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Obtaining biophysical measurements of woody vegetation from high resolution digital aerial photography in tropical and arid environments: Northern Territory, Australia

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ABSTRACT

Biophysical parameters obtained from woody vegetation are commonly measured using field based techniques which require significant investment in resources. Quantitative measurements of woody vegetation provide important information for ecological studies investigating landscape change. The fine spatial resolution of aerial photography enables identification of features such as trees and shrubs. Improvements in spatial and spectral resolution of digital aerial photographic sensors have increased the possibility of using these data in quantitative remote sensing. Obtaining biophysical measurements from aerial photography has the potential to enable it to be used as a surrogate for the collection of field data. In this study quantitative measurements obtained from digital aerial photography captured at ground sampling distance (GSD) of 15 cm (n = 50) and 30 cm (n = 52) were compared to woody biophysical parameters measured from 1 ha field plots. Supervised classification of the aerial photography using object based image analysis was used to quantify woody and non-woody vegetation components in the imagery. There was a high correlation ($r \geq 0.92$) between all field measured woody canopy parameters and aerial derived green woody cover measurements, however only foliage projective cover (FPC) was found to be statistically significant (paired *t*-test; $\alpha = 0.01$). There was no significant difference between measurements derived from imagery captured at either GSD of 15 cm and 30 cm over the same field site (n = 20). Live stand basal area (SBA) ($m^2\ ha^{-1}$) was predicted from the aerial photographs by applying an allometric equation developed between field-measured live SBA and woody FPC. The results show that there was very little difference between live SBA predicted from FPC measured in the field or from aerial photography. The results of this study show that accurate woody biophysical parameters can be obtained from aerial photography from a range of woody vegetation communities across the Northern Territory.

1. Introduction

Biophysical parameters obtained from woody vegetation such as stand basal area, canopy cover and foliage projective cover are important information for studies investigating landscape change (Armston et al., 2013; Clewley et al., 2012). These attributes are commonly measured in the field and have been used extensively in ecological studies (Cook et al., 2005; Williams et al., 1997), for forest inventories (Wulder et al., 2008), and monitoring mine rehabilitation (Ludwig et al., 2003). A number of studies have shown that biophysical parameters from woody vegetation can been derived from aerial photography with reasonable levels of accuracy (Sharp and Bowman, 2004; Fensham et al., 2007; Fensham and Fairfax, 2007; Browning et al., 2009; Laliberte et al., 2010). Aerial photography represents one of the earliest forms of remote sensing and its use has been diverse (Campbell, 1996), ranging from military reconnaissance, infrastructure mapping, natural disaster management and ecosystem monitoring. It has been used in a wide range of environmental studies, with applications ranging from invasive weed

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mapping (Robinson et al., 2008; Dorigo et al., 2012), rangeland mapping and assessment (Laliberte et al., 2010; Browning et al., 2009; Foran and Cellier, 1980), forestry management (Coggins et al., 2008; Wulder et al., 2012) and vegetation community mapping (Harvey and Hill, 2001; Lucas et al., 2002; Lewis et al., 2013). The spatial resolution and historical record of aerial photography provide an important resource for landscape investigations (Morgan et al., 2010; Fensham and Fairfax, 2002). The fine spatial resolution (<1 m ground sampling distance) of aerial photography enables features within the landscape, such as trees and shrubs to be identified (Morgan et al., 2010). It is also used as a source of information to produce calibration and validation data for use with coarser spatial resolution satellite imagery such as Landsat suite of sensors (Mellor et al., 2013; Wulder et al., 2012; Xu et al., 2003; Congalton and Green, 2009; Coops et al., 1997; Pu et al., 2003).

The development of digital sensors has led to a marked improvement in the spatial and spectral resolution of aerial photographic imagery (Rosso et al., 2008; Wulder et al., 2012). These improvements have increased the potential use of these data for quantitative remote sensing (Laliberte et al., 2010). Coggins et al. (2008) used 10 cm ground sampling distance (GSD) digital aerial photography to extract individual tree canopy cover in forest in the Canadian Rocky Mountains. These canopy cover measurements were then related to field measured tree canopy cover and stem diameter to estimate stocking density. There was a significant correlation between estimates derived from the aerial photography and field data to enable them to be used as inputs into a model to predict the potential impacts of mountain pine beetle on these forest stands (Coggins et al., 2008; Wulder et al., 2012). Laliberte et al. (2010) used ultra-high resolution digital aerial photography (4 cm GSD) to estimate percent cover of vegetation and bare ground for a range of vegetation communities in rangelands in south-western USA. They reported high correlations between shrub, grasses and non-vegetated surfaces derived from imagery and field-based measures (Laliberte et al., 2010). One of the motivating factors for their study was to develop reliable methods which enabled the assessment of plots at an equivalent scale and detail to field-based sampling measurements, over extensive and often remote areas (Laliberte et al., 2010).

