Int J Appl Earth Obs Geoinformation 73 (2018) 438–449

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

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

Vertical forest structure analysis for wildfire prevention: Comparing airborne laser scanning data and stereoscopic hemispherical images

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ARTICLE INFO

Keywords:
ALS
Stereoscopy
Ladder fuels
Vertical fuel continuity
Forest structure
ForeStereo

ABSTRACT

Vertical fuel structure is critical for fire hazard assessment in forest ecosystems. Forest stands with ladder fuels are more prone to crown fires because of canopy fuel continuity. However, characterization of ladder fuels is difficult in the field and few studies have developed explicit measurement procedures to account for these hazardous fuel situations. This study compares vertical profiles derived from airborne laser scanning (ALS) data and stereoscopic hemispherical images obtained in *Pinus sylvestris* stands in central Spain to test their ability to detect the presence or absence of vertical fuel continuity (VFC). Vertical fuel profiles based on canopy cover fraction estimations at different height strata were assessed at plot level and compared with field observations. The quadratic form distance (QFD) was the metric used to quantify the similarity between histogram distributions defined by the vertical profiles from different datasets. Logistic regression analysis was tested to discriminate areas with and without VFC from ALS data at two threshold levels (15% and 30%). The vertical fuel profiles of canopy cover showed a different level of correspondence depending on the relative amount of ladder fuels. Significant logistic models were found ($p < 0.0001$, c-index > 090) for different combination of ALS metrics, with low percentiles (up to P30), canopy relief ratio (CRR) and the percentage of returns normalized by height strata (PRN) up to 8 m as the best predictors to identify the presence of VFC. Results indicated that both datasets were useful in retrieving variability of forest fuel distribution, but further methodological improvements (e.g. understory segmentation in stereoscopic images, new algorithms to better account for occlusions, or ground calibration for laser attenuation in ALS) are needed to increase accuracy in highly continuous areas.

1. Introduction

Wildfire is a complex phenomenon with a global impact on ecosystems (Bowman et al., 2009). Fire behavior is highly conditioned by vegetation characteristics, and particularly by the amount and spatial distribution of fuels. The presence of ladder fuels, i.e. regeneration trees and understory vegetation between ground fuels and the upper tree canopy, creates forest stand structures with vertical fuel continuity that facilitates fire propagation into the crowns (Agee and Skinner, 2005; Scott and Reinhardt, 2001). Strategic fuel treatment planning at landscape level is commonly based on simulations of potential fire behavior that need spatial information on fuel load and arrangement in both understory and overstory vegetation (Finney, 2001; Finney et al., 2007; Stephens et al., 2009). More detailed 3D information of fuel complex structure is required in advanced wildfire modelling in order to better account for the effect of spatial heterogeneity on fire behavior predictions (Parsons et al., 2011).

Identifying the presence of vertical fuel continuity in forest areas is key for fuel treatment planning to prevent crown fires, but it is also very difficult to measure in the field (Kramer et al., 2014). Canopy or crown base height (CBH) is generally used as a surrogate to account for ladder fuels (Scott and Reinhardt, 2001). However, CBH estimation does not provide information on the complete distribution of the vertical fuel profile as model predictions generally refer to a specific tree species (Fernández-Alonso et al., 2013) and, hence, do not include understory fuels. Cruz et al. (2004) proposed the concept of fuel strata gap (FSG), the distance between tree canopy and the lower fuel strata, to better account for the potential transition from a surface to a crown fire due to the quantification of fuel discontinuity in the vertical profile. Forest dynamics impact fuel distributions in the middle to long term, but forest structure does not develop in a linear fashion. Moreover, unplanned perturbation events (e.g. wildfires, strong winds, droughts,

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https://doi.org/10.1016/j.jag.2018.07.015
Received 24 April 2018; Received in revised form 12 July 2018; Accepted 13 July 2018
0303-2434/