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Assessing ground cover at patch and hillslope scale in semi-arid woody vegetation and pasture using fused Quickbird data

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ABSTRACT

The amount and distribution of vegetation and ground cover are important factors that influence resource transfer (e.g. runoff, sediment) in patterned semi-arid landscapes. Identifying and describing these features in detail is an essential part of measuring and understanding ecohydrological processes at hillslope scales that can then be applied at broader scales. The aim of this study was to develop a comprehensive methodology to map ground cover using high resolution Quickbird imagery in woody and non-woody (pasture) vegetation. The specific goals were to: (1) investigate the use of several techniques of image fusion, namely principal components analysis (PCA), Brovey transform, modified intensity–hue–saturation (MIHS) and wavelet transform to increase the spatial detail of multispectral Quickbird data; (2) evaluate the performance of the red and near-infra-red bands (NIR), the difference vegetation index (DVI), and the normalised difference vegetation index (NDVI) in estimating ground cover, and (3) map and assess spatial and temporal changes in ground cover at hillslope scale using the most appropriate method or combination of methods. Estimates of ground cover from the imagery were compared with a subset of observed ground cover estimates to determine map accuracy. The MIHS algorithm produced images that best preserved spectral and spatial integrity, while the red band fused with the panchromatic band produced the most accurate ground cover maps. The patch size of the ground cover beneath canopies was similar to canopy size, and percent ground cover (mainly litter) increased with canopy size. Ground cover was mapped with relative accuracies of 84% in the woody vegetation and 86% in the pasture. From 2008 to 2009, ground cover increased from 55% to 65% in the woody vegetation and from 40% to 45% in the pasture. These ground cover maps can be used to explore the spatial ecohydrological interactions between areas of different ground cover at hillslope scale with application to management at broader scales.

1. Introduction

Vegetation cover and distribution are important factors controlling runoff and erosion in semi-arid environments. In many semi-arid landscapes, vegetation is organised in patches of individual or aggregated plants or in bands of plants interspersed in a low-cover matrix (Montaña et al., 2001). Hydrological and erosional dynamics differ between low cover areas (inter-patches) that produce runoff, sediment and nutrients, and patches that function as sinks for these resources (Ludwig and Tongway, 1995). Therefore, patches and inter-patches are considered to be fundamental hydrologic units (Muñoz-Robles et al., 2011b; Reid et al., 1999). Runoff and infiltration capacity are controlled mainly by soil surface condition, particularly the nature of the surface crust and the amount and type of vegetative cover (Greene et al., 1994).

Relating hydrological and erosional responses of small-scale vegetated patches and inter-patches (i.e. low and high ground cover) to their spatial distribution is vital for understanding resource transfer at coarser scales (Beeson et al., 2001; Puigdefábregas and Sanchez, 1996). Consequently, the identification of patches and inter-patches and their spatial configuration is essential for describing ecohydrological processes. High-resolution remote sensing (i.e. pixel size <4 m; Franklin, 2001) may provide a means of characterising spatial ground cover patterns in sufficient detail to describe ecohydrological interactions at a scale relevant to management. High-resolution imagery could identify patches and inter-patches that largely determine ecohydrological processes, an

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understanding of which is essential for managing vegetation and soil at paddock and hillslope scales, as well as at broader scales.

Imagery from the Quickbird satellite provides one of the best high spatial resolutions from a commercially available optical satellite. It captures panchromatic data at 0.6–0.7 m spatial resolution, and four bands of multispectral data at 2.4–2.8 m spatial resolution. Quickbird data facilitates ecological modelling and high detail vegetation mapping using GIS (Xie et al., 2008), and provides spectral radiances of the red and near-infra-red (NIR) bands, which are directly related to the intercepted fraction of photosynthetically active radiation (Jensen, 2007). Depending on the focal scale of the processes under investigation, Quickbird data show vegetation patterns at paddock and hillslope scales, which, in conjunction with field data and digital elevation models, can help to describe surface ecohydrological processes (Ludwig et al., 2007).

Ground cover mapping at sub-metre to metre resolution requires a multispectral image with very high spatial resolution. Image fusion involves the merging of a multispectral image with a pixel size greater than the pixel size of a second, panchromatic image (Teggi et al., 2003). The aim of image fusion is to create a high-resolution multispectral image by combining the spatial detail of a high-resolution panchromatic image with the radiometric information of a lower-resolution multispectral image (Nikolakopoulos, 2008). Ideally, image fusion produces spatially improved images that are appropriate for mapping of vegetation and land use (Teggi et al., 2003), and can result in higher classification accuracy than using non-fused multispectral data (Taylor et al., 2010). However, image fusion may modify the radiometric and spatial characteristics of the original data to varying extents, resulting in images that are not suitable for automated digital analysis (Shi et al., 2003). High-quality fused images incorporate the fine detail of the panchromatic data while conserving the original radiometric information and are suitable for quantitative analyses based on spectral signatures such as vegetation analysis (Wang et al., 2005). Therefore, both quantitative and qualitative evaluation of the quality of fused images are necessary to ensure high similarity between the original lower-resolution multispectral data and the derived higher-resolution fused data (Wald et al., 1997).

