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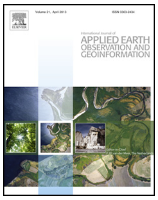

Multi-phenology WorldView-2 imagery improves remote sensing of savannah tree species

Sabelo Madonsela[a,b,*], Moses Azong Cho[a,b], Renaud Mathieu[a,c], Onisimo Mutanga[b], Abel Ramoelo[a], Żaneta Kaszta[d], Ruben Van De Kerchove[e], Eléonore Wolff[d]

[a] Earth Observation Research Group, Natural Resources and Environment, Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa
[b] School of Agric. Earth and Environmental Sciences, University of KwaZulu-Natal (UKZN), Pietermaritzburg, South Africa
[c] Department of Geography, Geoinformatics and Meteorology, University of Pretoria, Pretoria, South Africa
[d] IGEAT, Université Libre de Bruxelles (ULB), Belgium
[e] Unit Remote Sensing and Earth Observation Processes, Flemish Institute for Technological Research (VITO), Mol 2400, Belgium

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ABSTRACT

Biodiversity mapping in African savannah is important for monitoring changes and ensuring sustainable use of ecosystem resources. Biodiversity mapping can benefit from multi-spectral instruments such as WorldView-2 with very high spatial resolution and a spectral configuration encompassing important spectral regions not previously available for vegetation mapping. This study investigated i) the benefits of the eight-band WorldView-2 (WV-2) spectral configuration for discriminating tree species in Southern African savannah and ii) if multiple-images acquired at key points of the typical phenological development of savannahs (peak productivity, transition to senescence) improve on tree species classifications. We first assessed the discriminatory power of WV-2 bands using interspecies-Spectral Angle Mapper (SAM) via Band Add-On procedure and tested the spectral capability of WorldView-2 against simulated IKONOS for tree species classification. The results from interspecies-SAM procedure identified the yellow and red bands as the most statistically significant bands ($p = 0.000251$ and $p = 0.000039$ respectively) in the discriminatory power of WV-2 during the transition from wet to dry season (April). Using Random Forest classifier, the classification scenarios investigated showed that i) the 8-bands of the WV-2 sensor achieved higher classification accuracy for the April date (transition from wet to dry season, senescence) compared to the March date (peak productivity season) ii) the WV-2 spectral configuration systematically outperformed the IKONOS sensor spectral configuration and iii) the multi-temporal approach (March and April combined) improved the discrimination of tress species and produced the highest overall accuracy results at 80.4%. Consistent with the interspecies-SAM procedure, the yellow (605 nm) band also showed a statistically significant contribution in the improved classification accuracy from WV-2. These results highlight the mapping opportunities presented by WV-2 data for monitoring the distribution status of e.g. species often harvested by local communities (e.g. *Sclerocharya birrea*), encroaching species, or species-specific tree losses induced by elephants.

1. Introduction

Trees in African savannahs provides multiple essential resources to rural and peri-urban populations e.g. fuelwood, building material and non-timber products, such as fruits, barks and roots (Shackleton et al., 2007; Bruschi et al., 2014; Schlesinger et al., 2015) and often act as a safety net against increased poverty and food insecurity for the poorest communities (Djoudy et al., 2015). Monitoring savannah tree biodiversity remains critical in order to ensure that resource use or disturbances, e.g. impact of elephants in protected areas, remains within the resilience limits of the ecosystem (Druce et al., 2008; Asner et al., 2009). Tree species abundance, distribution, and richness in savannah landscapes are impacted by land use conversion, e.g. to urban or agricultural lands, (Schlesinger et al., 2015), land management (Wessels et al., 2011; Nacoulma et al., 2011), disturbance regimes, e.g. fire, herbivory (Shackleton et al., 1994; Mudongo et al., 2016), and climate change (Stevens et al., 2014). African savannahs, as other ecosystems of the earth, are subjected to high pressure from humans and the burden remains

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[*] Corresponding author at: Earth Observation Research Group, Natural Resources and Environment, Council for Scientific and Industrial Research (CSIR), Pretoria 0001, South Africa.
E-mail address: sabelo.reliable@gmail.com (S. Madonsela).

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with conservation authorities to maintain biodiversity and ensure sustainable use of biodiversity (Asner et al., 2009).

One key challenge is the lack of large scale information on tree species distribution upon which management decisions can be based to conserve biodiversity (Asner et al., 2009). The success of biodiversity management depends on the availability of up-to-date and spatially detailed assessments of species richness and distribution over large geographic areas (Turner et al., 2003). Spaceborne remote sensing serves as a major source of data for monitoring the Earth ecosystems especially due to its extensive spatial coverage and revisit capacity (Foody et al., 2005; Nagendra, 2001). Traditional multispectral imagery (e.g. Landsat) dominated by mixed pixels, especially in heterogeneous landscapes, and typically of poor spectral resolution (small number of bands <10, typically with large bandwidths, bands not strategically placed across the electromagnetic spectrum for optimally capturing biochemical composition of plants) are generally suitable for mapping broad vegetation communities from regional to landscape scales (Nagendra and Rocchini, 2008). For instance, these systems are particularly efficient in mapping species in regions dominated by stands of planted commercial species or semi-managed forests with low species diversity (Nagendra and Rocchini, 2001).

