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Assessment of SPOT 5 and QuickBird remotely sensed imagery for mapping tree cover in savannas

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ABSTRACT

The relative abundance and distribution of trees in savannas has important implications for ecosystem function. High spatial resolution satellite sensors, including QuickBird and IKONOS, have been successfully used to map tree cover patterns in savannas. SPOT 5, with a 2.5 m panchromatic band and 10 m multispectral bands, represents a relatively coarse resolution sensor within this context, but has the advantage of being relatively inexpensive and more widely available. This study evaluates the performance of NDVI threshold and object based image analysis techniques for mapping tree canopies from QuickBird and SPOT 5 imagery in two savanna systems in southern Africa. High thematic mapping accuracies were obtained with the QuickBird imagery, independent of mapping technique. Geometric properties of the mapping indicated that the NDVI threshold produced smaller patch sizes, but that overall patch size distributions were similar. Tree canopy mapping using SPOT 5 imagery and an NDVI threshold approach performed poorly, however acceptable thematic accuracies were obtained from the object based image analysis. Although patch sizes were generally larger than those mapped from the QuickBird image data, patch size distributions mapped with object based image analysis of SPOT 5 have a similar form to the QuickBird mapping. This indicates that SPOT 5 imagery is suitable for regional studies of tree canopy cover patterns.

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1. Introduction

A landscape can be conceptualized as a shifting mosaic of patches associated with changing patterns in ecological and physical processes (Young and Aspinall, 2006). The value of quantifying landscape pattern can be found both in its link to causal mechanisms and significance in terms of ecosystem health or value. Landscape patterns arising in savannas are primarily a function of the relative abundance of grass and trees and this balance has been shown to be a function of resource availability (e.g. nutrients and moisture) and disturbance mechanisms (e.g. fire and herbivory) (Higgins et al., 2000; van Langevelde et al., 2003; Sankaran et al., 2004, 2005). The relative abundance of these two life forms has important implications for plant and livestock production as well as ecosystem function, including carbon, nutrient and hydrological cycles (Sankaran et al., 2005). Within a savanna, the size, shape and distribution of tree clusters may have important effects on fuel accumulation, moisture availability, soil development and tree survival, while also having important implications for fauna through variation in shelter, breeding and food resource availability (Fisher et al., 2005; Hendrickx et al., 2007).

Mapping tree cover characteristics from remotely sensed imagery has been the subject of significant research and can be grouped into those studies that examine broadscale patterns of woody cover distribution and those that attempt to identify tree canopies. These studies are generally tied directly to image resolution. Studies of broadscale patterns in savanna vegetation cover have generally been undertaken using moderate or coarse resolution sensors including Landsat, MODIS and NOAA AVHRR (Korontzi, 2005; Spessa et al., 2005). These studies have generally used vegetation indices, such as leaf area index (LAI) or the normalised difference vegetation index (NDVI) to examine broad patterns in landscape heterogeneity (Riera et al., 1998). These sensors, with the added advantage of relatively high return periods and lower cost, are also commonly used to examine temporal patterns in vegetation (Murwira and Skidmore, 2006; Archibald and Scholes, 2007). However, these sensors can only provide proportional estimates of woody cover and cannot be used for analyzing tree cluster patterns.

High spatial resolution imagery (<5 m resolution), sourced from both aerial and satellite based platforms (<5 m resolution), has been used to map tree cover patterns at the local-scale. At the most complex end, highly advanced algorithms have been developed for identifying individual trees and their associated

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canopies, particularly for use in forestry management. However, these techniques are generally limited to application in natural or plantation conifer forests and orchards (Rautainen et al., 2004; Wang et al., 2004, 2007; Leckie et al., 2005; Gougeon and Leckie, 2006), although some success has been achieved in structurally complex forests with hyperspectral and LiDAR imagery (Bunting and Lucas, 2006; Chen et al., 2006). More simple techniques have also been used to map tree cover patterns. Fensham et al. (2002) have demonstrated an accurate technique, based on point based image interpretation, for mapping woody vegetation cover from aerial photography, and this has been adopted in a number of analyses of vegetation change (Fensham and Fairfax, 2003; Fensham et al., 2005; Seabrook et al., 2007). More automated techniques using object based image analysis (OBIA) techniques have also been used to map woody vegetation patterns from aerial photography (Laliberte et al., 2004). However, high spatial resolution satellite based multispectral sensors (<5 m resolution) are increasingly being used to map tree cover patterns given their inclusion of near infra red (NIR) and visible bands and their relatively low pre-processing requirements (Hajek, 2006; Johansen and Phinn, 2006; Valdez-Lazalde et al., 2006; Scanlon et al., 2007).