This study compared image fusion techniques applied to Quickbird images, with the aim of mapping ground cover and identifying functional units from a hydrological perspective in woody vegetation and pasture in semi-arid south-eastern Australia. The specific goals were to: (1) investigate the use of four image fusion algorithms for increasing the original spatial detail of the multispectral Quickbird data, namely principal component analysis (PCA), Brovey transform, modified intensity–hue–saturation (MIHS) and wavelet transform; (2) evaluate the performance of the red and NIR bands, the difference vegetation index (DVI), and the normalised difference vegetation index (NDVI) in estimating ground cover, and (3) map and assess spatial and temporal changes in ground cover at hillslope scale using the most appropriate method or combination of methods.

2. Methods

2.1. Site description

Two adjacent hillslopes located in the central-east of the Cobar pediplain, New South Wales, Australia were selected for this study (Fig. 1). The hillslopes were 185 m above sea level on a gently sloping (1–3%), undulating landscape with low ridges of Quaternary colluvium (Fleming and Zhang, 1999). The soil type on both hillslopes was a red Kandosol in the Australian soil classification system (Isbell, 1996). Annual mean rainfall is 441 mm; average minimum and maximum temperatures are 4 °C and 34 °C, respectively, according to data from the nearest weather station at Nyngan (Bureau of Meteorology, 2008), 40 km south-east of the study site.

One hillslope consisted of woody vegetation dominated by *Callitris glaucophylla* and *Eremophila mitchellii* (3500 stems ha^{-1}) in the overstorey and midstorey. Stem densities of shrubs and trees were counted at each site in nine plots (5 m × 5 m), evenly spaced along the three transects established within 25 m × 25 m plots. Woody vegetation was spatially distributed as individual shrubs and clumped shrubs and trees (i.e. canopies touching) with open areas or inter-canopy zones between them (Fig. 2). The ground cover formed patches, indicating resource accrual areas associated with relatively long-term features such as herbaceous and litter cover, separated by inter-patches, in which resources were freely transported by water or wind (Fig. 2). Patches occurred under the canopies of woody plants and in the inter-canopy zone. Ground cover on the woody hillslope consisted of perennial and annual grasses and forbs, litter and cryptogam cover dominated by a thin layer of cyanobacteria. Grasses, forbs and litter occurred in various combinations under the canopies of woody plants, but occurred in lower amounts in the inter-canopy zone, which was dominated by cryptogams and bare, physically crusted soil.

The second hillslope was a pasture that had been developed by clearing the woody vegetation 23 years previously and had been cultivated 1.5 years prior to field data collection in October 2008. On this hillslope, ground cover formed patches composed of introduced, native and naturalised perennial and annual grasses (including a small amount of oats (*Avena sativa*) from recent cultivation), forbs and litter. Cryptogam cover was absent from this hillslope, and bare soil dominated the spaces (inter-patches) between the patches of medium to high ground cover. Muñoz-Robles et al. (2011a,b) provided details of patch/inter-patch characteristics, and pasture and woody vegetation in the study area. Pasture in this study corresponded to recent pasture, and woody vegetation to woody encroachment in Muñoz-Robles et al. (2011a,b).

Patches and inter-patches were identified using landscape function analysis (LFA) transects (Tongway and Hindley, 2004). The pasture hillslope had a water spreading system of contour banks installed in August 2009, between the two dates of the Quickbird imagery (September 2008 and December 2009). The water spreading used shallow earth walls to divert or delay the movement of water down its natural flow path, increasing water infiltration into the soil. The water spreading system was designed to slow down and spread runoff laterally, allowing water to pass through gaps in the banks and move in a stepwise fashion downslope. This disrupts hydrological connectivity and increases ground cover (Thompson, 2008). The pasture hillslope had low ground cover and high runoff (personal observation) relative to many other pastures in the area, which is why it was chosen for the establishment of the water spreading system. Annual rainfall over the 15-month study was 333 mm in 2008 and 395 mm in 2009, and domestic livestock were excluded from both hillslopes after the establishment of the water spreading system.

2.2. Input data

2.2.1. Image acquisition and pre-processing

Two sets of Quickbird data were used. The first image, captured on 28 September 2008, was used to derive equations for estimating the extent and spatial distribution of ground cover. The second image, captured on 17 December 2009, was used to evaluate changes in extent and spatial distribution of ground cover after the establishment of the water spreading system on the pasture hillslope, and any changes in ground cover in