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Calibration and validation of the relative differenced Normalized Burn Ratio (RdNBR) to three measures of fire severity in the Sierra Nevada and Klamath Mountains, California, USA

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ABSTRACT

Multispectral satellite data have become a common tool used in the mapping of wildland fire effects. Fire severity, defined as the degree to which a site has been altered, is often the variable mapped. The Normalized Burn Ratio (NBR) used in an absolute difference change detection protocol (dNBR), has become the remote sensing method of choice for US Federal land management agencies to map fire severity due to wildland fire. However, absolute differenced vegetation indices are correlated to the pre-fire chlorophyll content of the vegetation occurring within the fire perimeter. Normalizing dNBR to produce a relativized dNBR (RdNBR) removes the biasing effect of the pre-fire condition. Employing RdNBR hypothetically allows creating categorical classifications using the same thresholds for fires occurring in similar vegetation types without acquiring additional calibration field data on each fire. In this paper we tested this hypothesis by developing thresholds on random training datasets, and then comparing accuracies for (1) fires that occurred within the same geographic region as the training dataset and in similar vegetation, and (2) fires from a different geographic region that is climatically and floristically similar to the training dataset region but supports more complex vegetation structure. We additionally compared map accuracies for three measures of fire severity: the composite burn index (CBI), percent change in tree canopy cover, and percent change in tree basal area. User's and producer's accuracies were highest for the most severe categories, ranging from 70.7% to 89.1%. Accuracies of the moderate fire severity category for measures describing effects only to trees (percent change in canopy cover and basal area) indicated that the classifications were generally not much better than random. Accuracies of the moderate category for the CBI classifications were somewhat better, averaging in the 50%–60% range. These results underscore the difficulty in isolating fire effects to individual vegetation strata when fire effects are mixed. We conclude that the models presented here and in Miller and Thode ([Miller, J.D. & Thode, A.E., (2007). Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sensing of Environment, 109, 66–80.]) can produce fire severity classifications (using either CBI, or percent change in canopy cover or basal area) that are of similar accuracy in fires not used in the original calibration process, at least in conifer dominated vegetation types in Mediterranean–climate California.

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1. Introduction

Multispectral satellite data have become a common tool in the mapping of wildland fire effects (Tanaka et al., 1983; Lopez Garcia & Caselles, 1991; Rogan & Franklin, 2001; Miller & Yool, 2002; Brewer et al., 2005; Wimberly & Reilly, 2007). "Fire severity" is one of the most commonly mapped measures of fire effects to vegetation and soils (Ryan & Noste, 1983; Agee, 1993; DeBano et al., 1998; Lentile et al., 2006). In the disturbance ecology literature, "severity" is usually defined as the effect of a change agent on an ecological community, or a measure of the degree to which a site has been altered (Pickett & White, 1985; Turner et al., 1998). The composite burn index (CBI) was developed by Key and Benson (2005a) as a semi-quantitative field measure of fire severity experienced in a plot, and has recently been

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used in several fire severity mapping studies (van Wagtendonk et al., 2004; Epting et al., 2005; De Santis & Chuvieco, 2007). CBI is normally calculated as the linear average of fire effects seen in all vegetation strata (i.e., understory, midstory and overstory), exposed surface soil, and non-photosynthetic surface fuels. CBI should therefore be correlated to satellite derived indices since satellites provide integrated measurements at the pixel level (Key, 2006). Chuvieco et al. (2006) have shown that CBI is highly correlated to the Landsat near infrared (NIR) band in combination with either the red or short wave infrared (SWIR) bands.

While CBI field values can be calculated for an individual stratum, i.e. the upper canopy, or as an average across all strata, CBI is not a variable that is familiar to most resource managers. In forested environments, Landsat derived indices are predominantly correlated to variables describing the upper canopy structure (Stenback & Congalton, 1990; Cohen & Spies, 1992; Zhu et al., 2006; De Santis & Chuvieco, 2007). Landsat-derived indices of fire effects to forestlands should therefore theoretically be correlated to pre- and post-fire measures of basal area and canopy cover, which are commonly used field measures of upper forest canopy structure (Cade, 1997). Basal area, defined as the sum of the cross-sectional areas of tree boles in a sampled area, forms the fundamental basis for mensuration, analysis, mapping and management of forest resources (USDA, 1992; Avery & Burkhart, 1994). Canopy cover, defined as "the proportion of ground… expressed as a percentage that is occupied by the perpendicular projection downward of the aerial parts of the vegetation" is an important variable most often used in models of wildlife and plant species habitat (Cade, 1997; Brohman & Bryant, 2005; Zielinski et al., 2006). Habitat maps are often made, and habitat models calibrated, from aerial photography where canopy cover can be the only practicable measure of tree cover (Cade, 1997). Moreover, basal area and canopy cover can be derived from Forest Inventory and Analysis (FIA) plot data that form the backbone of forest inventory data on USDA Forest Service lands (USDA, 1992; Dixon, 2002). The FIA program does not explicitly measure canopy cover; it must be modeled using tree inventories by species and diameter. In order to meet the needs of silviculturists and biologists, severity maps in both units of canopy cover and basal area are often desirable.

