ISPRS Journal of Photogrammetry and Remote Sensing 119 (2016) 187–197

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

# Assessing post-fire ground cover in Mediterranean shrublands with field spectrometry and digital photography

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ARTICLE INFO

*Article history:*
Received 10 December 2015
Received in revised form 1 April 2016
Accepted 3 June 2016

*Keywords:*
Fire severity
Empirical models
Hyperspectral
VNIR data
Spectral properties
First derivative spectra

ABSTRACT

Fire severity can be assessed by identifying and quantifying the fractional abundance of post-fire ground cover types, an approach with great capacity to predict ecosystem response. Focused on shrubland formations of Mediterranean-type ecosystems, three burned areas (Ibieca and Zuera wildfires and Peñaflor experimental fire) were sampled in the summers of 2006 and 2007. Two different ground measurements were made for each of the 356 plots: (i) 3-band high spatial resolution photography (HSRP) and (ii) the hemispherical-conical reflectance factor (HCRF) in the visible to near-infrared spectral range (VNIR, 400–900 nm). Stepwise multiple lineal regression (SMLR) models were fitted to spectral variables (HCRF, first derivative spectra or FDS, and four absorption indices) to estimate the fractional cover of seven post-fire ground cover types (vegetation and soil – unburned and charred components – and ash – char and ash, individually and as a combined category). Models were developed and validated at the Peñaflor site (training, $n = 217$; validation, $n = 88$) and applied to the samples from the Ibieca and Zuera sites ($n = 51$). The best results were observed for the abundance estimations of green vegetation ($R^2_{adj.}$ 0.70–0.90), unburned soil ($R^2_{adj.}$ 0.40–0.75), and the combination of ashes ($R^2_{adj.}$ 0.65–0.80). In comparison of spectral data, FDS outperforms reflectance or absorption data because of its higher accuracy levels and, importantly, its greater capacity to yield generalizable models. Future efforts should be made to improve the estimation of intermediate severity levels and upscaling the developed models. In the context of fire severity assessment, our study demonstrates the potential of hyperspectral data to estimate in a quick and objective manner post-fire ground cover fractions and thus provide valuable information to guide management responses.


## 1. Introduction

Immediate or first-order effects of fire on an environment, referred to as fire severity following the terminology of Lentile et al. (2006), Veraverbeke et al. (2010) and others, is of interest to forest management primarily because it is presumed to be an indicator of long-term ecosystem response (also referred to as burn severity or second-order effects). Many researchers have already shown its influence on vegetation recovery (Díaz-Delgado et al., 2003), changes in below-ground flora and fauna (Neary et al., 1999), seedling germination after fire (De Luís et al., 2005), species richness (Keeley et al., 2005), changes in soil structure (Mataix-Solera and Doerr, 2004), and runoff and erosion processes (Doerr et al., 2006; Moody et al., 2013), among others.

An adequate remote sensing assessment of fire severity is of great importance, especially in a region such as the Mediterranean, where forest fire size and frequency are increasing (Tedim et al., 2013) and higher intensity and severity levels are being observed (Chuvieco et al., 2008). Traditional assessment has been based on spectral indices derived from multispectral satellite imagery, mostly from Landsat TM or ETM+ sensors (a.o. Epting et al., 2005; Picotte and Robertson, 2011; van Wagtendonk et al., 2004). The normalized ratio of near-infrared (NIR, band 4) and short-wave infrared (SWIR, band 7), known as the Normalized Burn Ratio (NBR, López and Caselles, 1991), and its delta or relative delta versions (dNBR and RdNBR, Key and Benson, 2006; Miller and Thode, 2007) have been widely applied empirically to estimate the field severity index Composite Burn Index (CBI, Key and Benson,

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http://dx.doi.org/10.1016/j.isprsjprs.2016.06.002
0924-2716/

2006) or its modified version, the GeoCBI (De Santis and Chuvieco, 2009). Although moderate to high determination coefficients are frequently observed (a.o. Tanase et al., 2011; Veraverbeke et al., 2010), a number of limitations and disadvantages of this approach have been reported in the literature (see Lentile et al., 2009 for examining the limitations in detail). Apart from the criticism of the performance of NBR as a severity index (Roy et al., 2006), the arguments against a CBI that mixes first and second-order effects (Keeley, 2009), or the uncertainties regarding the best suitability of NBR from a mono- or bi-temporal point of view, and between initial or extended assessment (e.g. Epting et al., 2005; Hudak et al., 2007; Picotte and Robertson, 2011; Veraverbeke et al., 2010; Zhu et al., 2006), two main drawbacks of this approach can be highlighted. These are: (i) some studies developed in Mediterranean areas report an inadequate prediction of second order effects in terms of vegetal regeneration (Keeley et al., 2008; Vicente-Serrano et al., 2011) and erosion (Pérez-Cabello et al., 2006); and (ii) spectral indices are physically meaningless without field calibration (Hudak et al., 2007; Lentile et al., 2006).

