International Journal of Applied Earth Observation and Geoinformation 44 (2016) 23–30

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

# Testing the discrimination and detection limits of WorldView-2 imagery on a challenging invasive plant target

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ARTICLE INFO

*Article history:*
Received 3 November 2014
Received in revised form 7 July 2015
Accepted 10 July 2015

*Keywords:*
Invasive plants
Remote sensing
Woody weeds
Mesquite
*Prosopis*
WorldView-2

ABSTRACT

Invasive plants pose significant threats to biodiversity and ecosystem function globally, leading to costly monitoring and management effort. While remote sensing promises cost-effective, robust and repeatable monitoring tools to support intervention, it has been largely restricted to airborne platforms that have higher spatial and spectral resolutions, but which lack the coverage and versatility of satellite-based platforms. This study tests the ability of the WorldView-2 (WV2) eight-band satellite sensor for detecting the invasive shrub mesquite (*Prosopis* spp.) in the north-west Pilbara region of Australia. Detectability was challenged by the target taxa being largely defoliated by a leaf-tying biological control agent (Gelechiidae: *Evippe* sp. #1) and the presence of other shrubs and trees. Variable importance in the projection (VIP) scores identified bands offering greatest capacity for discrimination were those covering the near-infrared, red, and red-edge wavelengths. Wavelengths between 400 nm and 630 nm (coastal blue, blue, green, yellow) were not useful for species level discrimination in this case. Classification accuracy was tested on three band sets (simulated standard multispectral, all bands, and bands with VIP scores ≥1). Overall accuracies were comparable amongst all band-sets (Kappa = 0.71–0.77). However, mesquite omission rates were unacceptably high (21.3%) when using all eight bands relative to the simulated standard multispectral band-set (9.5%) and the band-set informed by VIP scores (11.9%). An incremental cover evaluation on the latter identified most omissions to be for objects <16 m$^2$. Mesquite omissions reduced to 2.6% and overall accuracy significantly improved (Kappa = 0.88) when these objects were left out of the confusion matrix calculations. Very high mapping accuracy of objects >16 m$^2$ allows application for mapping mesquite shrubs and coalesced stands, the former not previously possible, even with 3 m resolution hyperspectral imagery. WV2 imagery offers excellent portability potential for detecting other species where spectral/spatial resolution or coverage has been an impediment. New generation satellite sensors are removing barriers previously preventing widespread adoption of remote sensing technologies in natural resource management.



## 1. Introduction

Invasive plants pose a significant threat to biodiversity and ecosystem functioning globally (Vilà et al., 2011; Arianoutsou et al., 2013). Knowledge of their location, areal extent, and spread dynamics is necessary to develop control strategies (Schlesinger et al., 1990; Mack et al., 2000) leading to a requirement for robust and repeatable monitoring tools. Assessments have traditionally been based on ground survey, but these are costly and difficult for broad-scale invasions, particularly in inaccessible, but globally significant (Dean et al., 2012) rangelands. While aerial visual surveys can have high discrimination, species and density classes must be interpreted, making temporal quantification difficult (van Klinken et al., 2007). Therefore, remotely sensed imagery is now the most desirable data source because it can provide timely, repeatable, information over large and inaccessible areas (Underwood et al.,

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http://dx.doi.org/10.1016/j.jag.2015.07.004

2003). A wide range of sensors and sensor platforms are available. Choosing between them is a function of the size of infestation, smallest object that must be detected, distinguishing biological traits (e.g. flower/leaf colour) of the target taxon relative to other coexisting species, and budget (Yang and Everitt, 2010).

When compared to airborne platforms, satellite sensors offer the advantages of greater coverage and pilot-free acquisitions (Huang and Asner, 2009). Many offer long-term archives for retrospective studies (e.g. Landsat series), acquire imagery in near-real time (e.g. MODIS, AVHRR) and are provided free (e.g. Landsat, MODIS, AVHRR). The most widely available satellite images are from Landsat TM/ETM. However, its' moderate spatial resolution sensors (*c.* 30 m) do not permit mapping of individual plants, which makes differentiation between species challenging (Foody et al., 2005). This has restricted its application to a few cases where the biological traits of the target species contrasts markedly with other vegetation and forms large (e.g. 0.5 ha) homogenous patches (e.g. Silván-Cárdenas and Wang, 2010; Gavier-Pizarro et al., 2012). SPOT-4 imagery, with a spatial resolution of 20 m, has also had a similarly low level of applicability (e.g. Anderson et al., 1993) and both are insufficient to be useful for monitoring and managing most invasive populations (Lass et al., 2005).

Higher spatial resolution (e.g. 2.44–4 m), multispectral (e.g. four-band) satellite imagery capable of identifying individual tree crowns (e.g. QuickBird and IKONOS imagery), has been available since *c.* 2000 and applied to differentiate plant species (e.g. Carleer and Wolff, 2004; Wang et al., 2004). However, the combination of each instruments spatial and spectral resolution still lagged behind standard airborne acquisitions. Consequently, monitoring tools have routinely relied on airborne platforms that can acquire high spatial resolution video (e.g. Everitt et al., 1992; Frazier, 1998), multispectral (e.g. Lass et al., 1996; Everitt et al., 1999), and hyperspectral (e.g. Underwood et al., 2003; Yang and Everitt, 2010) imagery.

