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Investigating the robustness of the new Landsat-8 Operational Land Imager derived texture metrics in estimating plantation forest aboveground biomass in resource constrained areas

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ABSTRACT

The successful launch of the 30-m Landsat-8 Operational Land Imager (OLI) pushbroom sensor offers a new primary data source necessary for aboveground biomass (AGB) estimation, especially in resource-limited environments. In this work, the strength and performance of Landsat-8 OLI image derived texture metrics (i.e. texture measures and texture ratios) in estimating plantation forest species AGB was investigated. It was hypothesized that the sensor's pushbroom design, coupled with the presence of refined spectral properties, enhanced radiometric resolution (i.e. from 8 bits to 12 bits) and improved signal-to-noise ratio have the potential to provide detailed spectral information necessary for significantly strengthening AGB estimation in medium-density forest canopies. The relationship between image texture metrics and measurements of forest attributes can be used to help characterize complex forests, and enhance fine vegetation biophysical properties, a difficult challenge when using spectral vegetation indices especially in closed canopies. This study examines the prospects of using Landsat-8 OLI sensor derived texture metrics for estimating AGB for three medium-density plantation forest species in KwaZulu Natal, South Africa. In order to achieve this objective, three unique data pre-processing techniques were tested (analysis I: Landsat-8 OLI raw spectral-bands vs. raw texture bands; analysis II: Landsat-8 OLI raw spectral-band ratios vs. texture band ratios and analysis III: Landsat-8 OLI derived vegetation indices vs. texture band ratios). The landsat-8 OLI derived texture parameters were examined for robustness in estimating AGB using linear regression, stepwise-multiple linear regression and stochastic gradient boosting regression models. The results of this study demonstrated that all texture parameters particularly band texture ratios calculated using a 3×3 window size, could enhance AGB estimation when compared to simple spectral reflectance, simple band ratios and the most popular spectral vegetation indices. For instance, the use of combined texture ratios yielded the highest R^2 values of 0.76 (RMSE = 9.55 t ha^{-1} (18.07%) and CV-RMSE of 0.18); 0.74 (RMSE = 12.81 t ha^{-1} (17.72%) and CV-RMSE of 0.08); 0.74 (RMSE = 12.67 t ha^{-1} (06.15%) and CV-RMSE of 0.06) and 0.53 (RMSE = 20.15 t ha^{-1} (14.40%) and CV-RMSE of 0.15) overall for *Eucalyptus dunii*, *Eucalyptus grandis*, *Pinus taeda* individually and all species, respectively. Overall, the findings of this study provide the necessary insight and motivation to the remote sensing community, particularly in resource constrained regions, to shift towards embracing various texture metrics obtained from the readily-available and cheap multispectral Landsat-8 OLI sensor.

1. Introduction

Aboveground biomass (AGB) is an important indicator of bio-physical processes related to forest dynamics. Information on AGB is valuable in understanding and monitoring ecosystem response and its contribution to the global carbon cycle and climate change for accurate greenhouse gas inventorying, and terrestrial carbon accounting (Chinembiri et al., 2013; Gara et al., 2014; Güneralp et al., 2014; Lu, 2006). Accurate and regularly repeated AGB estimation at regional or local scales is critical in reducing the uncertainty in estimating carbon sequestration and emissions (Güneralp et al., 2014; Lu, 2006). Information on AGB is important in greenhouse gas life cycle assessments and global climate change

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mitigation strategies. Moreover, accurate and repeated monitoring of forest ecosystems status can also help in introducing appropriate planning and monitoring conservation efforts. Therefore identifying affordable, timely and readily-available remote sensing datasets, together with robust image processing techniques, is essential to improve forest AGB estimates.

Although the application of remote sensing in forest AGB estimation remains one of the most favourable and invaluable potential approaches, the issue of image resolution (i.e. spectral and spatial properties) plays a major role in the accurate retrieval of AGB estimates. Spectral vegetation indices normally rely on the relationship between the red and near infra-red bands of the electromagnetic spectrum to augment the spectral influence from the green vegetation, concurrently reducing contribution from the soil background, sun zenith angle, sensor viewing angle, senesced vegetation and the atmosphere (Bannari et al., 1995; Carlson and Ripley, 1997; Choudhury, 1987; Elvidge and Chen, 1995; Foody et al., 2003; Huete, 1988; Lu, 2006; Tarpley et al., 1984; Teillet et al., 1997; Tucker, 1979; Wiegand et al., 1991). However, previous studies show that the use of spectral vegetation indices computed from medium-to-coarse spatial resolution multispectral sensors in places with moderate or high canopy closure produce poor results primarily due to saturation challenges and the existing problem of multiple layering (Dube et al., 2014b; Godsmark, 2010; Ingram et al., 2005; Lu, 2006; Mutanga et al., 2012; Mutanga and Skidmore, 2004; Nichol and Sarker, 2011). Recent studies on aboveground biomass estimation advocate for the use of texture parameters instead of spectral vegetation indices (Kelsey and Neff, 2014). This is because texture parameters correlate much better with field datasets, since they allow for finer distinction of vegetation structural details (Eckert, 2012; Fuchs et al., 2009; Nichol and Sarker, 2011; Sarker and Nichol, 2011).

