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Detecting forest damage after a low-severity fire using remote sensing at multiple scales

John T.T.R. Arnett[a,*], Nicholas C. Coops[a], Lori D. Daniels[b], Robert W. Falls[c]

[a] Department of Forest Resource Management, 2424 Main Mall, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4
[b] Department of Forest and Conservation Sciences, 2424 Main Mall, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4
[c] Biosphere Management Systems Inc., 870 Handsworth Road, North Vancouver, British Columbia, Canada V7R 2A2

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ABSTRACT

Remote sensing technologies are an ideal platform to examine the extent and impact of fire on the landscape. In this study we assess that capacity of the RapidEye constellation and Landsat (Thematic Mapper and Operational Land Imager to map fine-scale burn attributes for a small, low severity prescribed fire in a dry Western Canadian forest. Estimates of burn severity from field data were collated into a simple burn index and correlated with a selected suite of common spectral vegetation indices. Burn severity classes were then derived to map fire impacts and estimate consumed woody surface fuels (diameter ≥2.6 cm). All correlations between the simple burn index and vegetation indices produced significant results ($p < 0.01$), but varied substantially in their overall accuracy. Although the Landsat Soil Adjusted Vegetation Index provided the best regression fit ($R^2 = 0.56$), results suggested that RapidEye provided much more spatially detailed estimates of tree damage (Soil Adjusted Vegetation Index, $R^2 = 0.51$). Consumption estimates of woody surface fuels ranged from 3.38 ± 1.03 Mg ha^{-1} to 11.73 ± 1.84 Mg ha^{-1}, across four derived severity classes with uncertainties likely a result of changing foliage moisture between the before and after fire images. While not containing spectral information in the short wave infrared, the spatial variability provided by the RapidEye imagery has potential for mapping and monitoring fine scale forest attributes, as well as the potential to resolve fire damage at the individual tree level.

Introduction

Fires play an important role in determining the structure and composition of forest ecosystems (Franklin et al., 2002; Turner, 2010). The legacy of fire on landscapes can have major impacts on the composition and ecological function of forests in western North America (Palmer et al., 1997). Fire suppression during the 20th century has resulted in reduced forest heterogeneity, potential reductions in biodiversity, and the accumulation of fuels, particularly in dry forest types (Schoennagel et al., 2004; Adams, 2013). The lack of surface fires in some dry forests has led to accumulation of woody surface fuels, increasing the chance of severe wildland and interface fires (Miller et al., 2009). However, management protocols regarding the normative state of fire on the landscape remains a contentious issue, even amongst researchers (Fulé et al., 2013; Odion et al., 2014).

Emissions from wildfires contribute substantially to global carbon emissions (Schimel and Baker, 2002), thus global, national, and regional carbon accounting frameworks are tuned to address concerns over emissions from wildfires (Hurteau et al., 2008). Currently, research is underway to monitor carbon emissions from fires in both the United States and Canada (Masek et al., 2013). The Canadian National Carbon Forest Monitoring programme (NCFM) as well as the American Monitoring Trends in Burn Severity project (MTBS) are both mandated to estimate emissions produced by forest fires at a national scale (Eidenshink et al., 2007). Both the NCFM and the MTBS rely on spatial data from remotely sensed imagery as a primary means of assessing the extent and severity of disturbances.

The management of wildfires presents a challenge for balancing sustainable stewardship and carbon emission targets. Prescribed burning of forest fuels is often seen as a means of managing ecosystems by reducing fuel loading and increasing forest resistance to severe fires; however, these practices also contribute considerably to atmospheric carbon levels through fuel combustion and smoke production (Wiedinmyer and Hurteau, 2010; Pan et al., 2011). Improved quantification of the effects of fires on vegetation will allow for a better understanding of the trade-offs between

* Corresponding author. Tel.: +1 604 822 6592; mobile: +1 604 928 5101.
E-mail addresses: arnett@alumni.ubc.ca, arnett.jtt@gmail.com (J.T.T.R. Arnett).

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ecological and climatological objectives. Remote sensing provides the only feasible solution to operationalize both local and national monitoring of fires (Kerr and Ostrovsky, 2003).

Within the wildfire literature several key terms exist for describing the impact of wildfires on the landscape (Key and Benson, 2006). Fire severity generally describes the degree of ecological change that is observed after the fire has occurred (Keeley, 2009). Since no absolute metrics for assessing fire severity exist, the term has been used to describe a range of characteristics associated with selecting measureable change caused by fire (Roy et al., 2006). Previous studies have used measureable attributes such as fuel consumption, vegetation damage, changes to floristic communities, and changes to soil composition to measure fire severity (White et al., 1996). In this study we assess fire severity by quantifying tree damage and consumption of downed woody fuels; these attributes are then related to changes in ground spectra as observed by satellite imagery.

