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Thermally-enhanced spectral indices to discriminate burn severity in Mediterranean forest ecosystems

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ABSTRACT

Fires are a problematic and recurrent issue in Mediterranean forest ecosystems. Accurate discrimination of burn severity level is fundamental for the rehabilitation planning of affected areas. Though fieldwork is still necessary for measuring post-fire burn severity, remote sensing based techniques are being widely used to predict it because of their computational simplicity and straightforward application. Among them, spectral indices classification (especially difference Normalized Burn Ratio –dNBR- based ones) may be considered the standard remote sensing based method to distinguish burn severity level. In this work we show how this methodology may be improved by using land surface temperature (LST) to enhance the standard spectral indices. We considered a large wildfire in August 2012 in North Western Spain. The Composite Burn Index (CBI) was measured in 111 field plots and grouped into three burn severity levels. Relationship between Landsat 7 Enhanced Thematic Mapper (ETM+) LST-enhanced spectral indices and CBI was evaluated by using the normalized distance between two burn severity levels and spectral dispersion graphs. Inclusion of LST in the spectral index equation resulted in higher discrimination between burn severity levels than standard spectral indices (0.90, 8.50, and 17.52 NIR-SWIR Temperature version 1 vs 0.60, 2.83, and 6.46 NBR). Our results demonstrate the potential of LST for improving burn severity discrimination and mapping. Future research, however, is needed to evaluate the performance of the proposed LST-enhanced spectral indices in other fire regimes, and forest ecosystems.

Keywords: Burn severity, LST, Mediterranean ecosystem, forest fires, CBI, spectral indices

1. INTRODUCTION

Fires are a problematic and recurrent issue in Mediterranean forest ecosystems¹. Accurate discrimination of burn severity level is fundamental for the rehabilitation planning of affected areas². Remote sensing based techniques are increasingly being used to predict burn severity because of their computational simplicity and straightforward application³. Fieldwork, however, is still necessary to calibrate the remote sensing algorithms. Composite Burn Index (CBI)⁴ has been identified as a standard measurement. It was initially proposed for calibration and validation of remote sensing products of burn severity in Western United States and has been adapted to different regions^{5,6}. Among the remote sensing based methods, spectral indices classification (in particular difference Normalized Burn Ratio –dNBR- based ones) may be considered the standard remote sensing based method to distinguish burn severity level.

Though the mentioned spectral indices are based exclusively on reflective bands, thermal spectral domain has demonstrated its validity for discriminating burn severity. Spectral indices from Landsat TM and ETM+ enhanced with brightness temperature slightly improved burned area estimation (see 12, 13). A new proposed thermally enhanced spectral from MODIS/ASTER airborne simulator data showed a moderately high value of the separability index indicating the potential of thermal wavelengths to discriminate post-fire damage (see 14). Harris et al. (2011)¹⁵ analyzed

the validity of these thermally enhanced spectral indices for burn severity discrimination and compared them to commonly used spectral indices. One Land Surface Temperature (LST) enhanced spectral index showed the highest performance. Quintano et al. (2015)¹⁶ reported that post-fire LST could distinguish statistically two burn severity levels in Mediterranean large fires. Additionally, previous studies^{17,18,19,20,21} showed as well the relationship between LST and fire. In this context, our study aims to demonstrate that thermally enhanced spectral indices from Landsat ETM+ data are suitable to discriminate burn severity in Mediterranean forest ecosystems.

2. MATERIAL

2.1 Study area

Castrocontigo, our study area, is located in northwestern Spain (Figure 1). This small mountain range has an average slope of 10% and elevation ranges above sea level between 850 to 2,100 m. The Third Spanish National Forest Inventory indicates that the area was covered by *Pinus pinaster* Ait. (73%), by *Pinus nigra* Arm. (3%), by *Pinus sylvestris* L. (2%), by *Quercus ilex* L. (7%), by *Quercus pyrenaica* Willd (5%) and by shrubs (10%) (*Erica australis* L., *Calluna vulgaris* (L.) Hull, *Chamaespartium tridentatum* (L.) P.E. Gibbs, *Halimium alyssoides* Lam and *Genista florida* L.). The climate is Mediterranean with an average annual rainfall between 650 and 900 mm and two- three months of dryness in the summer. Soil in this area is very sandy and acidic (pH=5.5) with low organic matter content²². In August 2012 there was a large fire, which burned 117.75 km² for three days (between August 19-21, when a heat wave affected the study site).