Image-texture analysis technique can be applied in identifying spectrally unique objects, based on a function of local variance in the image and is also related to the spatial resolution and the size of the dominant scene objects (Haralick et al., 1973). Image-texture is an important source of information, capable of identifying different aspects of forest stand structure including density, age, leaf area index in medium-to-high spatial resolution images (Champion et al., 2008). Some of the major strengths of applying image-texture measures include: (1) the ability to simplify and define complex forest canopy structures such as multiple layering and even closed canopies; and (2) enhancing detection of fine vegetation biophysical properties; a complex challenge when using spectral vegetation indices especially in closed canopies (Champion et al., 2008). Moreover, earlier work (i.e. using high spatial resolution sensors) demonstrates that texture measures have the capability to enhance vegetation discrimination (Dekker, 2003; Podest and Saatchi, 2002; Shimada et al., 2014). However, the relationship between medium spatial resolution sensors and forest AGB has not yet been fully examined, especially when compared to the use of other image properties, such as raw spectral band information and vegetation indices. This is perhaps due to the difficulty of identifying and selecting proper texture parameters together with the optimal window-size and offset.

So far, the available studies have mostly demonstrated the application of texture measures derived from high resolution sensors such as synthetic aperture radar, Worldview-2, Advanced Visible and Near Infrared Radiometer type-2 (AVNIR-2) and SPOT-5 in estimating various tree-structural attributes namely: stand age, leaf area index, stand density and biomass (Eckert, 2012; Nichol and Sarker, 2011; Pandey et al., 2010; Pinto et al., 2012; Sarker and Nichol, 2011) and partly from medium resolution multispectral sensors, such as the Landsat products (Cutler et al., 2012; Kelsey and Neff, 2014). The majority of these studies have shown that image-texture measures have the potential to accurately improve the detection of different forest stand characteristics. More importantly, image-texture measures have the capability to enhance the discrimination of spatial information and simultaneously enhancing AGB detection levels by increasing the saturation levels that could not be measured with spectral vegetation indices (Eckert, 2012; Kuplich et al., 2005; Santos et al., 2003; Sarker and Nichol, 2011; Vashum and Jayakumar, 2012; Xu et al., 2011). For instance, Sarker and Nichol (2011) estimated AGB with a plausible adjusted *r*-square value of 0.88 using texture measures derived from the Advanced Land Observation Satellite, AVNIR-2. On the other hand, Eckert (2012) obtained high carbon estimates (R^2-value 0.84 and relative RMSE of 6.8%) for degraded forest, using WorldView-2 derived texture measures.

Thus, from the afore-mentioned studies, it is clear that image textural measures have the potential to provide an attractive opportunity for monitoring tree-structural attributes (i.e. AGB, leaf area index and chlorophyll content etc.) in areas with moderate or high canopy closure. However, the problem with the use of high resolution images in resource-constrained regions of sub-Saharan Africa, south-east Asia and South America is the associated cost, limited availability and related-technical challenges. Currently, the limited number of AGB studies in these regions, using high resolution images for instance, is probably an indication of the limitations associated with these datasets (Adelabu and Dube, 2014; Dube et al., 2014a; Dube and Mutanga, 2015; Dube et al., 2014b; Dube et al., in-press; Koch, 2010). Nevertheless, considering the inevitability of forest AGB estimation at regional to global scales, the prospects of investigating the performance of image texture parameters obtained from the multispectral sensors with medium-spatial resolution, a large swath-width and a repeated coverage is necessary in resource constrained regions.

The adoption of the free-and-readily available remotely sensed datasets is critical in such resource-constrained regions. The newly-launched pushbroom Landsat-8 OLI sensor with 30-m spatial resolution is one such dataset. So far, the rich information contained in this sensor has not yet been fully exploited in understanding the distribution of AGB. This mainly due to the fact that this sensor has just recently been launched and possibly due to the purported challenges of saturation and the presence of a few spectral bands, which can be used to compute simple spectral vegetation indices. Among the different types of the readily-available multispectral remote sensing sensors, a derivation of texture measures from this remotely sensed dataset (i.e. pushbroom Landsat-8 OLI sensor) can improve the estimation of regional to local scale forest AGB. The newly-launched Landsat-8 OLI sensor is hypothesized to display a great potential in estimating AGB across different scales especially in data-scarce areas. This is due to the enhanced sensor's sensitivity to different vegetation properties (e.g. chlorophyll, leaf area index and AGB), the presence of a large swath-width (i.e. 185-km) coupled with improved signal-to-noise ratios (SNR). These sensor improvements enhance the radiometric sensitivity which in turn improves spectral strength to detect the most important forest structural properties by thereby minimizing saturation problems. These saturation problems were normally common with the prior Landsat 7 ETM^+ products. Although the new Landsat-8 OLI sensor presents a more attractive potential in vegetation studies than its counterparts (i.e. MODIS, earlier Landsat products etc.), previous work using spectral vegetation indices computed from the Landsat-8 OLI, obtained relatively low AGB estimation accuracies (i.e. an R^2 of 0.69 between predicted and observed biomass and a moderately high average root mean square error (RMSE) of 14.91 t ha^{-1}) (Dube and Mutanga, 2015). This shows that accurate forest AGB estimation is not only dependent on the Landsat-8 OLI dataset but also requires advanced and robust image processing techniques such as texture metrics. Therefore, texture metrics are perceived to