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Identifying a suitable combination of classification technique and bandwidth(s) for burned area mapping in tallgrass prairie with MODIS imagery

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ABSTRACT

Prescribed fire is crucial to the ecology and maintenance of tallgrass prairie, and its application affects a variety of human and natural systems. Consequently, maps showing the location and extent of these fires are critical to managing tallgrass prairies in a manner that balances the needs of all stakeholders. Satellite-based optical remote sensing can provide the necessary input for this mapping, but it requires the development mapping methods that are specific to tallgrass prairie. In this research, we devise and test a suitable mapping method by comparing the efficacy of seven combinations of bands and indices from the MODIS sensor using both pixel and object-based classification methods. Due to the relatively small size of many prescribed fires in tallgrass prairie, scenarios based on the 250 m spatial resolution red and NIR bands outperformed those based on the coarser 500 m spatial resolution bands, and a combination of both red and NIR performed better than each 250 m band individually. Object-based classification offered no improvement over pixel-based classification, and performed poorer in some cases. Our results suggest that mapping burned areas in tallgrass prairie should be done at a minimum of 250 m spatial resolution, should used a pixel-based classification technique, and should use a combination of red and NIR.

1. Introduction

1.1. Background

1.1.1. The role of prescribed fire in tallgrass prairie

Prescribed fire influences sustainability, species composition and richness, and plant community productivity in tallgrass prairies (Knapp and Seastedt, 1998), and it is likely that these grasslands evolved in conjunction with fire (Bragg and Hulbert, 1976). Fire in tallgrass prairies is also closely related to grazing practices (Collins and Steinauer, 1998), nutrient cycling (Hobbs et al., 1991), and the abundance and diversity of wildlife species (Fuhlendorf et al., 2006). Additionally, smoke from burning tallgrass prairie can adversely affect human health within the airsheds of burned areas through the release of chemical compounds and particulate matter (Pope et al., 2002; Radke et al., 2001). Because the stakeholders affected by prescribed burning in tallgrass prairie are numerous and diverse, management decisions should be guided by sound science so that the interests of all parties are addressed objectively and fairly. One important step toward achieving this goal is to develop an accurate method for mapping burned areas in tallgrass prairie.

1.1.2. Burned area mapping in tallgrass prairie

Typically, satellite imagery is used to map burned areas for several reasons, including its temporal and spectral resolution, its ability to access areas that are inaccessible by other methods, and its cost-effectiveness (Pereira et al., 1997). In fact, a large body of knowledge exists concerning burned area mapping in cover types other than tallgrass prairie, such as forests, savannahs, scrublands, and even semi-arid grasslands.

Often, however, information presented in burn mapping studies from other cover types is not directly applicable to burn mapping in tallgrass prairie. For example, Stroppiana et al. (2002) found that spectral regions that excelled at differentiating between burned and unburned forest could not do so in grasslands, because the differences between burned and unburned areas remain on the landscape much longer in forests. Pereira (2003) provides another example, noting that the major reflectance change in burned woodland savannah is a decrease in NIR, while reflectance in burned grassland decreases across the spectrum.

Although these examples are from wooded and semi-wooded areas, studies from less-wooded savannahs and semi-arid grasslands often fail to provide burn mapping information that is directly applicable to tallgrass prairie. For example, Trigg and Flasse (2000) report that the char signal of a burned savannah area disappears quickly, even in the absence of vegetation regrowth. Cao et al. (2009), examining a semi-arid grassland, also found differentiation between burned and unburned areas difficult in the absence of a

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char signal, despite the absence of immediate vegetation regrowth. These studies stand in contrast to tallgrass prairies, where burning is typically done during the spring growing season. Consequently, a rapid decrease in the char signal, along with rapidly regrowing vegetation, quickly eliminates the spectral differences on which burned area detection depends (Mohler and Goodin, 2010; Trigg and Flasse, 2000). This has the obvious effect of causing confusion between unburned vegetation and older burned areas (Eva and Lambin, 1998).

Despite the fact that the aforementioned studies cannot be applied directly to burn mapping in tallgrass prairies, they still provide information on which mapping techniques, and which regions of the spectrum, might prove useful for this purpose. Regarding techniques, burned areas have been extensively mapped using both pixel-based and object-based classification methods. Typically, because burned areas are essentially discreet geometric shapes, object-based techniques have outperformed pixel-based techniques (Gitas et al., 2004, 2008; Mitri and Gitas, 2004a,b, 2006, 2008) for this purpose. It should be noted that most studies using object-based classification to map burned areas, including those cited above, were done in forested areas. Nonetheless, many of the technical aspects of these endeavors are applicable to grasslands as well.