On the other hand, hyperspectral sensors sample the electromagnetic spectrum into several tenths or hundreds of contiguous bands, allowing the capture of the biochemical composition of plants which is closely linked to species identity (Asner and Martin, 2009). Typically mounted on field or airborne platforms these systems provide sub canopy pixel size and can retrieve tree species at single crown scale. Although they can image a very high number of bands, most bands are highly correlated and a few information-rich spectral regions, linked to leaf pigment and other biochemical properties, are more relevant for species discrimination (Sobhan, 2007). High spatial resolution hyperspectral systems have been reported to be an efficient approach for tree species mapping in a variety of biomes or ecosystems (Asner et al., 2008; Oldeland et al., 2010; Naidoo et al., 2012; Higgins et al., 2014). However, airborne hyperspectral tools are not widely available, especially for inventories and management applications.

The recent advancement in spectral configuration and spatial resolution of spaceborne multispectral sensors has presented new opportunities for detailed examination of biodiversity (Pu and Landry, 2012; Nagendra and Rocchini, 2008). WorldView-2 fills an important gap between the above-mentioned scales. It possesses new, strategically important bands for vegetation mapping e.g. yellow, red-edge (Darvishzadeha et al., 2008; Mutanga and Skidmore, 2007) compared to well-known sensors such as Quickbird or IKONOS, and a spatial resolution (<2m) compatible with the detection of single crowns. For instance, Pu and Landry (2012) reported significantly improved classifications of seven urban tree species with WorldView-2 compared to IKONOS and attributed this improvement to the better spatial resolution (4–2m) and spectral configuration of the instrument. Cho et al. (2015) mapped with 90% accuracy dominant tree species in protected subtropical coastal forests in South Africa. Both studies noted that the additional yellow, red-edge and NIR-2 bands on WorldView-2 sensor enhance our ability to spectrally discriminate tree species. Moreover, Cho et al. (2012), using simulated WorldView-2 data from airborne CASI-like hyperspectral data, argued that 2 m spatial resolution of WorldView-2 image should be suitable for mapping tree canopy greater than 6 m in diameter in South African savannahs. These developments in spatial and spectral resolution are pushing the boundary beyond vegetation community mapping and provide opportunities for mapping vegetation at crown scale and species-level, thus enhancing the utility of multispectral data.

Remote sensing spectral data are used to assess species diversity because tree spectral signatures are linked to their biochemical and biophysical attributes (Nagendra 2001; Asner and Marin 2009; Cho et al., 2012, 2010). For instance, the yellow and/or red-edge regions are sensitive to subtle differences in carotenoid and chlorophyll pigments amongst species, and therefore they are useful for enhancing tree species discrimination (Pu and Landry, 2012; Cho et al., 2012). However, at the same time high intra-species spectral variability weakens the assumption of unique spectral signature for each species, and this calls for innovative classification approaches (Cho et al., 2010). High intra-species spectral variability has been observed in southern African savannah setting and it originates partly from differences in within-species phenology, possibly linked to tree size, soil type, landscape position, and climatic conditions across the landscape (Archibald and Scholes 2007; Cho et al., 2010; Naidoo et al., 2012).

Recent studies have resorted to redesigning spectral libraries that account for intra-species variability in the spectral discrimination of tree species (Cho et al., 2010; Cochrane, 2000). Cho et al. (2010) proposed a protocol for the application of the Spectral Angle Mapper (SAM) using multiple-endmembers and achieved higher overall accuracy compared to conventional SAM. Alternatively time-series data covering different periods during phenological cycle can be used to enhance tree species discrimination (Hill et al., 2010; Gilmore et al., 2008; Key et al., 2001). Phenological changes occur throughout the growing season at different rates amongst species and data that captures these changes amplify the spectral variability between deciduous species in relation with intra-species variability (Hill et al., 2010; Key et al., 2001). This makes a multi-temporal approach towards tree species mapping in the savannah environment a topical research question. The aim of this research was to assess if i) WorldView-2 spectral configuration helps discriminating tree species in a southern African savannah environment and if ii) multiple-images acquired at key points of the typical phenological development of savannahs further improve on tree species classifications.

2. Study area

The study site is situated between longitude 31°21′18.66″ to 31°31′01.61″E and latitude 24°50′42.61″ to 24°59′35.04″S, covering approximately 265 km^2 in the immediate vicinity of the Kruger National Park, South Africa (Fig. 1). It falls in the South African Lowveld within the broader savannah biome which is characterized by the coexistence of continuous grassy vegetation layer and discontinuous woody vegetation (du Toit et al., 2003). Granite and gabbro geologies dominate in the area with vegetation communities defined by these geological structures. Gabbro patches consists of shallow to moderately deep, dark clay soils with nutritious high-bulk grasses and sparse trees and shrubs, particularly *Acacia* spp. Conversely, the granitic substrate consists of nutrient-poor, shallow to moderately deep sandy soils with gently undulating terrain and it sustains broad-leaved deciduous tree species upslope while fine-leaved species dominate downslope. Granitic landscapes are characterized by high species diversity and dominance of *Combretum* spp. (du Toit et al., 2003; Eckhardt et al., 2000). The Sabi-region, where this study was carried out, receives an annual average rainfall of 630 mm. The average annual temperatures revolve around 22 °C in the same period and frost is rare (du Toit et al., 2003; Eckhardt et al., 2000).

3. Data and methods

3.1. Remote sensing data and pre-processing

Two WorldView-2 (hereafter called WV-2) satellite images were acquired by DigitalGlobe, Inc., USA on different dates: i) 19th of