (SL and SS) and control areas of non-intervention (CL); no difference is registered between zones of different intervention types (SL and SS). CL areas are on average 1 °C cooler and 10% greener than those corresponding to either SL or SS, because of the beneficial effects of burnt wood residuals, which favor forest recovery through (i) enhanced nutrient cycling in soils, (ii) avoidance of soil surface disturbance and mechanical damage of seedlings typical to the managed areas, and (iii) ameliorated microclimate. The results of the study show that in fire-resilient ecosystems, such as *P. halepensis* forests, NDVI is higher and LST is lower in areas with no management intervention, being an indication of more favorable conditions for vegetation regeneration.

1. Introduction

Wildfire is one of the main disturbance causes of Mediterranean forests (Pausas et al., 2009) being a main driver of vegetation and landscape dynamics (Agee, 1998; Lloret and Zedler, 2009). According to authors who have reviewed effects of fire on soils and vegetation (Cerdà and Robichaud, 2009; Certini, 2005; Pausas et al., 2009; among others), fires consume above surface biomass (trees, understory, litter) partly or completely, and modify physical, chemical and microbial properties of soils. The loss of vegetation canopies alters hydrological cycle modifying conditions for evapotranspiration and changing parameters controlling runoff and infiltration (DeBano, 2000; Wagenbrenner et al., 2015), which results in important increase of soil erosion (Badía et al., 2011; Pérez-Cabello et al., 2009). The degree of damage depends on several factors, which include fire severity (Lentile et al., 2006) and the type of survival strategy developed by predominant plant species (Vallejo et al., 2012).

Short term priority of the emergency post-fire activities is to prevent soil degradation and tree pests, and decrease risks to people from the burnt trees (Robichaud, 2009; Vallejo et al., 2012). Long-term objectives often consider reestablishment of the pre-fire structure and processes in the burned forests. At present forest restoration is not limited to reforestation and afforestation as earlier (Pausas et al., 2004). Besides active intervention, which consists in planting the trees, available approaches include indirect restoration, either passive (natural regeneration protecting against further disturbances) or assisted, when natural regeneration is complemented with management activities. The success

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of different management techniques varies a lot from one experience to another, and there is a great demand of objective and unbiased data from monitoring. Difficulties in generalization of fire effects and a great variation in natural capacity of environmental response explain the lack of consensus on the efficiency of current forest restoration strategies (Pausas et al., 2004).

One of the most controversial aspects is the role of the burnt wood. Strategy of post-fire wood management is a topic of ongoing intense scientific discussion. Recent examples include the controversy raised by the article from (Donato et al., 2006a) with the following responses and contra-responses (Baird, 2006; Donato et al., 2006b; Newton et al., 2006), and reports by McIver et al. (2000), Bautista et al. (2004) or Lindenmayer et al. (2008). In Spain, post-fire salvage logging is a common practice (Fernández et al., 2008; Hernández Jimenez, 2014; Vallejo et al., 2012). However, multiple studies show that burnt wood extraction can have multiple negative ecological consequences. It affects key ecosystem processes altering water, carbon and nutrients cycles (Serrano-Ortiz et al., 2011). When logs and other woody debris are removed, fire-affected areas are left without part of their biological legacies vital for forest regeneration (Perera and Buse, 2014). Removal of snags reduces the amount of seeds available for regeneration of serotinous tree species (Greene et al., 2013). Greater exposure to sunlight due to clear-cutting modifies microclimate and limits the number and variety of sites suitable for germination (Marañón-Jiménez et al., 2013b; Marzano et al., 2013); elevated temperatures and wind reduce soil moisture content and cause hydric stress of seedlings, sprouts and young trees (Martíınez-Sánchez et al., 1999; Vacchiano et al., 2014). Among the effects of salvage logging are vegetation homogenization (Purdon et al., 2004), loss of complexity in the forest structure (Lindenmayer et al., 2008) and changes in species composition (Leverkus et al., 2014; Marzano et al., 2013).