The Normalized Burn Ratio (NBR) computed from Landsat TM NIR and SWIR bands (4 and 7, respectively) has gained considerable attention in recent years for mapping burned areas (Miller & Yool, 2002; Brewer et al., 2005; Epting et al., 2005; Key & Benson, 2005b). NBR is formulated like the normalized difference vegetation index (NDVI) except Landsat TM SWIR band 7 is used in place of the red band 3 as follows:

$$\mathrm{NBR} = \frac{\mathrm{Band4}-\mathrm{Band7}}{\mathrm{Band4}+\mathrm{Band7}}. \quad (1)$$

NBR is primarily sensitive to living chlorophyll and water content of soils and vegetation, but it is also responsive to lignin, hydrous minerals, ash and char (Elvidge, 1990; Key, 2006; Kokaly et al., 2007). Most fire severity mapping applications to date have subtracted a post-fire NBR image from a pre-fire NBR image in an absolute change detection methodology to derive the "differenced NBR" (dNBR) as follows:

$$\mathrm{dNBR} = \mathrm{prefireNBR}-\mathrm{postfireNBR}. \quad (2)$$

Since chlorophyll contents vary due to vegetation type and density, each absolute differenced image should ideally be stratified by pre-fire vegetation type and independently calibrated (Miller & Yool, 2002; Key & Benson, 2005b; Zhu et al., 2006; Kokaly et al., 2007; Miller & Thode, 2007). Miller and Thode (2007) therefore proposed the creation of a relative differenced NBR (RdNBR) to remove the biasing of the pre-fire vegetation by dividing dNBR by the square-root of the pre-fire NBR as follows:

$$\mathrm{RdNBR} = \frac{\mathrm{dNBR}}{\sqrt{\mathrm{ABS}(\mathrm{prefireNBR}/1000)}}. \quad (3)$$

By convention, NBR is scaled by 1000 to transform the data to integer format; therefore the pre-fire NBR must be divided by 1000 in the RdNBR formula (Key, 2006; Miller & Thode, 2007). The absolute value of the pre-fire NBR in the denominator allows computing the square-root without changing the sign of the original dNBR. Positive RdNBR values therefore represent a decrease in vegetation cover, just like dNBR, while negative values represent an increase in vegetation cover. Ideally, normalization should not require applying a square-root transformation to the denominator, but Miller and Thode (2007) found that the square-root allowed a better fit of a relative dNBR index to field values in sparsely vegetated plots.

Ecological studies have long used either or both absolute and relative versions of the same measure (i.e. density, frequency, and dominance) depending on the definition of the measure being addressed (McCune & Grace, 2002). Both absolute and relative measures are useful and provide different information about fire effects, e.g. the amount of biomass killed vs. the percentage of biomass killed. It should be noted that most variables included in the CBI protocol are estimated from the relative change perspective (Key & Benson, 2005a). Hypothetically, a major advantage of relative indices is that a single set of thresholds can be used to create categorical severity classifications for fires occurring in similar vegetation types without requiring additional calibration field data for each fire (Zhu et al., 2006; Miller & Thode, 2007). This paper tests this hypothesis by using thresholds developed on a randomly selected training dataset to assess classification accuracy on independently mapped fires. Map accuracies were compared for: 1) fires that occurred within the same geographic region as the training dataset and in similar vegetation types, and 2) fires from a different geographic region that is climatically and floristically similar to the training dataset region but supported more complex vegetation structure. Additionally, three different measures of fire severity based on CBI, percent change in canopy cover, and percent change in basal area were calibrated to RdNBR and their accuracies assessed.

Miller and Thode (2007) presented a classification derived from a regression of CBI to RdNBR using all plots regardless of vegetation type, including non-forested types, and without withholding an independent set of plots for validation. However, high-quality accuracy assessment procedures require that validation data be independent of the training data so that the assessment is not biased in favor of the map (Congalton & Green, 1999). We therefore also compared a classification of plots randomly selected from the same fires used for training to the original classification reported in Miller and Thode (2007) to assess whether using all plots affected classification accuracies.

2. Data and methods

2.1. Study locations

2.1.1. Sierra Nevada

Twenty-five fires used in this study are located within the region formed by the Sierra Nevada Forest Plan Amendment (SNFPA) planning area (USDA, 2004), which guides land and resource management on 50,000 km^2 of National Forest land on eleven US National Forests (Fig. 1 and Table 1). CBI data from fourteen of these fires that occurred in 2002–2004 were originally used by Miller and Thode (2007). Four additional fires that occurred in 2001 along with seven fires that occurred entirely within Yosemite National Park (NP) were included in this study. Yosemite NP is not managed under the