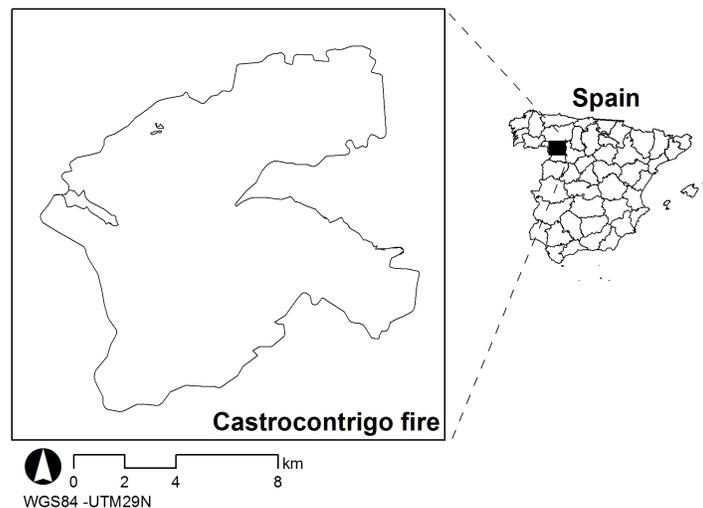


Figure 1. Study area location.

2.2 Datasets

CBI was measured in a total of 111 plots 9-12 weeks after the wildfire (see 4 for a complete description). The plots were located in areas of homogeneous forest structure and fire effects and the number of plots evaluated in each burn severity class was selected according to the proportional surface included in each class, taking into account the initial official severity map (27 unburned plots, 8 low severity plots, 29 moderate severity plots and 47 high severity plots). Following Miller and Thode (2007)¹¹, we chose to place the thresholds halfway between the CBI values as general guides for low, moderate and high categories: unburned (0.00-0.09), low severity (0.10–1.24), moderate severity (1.25–2.24) and high severity (2.25-3.00).

We used a post-fire Landsat 7 ETM+ scene (path/row 203/31), acquired on 6 September, 2012, downloaded from the US Geological Survey (USGS). Fortunately, the forest fire was located in the middle of the Landsat-7 ETM+ scenes and we did not locate any field plot in the affected area by the Scan Line Corrector (SCL) failure.

A digital elevation model (DEM) was used to perform the topographic normalization of the Landsat 7 ETM+ images. We utilized the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) provided by USGS.

3. METHODS

Firstly, the Landsat 7 ETM+ scene was preprocessed. Reflective bands were scaled to surface reflectance and thermal bands to LST. Secondly, thermal-enhanced indices were computed, we also included NBR as a reference. Finally, relationship between the thermal-enhanced indices at CBI plots was evaluated.

3.1 Pre-processing

A subset of the image covering the forest fire was selected (latitude / longitude coordinates: upper left corner, 42°20'38.27''N / 6°16'49.51''W; and lower right corner 42°13'59.97N / 6°8'28, 40''W). The subset image was topographically normalized²³ and atmospherically corrected²⁴ and reflective bands were scaled to surface reflectance²⁵. Thermal bands, first converted to radiance, were scaled to brightness temperature, following the equation and coefficients proposed by Chander et al. (2009)²⁵. Next, brightness temperature was transformed into surface temperature by using the generalized single-channel algorithm developed by Jiménez-Muñoz and Sobrino (2003)²⁶ and updated by Jiménez-Muñoz et al. (2009)²⁷. Atmospheric water vapor content values were obtained from MODIS product MOD05 and land surface emissivity was estimated from the red band reflectivity and the proportion of vegetation cover, following a semi-empirical NDVI-based method (see 28 and 29). As band 6H saturated in some pixels of LST images near to the forest fire date, we used band 6L to compute the definitive LST images.

3.2 Thermal-enhanced indices and burn severity

Thermal-enhanced indices were computed following equations on Table 1. In particular, we evaluated Normalized Burn Ratio⁴ (NBR), Normalized Difference Vegetation Index Thermal¹³ (NDVIT), Soil Adjusted Vegetation Index Thermal¹³ (SAVIT), Normalized Burn Ratio Thermal¹² (NBRT), Char Soil Index Thermal¹³ (CSIT), Vegetation Index Number 6 Thermal¹² (VI6T), NIR-SWIR-Temperature version 1¹⁴ (NSTv1), and NIR-SWIR-Temperature version 2¹⁴ (NSTv2). Next, after applying a mean 3x3 filter to the considered spectral indices, the digital values for the field plots surveyed were extracted for analysis.

Boxplots used as spectral dispersion graphs allowed us to evaluate which burn severity level can be discriminated from others. The boxplots illustrated minimum and maximum values, of the quartiles (Q1, 25%, lower edge of the box; Q2, 50%; and Q3, 75%, top edge of the box), median (Q2, central line of the box), and the atypical values and distribution symmetry, allowing for the identification of potential confusions (overlaps) between the burn severity levels. In addition, the inter-class statistical separability between each two contiguous classes (d_{hm} : high and moderate; d_{ml} : moderate and low; d_{lu} : low and unburned) was also measured using the normalized distance d_{ij} , defined as

$$d_{ij} = \frac{|\mu_i - \mu_j|}{\sigma_i + \sigma_j} \quad (1)$$

where μ_i and μ_j stand for the statistical mean for the classes 'i' and 'j', respectively, and σ_i and σ_j stand for the standard deviations. Values of d_{ij} larger than one indicate good separability, whereas values smaller than one represent a large degree of histogram overlap between the two classes.