Information on the spatial distribution of wildfires can offer valuable insights into ecological trends and risk associated with wildfire events and is now a primary initiative of government and conservation agencies (Krawchuk et al., 2009). National approaches to monitor and detect active fires are now operational in a number of nations using coarse spatial resolution satellite imagery (Ressl et al., 2009). Using remotely sensed imagery to conduct post-fire analysis tends to rely on mapping the presence/absence of fires, or the attribution of discrete severity classes, along a gradient of spectral changes caused by the loss or damage of vegetation (Lentile et al., 2006). Fire severity classes derived from remote sensing are somewhat arbitrary and do not necessarily reflect empirical changes in forest cover or consumed biomass (Lentile et al., 2006). Furthermore, the mapping of specific burn attributes using remote sensing has been most frequently applied to large, severe and stand replacing disturbances (Epting et al., 2005). As fires encompass a vast range of severity, intensity, and scalar gradients across a range of ecosystems it is necessary to develop fine scale methods to accurately monitor post-fire effects on the vegetation (Eidenshink et al., 2007). New remote sensing platforms offering higher spatial resolution, more frequent image acquisition times, and specific band configurations offer many opportunities to study the effects and impacts of fire on vegetation (Arroyo et al., 2008).

The Landsat series of satellites has been successfully used to map large fires (Masek et al., 2013). However, finer spatial detail and more frequent acquisition of imagery may be more desirable to a variety of disciplines including ecology, risk assessment, and carbon accounting (Whitman et al., 2013; De Groot et al., 2007).

Newer generation sensors that employ multiple satellites are now offering high spatial/temporal resolution ideal for fine-scale ecological mapping and are capable of capturing new imagery at daily return intervals. Conventional Earth observing satellites, such as Landsat, provide imagery at a coarser spatial resolution but may offer several advantages over fine spatial and temporal resolution sensors, including wider swath coverage, more bands included in the shortwave infrared (SWIR) region of the spectrum, a lengthy historical data archive, and radiometrically corrected imagery provided at no cost. Furthermore the longstanding availability of Landsat data has allowed for the much research on the sensor's abilities to detect and monitor change on the Earth's surface (Wulder et al., 2008).

A variety of change detection techniques can be used to identify fire and other disturbances using satellite imagery. Tracking of ground surface change using satellite imagery is generally conducted by the use of multitemporal, co-registered imagery (Coppin et al., 2004). Differences are then mapped by observing relatively large magnitude changes in surface reflectance between individual pixels (Coppin et al., 2004). The simplest change detection technique involves the subtraction of pixel values from one image to another co-registered image (Singh, 1989). Mapping change, however, is generally not undertaken on individual spectral bands. Vegetation indices, or band ratios, are usually derived prior to any image differencing (Singh, 1989; Lu et al., 2004). Indices derived from algebraic operations using band reflectance values are preferable because (1) indices are able to normalize the magnitude of change between images that may exhibit slightly different spectral levels (Huete et al., 2002), and (2) because vegetation indices have been correlated with specific structural, physiological, and chemical responses of vegetation due to stress or disturbance (Gao, 1996; Carlson and Ripley, 1997; Sims and Gamon, 2003). Most vegetation indices are used to create a single grey-scale univariate difference image; however, some indices, such as the Normalized Burn Ratio (NBR), can rely on a single image to detect fire (Epting et al., 2005). To map the extent of subtle disturbances, such as non-stand-replacing fires it is necessary to incorporate detailed spatial data, beyond the 30 m × 30 m resolution provided by Landsat.

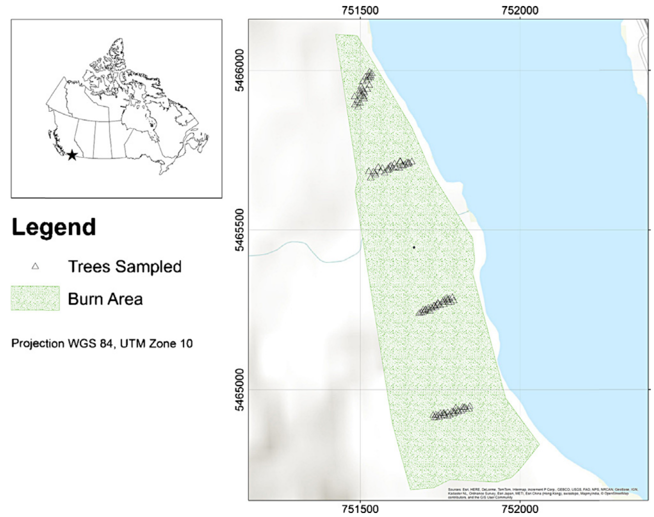

Fig. 1. A map depicting the location of the Vasuex lake study area and locations of sample trees.

In this paper we explore the potential of a multitemporal RapidEye imagery time series to detect changes in vegetation following a low-intensity prescribed fire. Metrics derived from RapidEye are compared to conventional fire identification techniques using Landsat satellite imagery from coincidental dates. Several commonly used vegetation indices were derived to assess spectral differences for both Landsat and RapidEye and compared to asses each sensor's ability to detect fire damage. Detected changes were correlated with aggregate measures of damage for individual trees and woody surface fuels.

Finally, we derived and mapped a set of burn severity classes and estimated consumption of woody surface fuels and biomass throughout the study area. In this study we hypothesize that estimates of burn impacts derived from RapidEye satellite imagery will be able to resolve stand damage at the individual tree level. It is expected that finer-scale disturbance attributes derived from RapidEye will be able to provide a more detailed assessment of the burn damage than conventional analysis of Landsat-imagery.

Site description

This study was conducted in the West Vaseux Lake unit of the Vaseux-Bighorn National Wildlife Area (VBNWA), located in the Southern Okanagan Region of British Columbia, Canada (Fig. 1). The VBNWA presents an ideal opportunity to assess the capacity of remote sensing due to the availability of pre- and post-fire forest and fuels data, an attribute often lacking in disturbance remote