Tree canopy mapping using high spatial resolution multispectral sensors generally uses relatively simple techniques that threshold either single band data or derived indices (e.g. NDVI) to map tree canopy patterns in a range of environments (Coops et al., 2004; Bunting and Lucas, 2006; Scanlon et al., 2007). These applications are sensitive to contributions from photosynthetic vegetation in the ground layer and can suffer from poor data quality (e.g. directional reflectance) that give rise to differences across the image (Bunting and Lucas, 2006). Seasonal variation in photosynthetic activity in savannas is particularly important as the grass layer is highly active during the growing season, but senesces during the dry season (often in a spatially variable pattern), while the tree layer is also often composed of deciduous species. These variations, combined with high wet season cloud cover and high fire activity in the dry season, create issues for the application of simple pixel based threshold approaches.

Errors associated with image quality and spectral variation within savannas are difficult to accomodate using pixel based approaches. However, OBIA offers the advantage of providing both spectral (tone, colour) and spatial (e.g. size, shape, texture, relation to neighbouring objects) information, which can be used to create a more locally adaptive classification technique. Furthermore, image segmentation, where objects are created based on within-object image variance being lower than between object variance, is a natural first step in tree canopy mapping given tree canopies are the key structural element of high spatial resolution imagery (Gougeon and Leckie, 2006).

IKONOS and QuickBird are most commonly referred to as high spatial resolution sensors and have been used for mapping tree canopy patterns. However, these image sources have the limitation of being expensive and only a relatively small archive of imagery exists for remote areas. Tree canopy mapping across large areas of savanna using these image sources are therefore difficult and most studies are limited to the analysis of representative areas (Scanlon et al., 2007; Bowman et al., 2008) SPOT 5, launched in 2002, has a panchromatic band of 2.5 m pixels (through the merging of two horizontally and vertically offset 5 m panchromatic bands) and three multispectral bands (two visible and one near infra red) of 10 m pixels. Image swaths are 60 km × 60 km to 80 km and, through the constellation of three SPOT satellites, any point on 95% of the earth may be imaged any day. This sensor therefore has the ability to produce high spatial resolution imagery (<5 m pixels), to be more temporally responsive and at approximately 10% of the cost of IKONOS or QuickBird is more appropriate for regional studies.

This paper evaluates the ability of QuickBird and SPOT 5 imagery for tree cover mapping in savannas. OBIA is compared and contrasted with traditional pixel based threshold approaches using the NDVI. While high spatial resolution sensors have been used for tree crown delineation, SPOT 5 has not been considered due to its larger pixel size. The ability of OBIA to use spatial and textural, as well as spectral, information has not been considered in previous studies for mapping tree crowns from SPOT 5 imagery. The imagery and techniques are applied to four areas in Kruger National Park in southern Africa that include a range in tree cover and represent two major savanna types in the region.

2. Study area

Kruger National Park is a 20,000 km^2 reserve located in the South African 'lowveld' bordering Mozambique, extending from approximately latitude 22.5° south to 25.5° south (Higgins et al., 2007) (Fig. 1). The park is dominated by gentle relief (approximately 300–800 m) and is underlain mostly by basalt and granite geologies, with rhyolite and other geologies making up the rest. Rainfall varies across a north-south gradient, ranging from around 750 mm per year in the south to 350 mm per year in the north. Most rain falls in the summer months and has a high degree of annual variation. The reserve is characterized by well-wooded savanna dominated by knobthorn *Acacia nigrescens*, marula *Sclerocarya birrea*, leadwood *Combretum imberbe* mopane *Colophospermum mopane* and silver cluster leaf *Terminalia sericea*.

Experimental burn plots (EBPs), established in 1954, are located in four major landscapes of the park. The plots were established to study the role of burning in the preservation of fauna and flora (Biggs et al., 2003). Each landscape contains four replicate strings and each string has twelve 7 ha plots that have been exposed to different burning treatments, including an absence of fire. Tree cover patterns are variable across each plot, with unburnt plots generally containing more large trees than the burnt plots (Higgins et al., 2007). This study maps tree cover on the Pretoriuskop and Satara landscape plots. The Pretoriuskop plots, located in the south of the park, have a mean annual rainfall of 737 mm, located on granite geologies and are dominated by dense tall (10–15 m) silver cluster leaf *T. sericea* trees. The Satara plots are located further north in an area with mean annual rainfall of 544 mm, basaltic soils and a savanna dominated by scattered tall (10–15 m) marula *S. birrea* and knobthorn *A. nigrescens* trees.

3. Methods

3.1. Data acquisition

SPOT-5 and QuickBird satellite imagery covering the Kambeni and Numbi EBP strings at Pretoriuskop and the Nwanetsi and Marheya EBP strings at Satara were obtained for this project. The SPOT-5 imagery were subset from a dataset that includes scenes that collectively cover the entire Kruger National Park. The QuickBird imagery was extracted from two archived scenes covering the southern region of Kruger National Park. Images were all captured in the dry season (March–November), with the QuickBird imagery captured in 2004 and SPOT-5 imagery in 2006 (Table 1). The SPOT-5 imagery was supplied as radiometrically and

Table 1
Image acquisition dates.

	Pretoriuskop	Satara
SPOT 5	11 May 2006	26 March 2006
QuickBird	02 July 2004	18 November 2004

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