4. RESULTS AND DISCUSSION

Table 1 displays d_{hm} , d_{ml} , and d_{lu} values. All indices, except CSIT, showed d_{lu} higher than one. Therefore, all spectral indices (except CSIT) should allow us to discriminate burned from unburned areas. Similarly, all indices, with the exception of CSIT displayed d_{ml} higher than one. On the contrary, none of them presented d_{hm} higher than one. Thus, it was only possible to differentiate two levels of burn severity (low and moderate-high) when using the proposed thermal-enhanced indices. Boxplots of Figure 2 demonstrated this fact graphically.

Table 1. Thermal-enhanced spectral indices and normalized distance between burn severity levels

Index	Equation	Reference	d_{hm}	d_{ml}	d_{lu}
NBR	$\frac{(\rho_{NIR} - \rho_{SWIR})}{(\rho_{NIR} + \rho_{SWIR})}$	Key and Benson (2006)	0.60	2.83	6.46
NDVIT	$\frac{(\rho_{NIR} - \rho_R T_b)}{(\rho_{NIR} + \rho_R T_b)}$	Smith et al. (2007)	0.22	2.26	3.79
SAVIT	$\frac{(\rho_{NIR} - \rho_R T_b)(1+L)}{(\rho_{NIR} + \rho_R T_b + L)}$	Smith et al. (2007)	0.36	7.03	15.37
NBRT	$\frac{(\rho_{NIR} - \rho_{SWIR} T_b)}{(\rho_{NIR} + \rho_{SWIR} T_b)}$	Holden et al. (2005)	0.13	2.97	9.24
CSIT	$\frac{\rho_{NIR}}{\rho_{SWIR} T_b}$	Smith et al. (2007)	0.15	0.46	0.90
VI6T	$\frac{(\rho_{NIR} - T_b)}{(\rho_{NIR} + T_b)}$	Holden et al. (2005)	0.12	2.93	6.35
NSTv1	$\frac{(\rho_{NIR} - \rho_{SWIR}) LST}{(\rho_{NIR} + \rho_{SWIR})}$	Veraverbeke et al. (2011)	0.90	8.50	17.42
NSTv2	$\frac{(\rho_{NIR} - \rho_{SWIR} - LST)}{(\rho_{NIR} + \rho_{SWIR} + LST)}$	Veraverbeke et al. (2011)	0.62	2.91	6.84

NBR: Normalized Burn Ratio; NDVIT: Normalized Difference Vegetation Index Thermal; SAVIT: Soil Adjusted Vegetation Index Thermal; NBRT: Normalized Burn Ratio Thermal; CSIT: Char Soil Index Thermal; VI6T: Vegetation Index Number 6 Thermal; NSTv1: NIR-SWIR-Temperature version 1; NSTv2: NIR-SWIR-Temperature version 2; ρ_R : red reflectance (ETM+ band 3); ρ_{NIR} : NIR reflectance (ETM+ band 4); ρ_{SWIR} : SWIR reflectance (ETM+ band 7); T_b : brightness temperature; LST: Land Surface Temperature; L: soil constant set to 0.5; d_{hm} : normalized distance between high and moderate burn severity levels; d_{ml} : normalized distance between moderate and low burn severity levels; d_{lu} : normalized distance between low burn severity level and unburned.

Thermal-enhanced spectral indices enabled us to distinguish two burn severity levels (low and moderate-high) instead of the three levels initially proposed. Discrimination of only two severity levels has been also reported by other remote sensing based studies^{30,31,11}. Given that perhaps the most common reason for studying burn severity is to target areas for recovery³⁰, differentiating the highest severity levels from the rest of the burn severity levels may provide enough information for forest managers.

SAVIT, NBRT, NSTv2 and specially NSTv1 presented d_{ml} and d_{lu} values higher than NBR, suggesting a higher capacity for burn severity discrimination of thermal-enhanced indices than conventional ones. In this way, our results agree with other authors' findings (see 12, 13, 14 and 15).