Remote sensing technology is particularly suited to the Northern Territory, due to the low population density, harsh climate and vast areas (Hill and Carter, 1999; Whiteside et al., 2011). The Northern Territory Government (NTG) is currently implementing a remote sensing monitoring program based on the Landsat suite of sensors. The temporal and spatial scale of these data has the potential to enable objective assessment of the landscape at a regional scale (Wallace et al., 2006; Karfs et al., 2009). The aim of this remote sensing program is to use quantitative information derived from both the historical archive and current Landsat imagery to monitor and assess land cover across the entire Northern Territory. This requires the development and assessment of models to predict biophysical parameters (e.g. woody cover estimates and fractional ground cover) from the suite of Landsat sensors. Studies that use coarser spatial resolution satellite imagery, such as Landsat (30 m GSD), to estimate biophysical parameters often develop predictive models by relating field measured data to the satellite imagery (Armston et al., 2009; Scarth et al., 2010). To enable these models to be developed, a sufficient quantity of field data covering the range of variability across the landscape is required. The collection of an adequate number of field sites to calibrate and validate products derived from sensors such as Landsat at a regional scale can be inhibited by both financial cost and logistical constraints (Laliberte et al., 2010; Armston et al., 2013). In addition to these constraints, assessment of the models applied to historical imagery needs to be compared to biophysical parameters measured at the time of the image capture. The level of detail within aerial photography has enabled it to be used as a surrogate for the collection of ground data (Mannel et al., 2006). A number of studies have used aerial photography to derive biophysical parameters to calibrate Landsat satellite imagery (Xu et al., 2003; Pu et al., 2003; Carreiras et al., 2006; Samani Majd et al., 2013). Samani Majd et al. (2013) reported significant correlation between Landsat derived NDVI (normalised difference vegetation index) and fractional canopy cover measured from digital aerial photographs. In many instances, aerial photographs may be the only available data from which to assess the accuracy of results derived from coarse scale historical satellite imagery. Often when aerial photography is used to produce calibration and validation data the assumption is made that the interpretation of the aerial photographs are correct, when in fact there may be significant errors in the interpretation which remain unknown unless validation of the results are undertaken (Congalton and Green 2009).

The NTG has a large archive of aerial photographs captured since 1940s (http://www.ntlis.nt.gov.au/imfPublic/airPhotoimf.jsp). In 2008 the NTG moved away from the traditional film aerial photography and now routinely captures imagery using digital format cameras. The extensive archive of very high resolution digital aerial photography held by the NTG has the potential to be a valuable source of calibration and validation data for use with coarser spatial resolution sensors. The combined spatial resolution and radiometric quality of the digital sensors (Leberl et al., 2012) used to capture the imagery across the Northern Territory has the potential to enable accurate measurements of biophysical parameters from woody vegetation. The spatial extent of these data would enable a large number of surrogate field sites to be randomly generated across the Northern Territory, representing a broad range of vegetation communities. To enable these data to be used as a surrogate for field data the biophysical parameters measured need to be first extracted from the imagery, and secondly, the accuracy of the information derived needs to be quantified. The objectives of this study are: (1) develop a methodology that enables the extraction of quantitative woody vegetation biophysical parameters from very high resolution digital aerial photography, (2) statistically quantify the relationship between digital aerial photography and field measured biophysical parameters, and (3) identify and assess the effect of different GSD on the biophysical parameters extracted from digital aerial photographs. The overall aim of this study is to investigate the utility of very high resolution digital aerial photography to be used as a surrogate for the collection of field data. This paper presents the methodology developed to extract biophysical parameters from digital aerial photography captured at both 15 cm and 30 cm GSD and evaluates the accuracy of the quantitative information derived from the imagery.

2. Methods

2.1. Study area

The field sites and aerial photography used in this study are distributed across the Northern Territory of Australia (Fig. 1). The Northern Territory covers an area of 1,346,664 km^2, representing approximately 16.5% of the entire Australian landmass. It is sparsely populated with most people living in the main urban centres of Darwin, Katherine and Alice Springs. The climate is varied, ranging from wet dry tropics in the north, transitioning to semi-arid and arid regions in the south (Ringrose et al., 1994). Temperatures are generally warm all year with the annual average temperature ranging from 32 °C in Darwin, 34 °C in Katherine, 32 °C in Tennant creek and 29 °C in Alice Springs. Much of the Northern Territory is influenced by a monsoonal climate with a majority of the rainfall occurring between the months of October and April