Identification and quantification of the fractional abundance of post-fire ground cover types has emerged as an alternative approach for fire severity assessment (Lentile et al., 2006; Roy et al., 2013). A typical post-fire environment is thus considered to be a mixture of vegetation and soil, as unburned cover types, with ash and charred components (a.o. Edwards et al., 2013; Lewis et al., 2007; Robichaud et al., 2007; Veraverbeke et al., 2012b). In contrast to the spectral indexes, as Lentile et al., 2009 points out, this approach produces measures with a physical meaning, directly analogous to traditional field measurements of % green, % brown, and % black. Furthermore, many researchers have shown the important influence of these cover types on ecosystem response: e.g., presence of green vegetation controls runoff and erosion processes (Cerdà and Doerr, 2005); charred vegetation increases soil water retention and decreases overland flow and soil losses (Cerdà and Doerr, 2008; Pannkuk and Robichaud, 2003; Shakesby and Doerr, 2006); loss of organic matter in burned soils alters aggregate stability and porosity and then resistance to erosion and infiltration rates (Arcenegui et al., 2008; Doerr et al., 2006; Mataix-Solera and Doerr, 2004; Mataix-Solera et al., 2002); presence of an ash layer may reinforce or delay overland flow (Balfour et al., 2014; Bodí et al., 2012; Cerdà and Doerr, 2008), can increase or decrease sediment concentration depending on the temporal approach (Cerdà and Doerr, 2008; Pérez-Cabello et al., 2012; Woods and Balfour, 2008), and can alter soil hydrophobicity depending on the soil and ash properties and the ash thickness (Bodí et al., 2011).

Using different techniques such as sub-pixel methods (SMA, a.o. Lewis et al., 2011; Veraverbeke et al., 2012b and MTFM, a.o. Lewis et al., 2008; Robichaud et al., 2007) or continuum-removal transformation (Kokaly et al., 2007), hyperspectral data have been the basis of studies developed under this approach. Hyperspectral sensors provide data in contiguous narrow bands of reflectance spectra, thus offering a greater capability to distinguish specific spectral features and thereby identify the diversity of post-fire cover types. Visible to short-wave infrared (VSWIR, 0.4–2.5 μm) has been the spectral range most deeply explored, although recent research has also examined the potential benefits of a combination of VSWIR and mid to thermal infrared (MTIR, 3.5–12.5 μm) data (Veraverbeke et al., 2012a).

In this context, we aim to explore and characterize the spectral properties of post-fire ground cover types and develop empirical models that allow the quantification of their fractional abundance. We focus on Mediterranean shrubland areas and work with field methodologies (high spatial resolution photography and field spectrometry) that provide an accurate mapping of observed fractions and hyperspectral reflectance values. Using original and transformed spectral data, we assess the accuracy of the models and the suitability of the spectral datasets in a practical application of the results.

## 2. Study area

In a broader sense, this study focuses on the shrubland formations of Mediterranean areas. Various reasons explain the interest in these formations. Shrublands are one of the most important plant formations in Mediterranean-type ecosystems. Considering its dynamic, shrublands now occupy abandoned arable fields (Gartzia et al., 2014; Lasanta et al., 2011) and are also replacing previously forested areas as a consequence of increasing fire frequency and severity (De Luís et al., 2006; Pausas et al., 2008). Following this growing trend, they constitute the highest percentage of annual burned area in Spain over the last decade (data from the Spanish Statistical Office http://www.ine.es/dyngs/IOE/es/operacion.htm?numinv=04002, accessed October 10, 2015). This highlights their interest from a forest fire perspective, especially as future climatic trends will tend to reinforce the changes already observed (Komac et al., 2013; Rodrigo et al., 2004), pointing to higher fire risk indices in these shrub-type species Mouillot et al., 2002. From a fire severity viewpoint, shrubland is the vegetation type where assessment of this variable has achieved less satisfactory results (Epting et al., 2005), and consequently where the hyperspectral approach could produce the most significant progress (Finley and Glenn, 2010). Finally, the low height of this plant formation provides the perfect methodological setting to apply the selected field techniques.

Specifically, post-fire ground cover in Mediterranean shrublands was examined in three burned areas in Aragón, in the northeast of the Iberian Peninsula (Fig. 1). Shrubland formations in these areas vary according to location, from the semiarid environment in the central Ebro Depression to the transitional environment of the Pyrenees.

The first area is the wildfire that occurred in Ibieca ($I_{WF}$) on June 14th, 2006, where 300 ha of crops and 200 ha of shrubland and *Quercus ilex* L. were burned. The specific study site (coordinates of centroid *X*, *Y*: 732,345E, 4,671,170N, UTM 30T, European Datum 1950; EPSG 23030) covers 3200 $m^2$ and is composed of *Juniperus oxycedrus* L., *Rubia peregrina* L., and *Ligustrum vulgare* L. as main plant species.

The second area is also a wildfire, occurring in the pine forest of Zuera ($Z_{WF}$) on July 25th, 2006. Caused by lighting, the fire burned 40 ha of *Pinus halepensis* Mill. and a dense shrub understory of *Quercus coccifera* L., *Rosmarinus officinalis* L., *Thymus vulgaris* L., *Genista scorpius* L., and *Juniperus communis* Lam. at the study site (coordinates of centroid *X*, *Y*: 671,501E, 4,639,210N, UTM 30T, European Datum 1950; EPSG 23030).

The third area is in Peñaflor ($P_{EF}$) where two experimental fire plots, covering a total area of 455 $m^2$, were burned on October 19th, 2007 (coordinates of centroid *X*, *Y*: 685,539E, 4,628,820N, UTM 30T, European Datum 1950; EPSG 23030). The experimental fire plots consisted of sparse shrubland dominated by *Rosmarinus officinalis* L. and *Brachypodium retusum* Pers. The species *Helianthemum lavandulifolium* Desf., *Helianthemum marifolium* L., *Thymus vulgaris* L., *Artemisia herba-alba* Asso., *Salsola vermiculata* L., and *Linum strictum* L. were also present.

## 3. Materials and methods

### 3.1. Ground measurements

#### 3.1.1. Experimental design

Data were acquired in the immediate hours or days after the fire events, giving a total sample of 356 plots from the three study sites