Studies in other cover types can also serve as the basis for selecting bands and indices that might be useful for mapping burned areas in tallgrass prairie. For example, the middle-infrared burn index (MIRBI) was shown to be useful for differentiating burned from unburned shrub savannah by Trigg and Flasse (2001). It is calculated as

$$\text{MIRBI} = 10(\rho_{\text{LMIR}}) - 9.8(\rho_{\text{SMIR}}) + 2 \quad (1)$$

where ρ_{LMIR} is the reflectance value of MODIS band 7, and ρ_{SMIR} is the reflectance value of MODIS band 6. Near-infrared (NIR) was shown to be useful for burned area mapping by Lopez-Garcia and Caselles (1991), Koutsias and Karteris (1998), Pereira (1999), Pu and Gong (2004), and Shao and Duncan (2007) in shrubland and forest. The red spectral region also performed well according to Lopez-Garcia and Caselles (1991) in forest, and according to Stroppiana et al. (2002) in savannah. Both NIR and red were useful for differentiating burned from unburned areas in tallgrass prairie according to Mohler and Goodin (2010). Finally, long wave near infrared (LNIR) was found useful for differentiating burned and unburned areas by Li et al. (2004) in forest and by Trigg and Flasse (2000) in savannah.

The objective of this study, therefore, was to identify at classification technique and those spectral bandwidth(s) (and/or the MIRBI index) that could accurately map burned areas in tallgrass prairie. Because past burned area mapping efforts have focused on other cover types, this technique would be the first specifically designed to map burned areas in the tallgrass prairie biome.

1.2. Study area

The study area was a portion of the northern Flint Hills, Kansas, USA (Fig. 1). The Flint Hills region is the largest extant tract of tallgrass prairie in North America (Knapp and Seastedt, 1998; Kollmorgen and Simonett, 1965). Though the study area is dominated by tallgrass prairie, other cover types such as croplands and woody vegetation can be found, particularly in the floodplains of the area's watercourses. The prairie portions of this study area are dominated by a matrix of tall, warm-season grasses, including *Andropogon gerardii*, *Schizachyrium scoparium*, *Sorghastrum nutans*, and *Panicum virgatum* (Freeman, 1998). Non-graminoid forbs and shrubs are often interspersed with the matrix species, and short and mid-sized grasses such as *Bouteloua gracilis* (blue grama), *Bouteloua curtipendula* (sideoats grama), and *Buchloe dactyloides* (buffalograss) are often found in more xeric sites (Freeman, 1998).

Table 1
Specifications of MODIS bandwidths. Shaded bandwidths were used in this study, either individually or as part of the MIRBI index.

Bandwidth	Band number	Spatial resolution	Wavelength range (μm)
Red	1	250 m or 500 m	0.62–0.67
NIR	2	250 m or 500 m	0.841–0.876
Blue	3	500 m	0.459–0.479
Green	4	500 m	0.545–565
LNIR	5	500 m	1.23–1.25
SMIR	6	500 m	1.628–1.652
LMIR	7	500 m	2.105–2.155

Typically, burning of the prairie portions of the study area begins in mid-March and ends in mid-May, with the vast majority of burning taking place during the month of April.

2. Methods

2.1. Data

The satellite imagery classified in this analysis consisted of the first seven bands from the Moderate Resolution Imaging Spectroradiometer (MODIS). These were downloaded through the National Aeronautics and Space Administration's (NASA's) Warehouse Inventory Search Tool (WIST) for four dates in 2008 and three dates in 2010. These particular dates were chosen because they roughly corresponded with Thematic Mapper (TM) scenes that would later be used to evaluate accuracy. MODIS bands 1 and 2 were downloaded at their highest possible resolution of 250 m (MOD09GQ, MYD09GQ). Additionally, bands 1–7 were downloaded at 500 m spatial resolution (MOD09GA, MYD09GA). The specifications for these bands are shown in Table 1.

All MODIS images were converted to TIFF files and georectified to the Universal Transverse Mercator (UTM) system (zone 14) using the MODIS Reprojection Tool (MRT) version 4.0, and subset to include only the study area shown in Fig. 1. Because MODIS images could come from either the Aqua (afternoon pass) or Terra (morning pass) satellites, both sometimes provided a clear image on the date in question. In these cases, the image in which the study area was closest to nadir was used, as that allowed for the highest possible spatial resolution. It should be noted that because Aqua passes over the study area in the afternoon, while Terra passes over the study area in the morning, Aqua would likely be the better candidate for burned area mapping, as it will allow the detection more burned area for a given day. However, this research will show that the advantage of an early overpass time is less important than spatial resolution, particularly since burned areas not mapped by Terra on a given day can be capture on a later day with no reduction in accuracy.

TM scenes were used in this study to evaluate the accuracy of the MODIS classifications, as comparison with higher-resolution imagery is a reliable and widely accepted technique for evaluating the accuracy of burned area classifications (Eva and Lambin, 1998). For each of the seven MODIS images mentioned above (4 in 2008 and 3 in 2010), a TM scene that was downloaded through the United States Geological Survey's (USGS's) Global Visualization Viewer (GloVis). In all seven cases, the corresponding MODIS and TM scenes were taken within 1 day of each other. Information for the seven pairs of scenes is given in Table 2.

Ground truth data that showed the extent of several specific burned areas were collected during the 2008 and 2010 burn seasons. These data were used for local classification accuracy assessment. Six burned areas from 2008 were digitized from oblique digital photographs taken by a handheld digital camera while flying over burned areas. Digitization was accomplished by matching burned pastures depicted in the