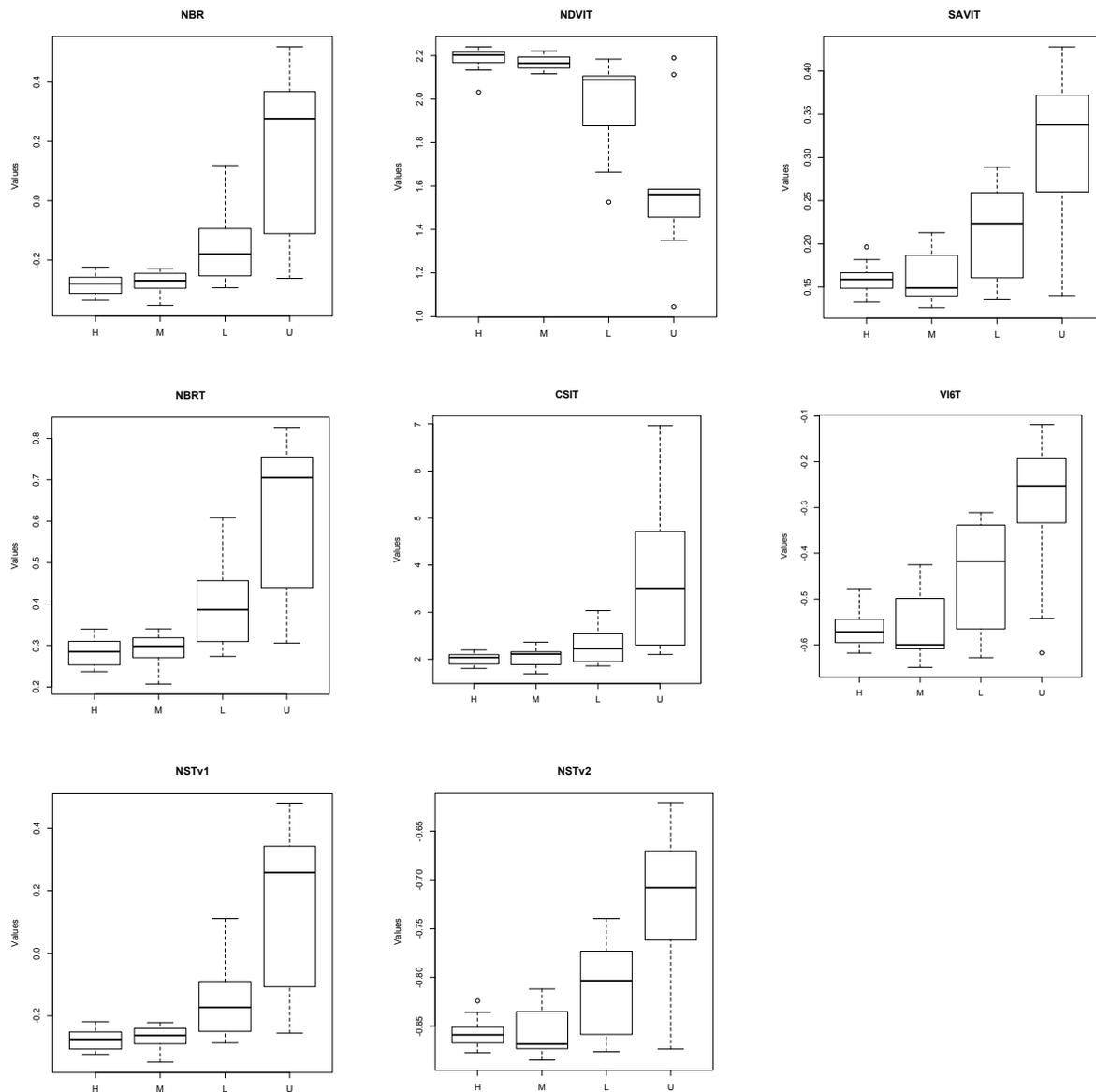


Figure 2: Spectral dispersion graphs (boxplots) for the tested thermal-enhanced spectral indices

NBR: Normalized Burn Ratio; NDVIT: Normalized Difference Vegetation Index Thermal; SAVIT: Soil Adjusted Vegetation Index Thermal; NBRT: Normalized Burn Ratio Thermal; CSIT: Char Soil Index Thermal; VI6T: Vegetation Index Number 6 Thermal; NSTv1: NIR-SWIR-Temperature version 1; NSTv2: NIR-SWIR-Temperature version 2; H; high burn severity level; M; moderate burn severity level; L; low burn severity level; U: unburned class

5. CONCLUSION

We analyzed the performance of thermal-enhanced spectral indices to assess burn severity in Mediterranean forest ecosystems, considering as study area a large forest fire in north-western Spain. Post-fire burn severity level (unburned, low, moderate and high) was measured in 111 field plots by CBI. Normalized distance and boxplots suggested that the thermal-enhanced indices could differentiate accurately two levels of burn severity with higher accuracy than NBR. These results demonstrate the potential of thermal-enhanced indices for assessing burn severity in Mediterranean ecosystems. Forest managers could benefit from the use of the thermal-enhanced indices, and in particular of NSTv1 for

estimating burn severity assessment as an effective tool to define post-fire management strategies. The performance of the proposed spectral indices should be, however, evaluated in other fire regimes and vegetation types.

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