Recovery after wild fire is a slow process requiring scientific short- and longtime monitoring (Pausas et al., 2009). Ecological effects of salvage logging are usually evaluated based on field studies, but the use of alternative techniques, such as satellite remote sensing, in studying the influence of wood removal on vegetation regeneration can complement fieldwork results and provide another spatial dimension to analysis. Remote sensing is a valuable tool for environmental monitoring because it provides systematic coverage of extensive areas (Lentile et al., 2006; Schroeder et al., 2010). Remotely sensed data have been widely applied in fire science and management for detecting active fires (Roy, 1999); assessing active fire behavior (Smith and Wooster, 2005); and evaluating post-fire vegetation response (Díaz-Delgado et al., 2003; Hernández Clemente et al., 2009). Data from Landsat satellites are especially suitable because of their temporal and spatial resolution (16 days and 30 m, respectively). The potential of Landsat data in detecting patterns of post-fire forest recovery resulting from application of different management strategies has been reported by Chen et al. (2014). Landsat images provide data from visible, near infrared, shortwave infrared and thermal spectral regions, which makes possible the analysis of biophysical variables using LST synchronous with spectral indices.

One of the most popular spectral indices used for vegetation assessment from the satellite images is the Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1973). It is based on the contrasting reflectance values in near-infrared and red wavelengths characteristic to plants and has been often used as indicator of management success in post-fire vegetation regeneration. Multiple studies (Van Leeuwen et al., 2010; Vila and Barbosa, 2010 among others) observed that NDVI has higher correlation with post-fire vegetation recovery estimated from the field data than other vegetation indices.

Changes in land surface energy balance due to the vegetation loss are reflected in modified LST values and distribution (Quintano et al., 2015; Veraverbeke et al., 2012; Vlassova et al., 2014). LST is a key factor conditioning soil physical environment since it determines the speed and direction of physico-chemical processes and energy/matter interchanges with the atmosphere (Quattrochi and Luvall, 2004). It affects soil microbiological activity; controls root development, levels of seed germination and plant growth rates (Mexal and South, 1991; Spanos et al., 2000). Moreover, increased temperature is a clear indication of plant moisture stress, which occurs when demand for water exceeds available soil moisture level (Liang, 2004). As vegetation transpires, the evaporated water cools the leaves so that their temperatures are below air temperature. When the plant becomes water stressed, transpiration decreases and the canopy temperature increases (Jackson, 1982). Because it affects photosynthesis and respiration (Hatfield, 1997), transpiration rate is a primary indicator of adequate functioning of any plant ecosystem, including forests (Vidal and Devaux-Ros, 1995). The direct link between the process of transpiration and the vegetation thermal response explains the potential of the use of LST as a metric of plant ecosystem health in monitoring of the fire-affected zones (Moran, 2004).

Monitoring of NDVI and LST as indicators of post-fire landscape regeneration can be performed using remote sensing, which provides a cost-efficient alternative for estimation of these variables on a regular basis with precision required for assessment of post-fire landscape recovery (Gitas et al., 2008; Vicente-Serrano et al., 2008).

The objective of this research is to study the effect of different post-fire wood treatments on vegetation recovery (through NDVI) and LST. Precise information on spatio-temporal distribution of surface temperature in areas of salvage logging can help understand its role in processes taking place in soil and vegetation after fire.

2. Materials and methods

2.1. Study area

The study area (Fig. 1) is situated in the Zuera Mountains, NE Spain (41°56′- 4°58′N, 0°55′- 1°0′W), where in four days between 5 and 8 of August 2008 a wildfire consumed more than 2500 ha of forest managed by Forest Administration of Aragon Autonomous Region DGA causing damage to Special Bird Protection Zone (ZEPAS) and Places of Community Importance (LIC) (EGIF, 2008).

The burnt area located at 500–740 m above sea level is characterized by Mediterranean climate with average annual temperature of 12.5 °C and average annual precipitation ~560 mm with summer minimum (Cuadrat et al., 2007). The fire destroyed forests dominated by *Pinus halepensis Mill* on sandy-loam soils over Rendzic Phaeozem (Badía et al., 2013). The understory is rich in typical Mediterranean species, such as *Quercus coccifera L.*, *Juniperus oxycedrus L.*, *Rosmarinus officinalis L.* and *Genista Scorpius (L.)DC.* Forests are interspersed with patches of shrublands dominated by *Q. coccifera, G. scorpius* and *Brachipodium retusum.*

Three different burnt wood treatments were implemented in the fire-affected area (Fig. 1) between November 2009 and September 2011: (1) salvage logging (SL): felling of the snags, their removal from the burnt site on the skidder in suspended position with following branch cutting and wood shredding outside the site; (2) shredding of snags in situ (SS): mastication of the standing burnt trees with a mulching head attached to a retroexcavator, leaving wood debris on site; (3) non-intervention/control (CL): areas where burnt trees were not logged and no management activities were realized.

Fig. 2 shows typical vegetation cover in the study area at the moment of sampling in August of 2014. Vegetation in Salvage