Several closely related *Prosopis* species (Family: Fabaceae), collectively referred to as mesquite, are invasive shrubs native to the Americas. They have become serious invaders in arid and semi-arid regions globally where they form extensive and difficult to manage thorn-forests (Archer, 1995; Ansley et al., 2001; van Klinken and Campbell, 2009). The development of quantitative, repeatable mapping techniques is a priority for guiding management activities (Hennessy et al., 1983; Gibbens et al., 1992; Goslee et al., 2003). This can be challenging because mesquite often coexist with structurally similar shrubs, and invasions often begin as individual plants that form clumps before coalescing to form monocultures (Archer, 1995; van Klinken et al., 2006). Furthermore, the largest population in Australia, located in the Pilbara Region (north-western Australia) remains heavily defoliated since the release of a defoliating biocontrol agent in 1998 (van Klinken et al., 2003).

Previous research by Robinson (2008) has trialled airborne multispectral (4 band, 1 m) and hyperspectral (126 band, 3 m) imagery on the mesquite population in the Pilbara Region. Limited spectral differentiation between mesquite and coexisting species was found in the near infrared band (around 780 nm) of the multispectral imagery but it was insufficient for accurate classification. Spectral analysis of 3 m spatial resolution, hyperspectral imagery identified additional discrimination in the the red-edge wavelengths (ca. 700–750 nm). However, plants needed to be at least four pixels (36 m$^2$) in size to be accurately detected, which was considered too large for monitoring purposes.

WorldView-2 (WV2) satellite imagery represents a new generation of satellite-based sensors that are beginning to bridge the gap between airborne and satellite-based platforms, particularly in terms of spatial (2 m) and spectral (8-band) resolution (Mutanga et al., 2012). It senses the standard visible to near infrared region of the spectrum (red, green, blue, near infrared) and has an additional four bands that are sensitive to the key absorption features of carotenoids (yellow band), chlorophyll (coastal blue), vegetation health (red-edge), and a second near-infrared band for detecting leaf mass and moisture content (Ustin et al., 2009; Cho et al., 2012). Multiple studies have demonstrated the importance of these additional bands for mapping purposes. For example, Oumar and Mutanga (2014) identified the red-edge to be useful for detecting defoliation and stress caused by bronze bug feeding on Eucalypt plantations. Other studies have shown improved plant species differentiation by comparison to other image sources, including IKONOS (e.g. Pu and Landry, 2012), standard (4-band, 0.5 m spatial resolution) airborne imagery (Fernandes et al., 2014) or by simulation (e.g. Immitzer et al., 2012).

The spatial and spectral resolutions of WV2 are also respective improvements on the 3 m airborne hyperspectral imagery and 4-band multispectral imagery previously trialled by Robinson (2008). Therefore, it was hypothesised that the spectral separation in the red-edge and near infrared regions identified from hyperspectral imagery may also be detectable in the corresponding bands of WV2 and that the 2 m spatial resolution may make it more suitable for mapping smaller plants. To assess this hypothesis, we aimed to: a) provide a measure of each bands' importance in the classification; b) process the imagery and compare differences class differences between three band sets: i) standard 4-band multispectral (blue, green, red, near infrared); ii) all 8-bands available; and iii) band selection informed by the band importance measure); and c) determine discrimination (accuracy) potential and the size of plant that can be accurately detected.

## 2. Materials

### 2.1. Target species and study site

The 430 ha study site was located within a 150,000 ha population of mesquite on the Fortescue River delta, north-west Pilbara, Australia (Mardie Pastoral Station, 21°11′N. 115°58′E). The population is a hybrid complex of *Prosopis pallida* (H & B. ex Willd.) H.B.K., *Prosopis pallida* Wooton and *Prosopis glandulosa* var. *glandulosa* Torrey (van Klinken and Campbell, 2009). *P. pallida* is native to southern Central America, while *P. velutina* and *P. glandulosa* are native to the USA and Mexico (Pasiecznik et al., 2001).

Individual mesquite plants within the study site can grow to 6 m tall, although most mature plants are between 3 and 4 m tall, often growing in dense stands. The canopy areas of individual plants reach 53 m$^2$, but most are less than 25 m$^2$ (van Klinken et al., 2006). Feeding by a leaf-tying moth (Gelechiidae: *Evippe* sp. #1), introduced as biocontrol from Argentina, causes high levels of prolonged defoliation (Fig. 1a), ultimately leading to greatly reduced growth and seed production (van Klinken et al., 2003; van Klinken and Campbell 2009). It can also make mesquite plants particularly difficult to detect visually from the air (van Klinken et al., 2007).

The study site naturally includes scattered to open eucalypt woodland (Fig. 1b) including *Eucalyptus victrix* L.A.S. Johnson and K. D. Hill (coolibah) and *Eucalyptus camaldulensis* Dehn. (river red gum). Two distinct soil types (stony soils – Fig. 1c and red loamy soils – Fig. 1d) support mixed grasslands at the site (Astron, 2009). The dominant native perennial grasses are spinifex (*Triodia wiseana* C. Gardner and *Triodia pungens* R. Br.) and knottybutt neverfail grass (*Eragrostis exerophila* Domin.) (Robinson et al., 2008). The exotic grasses, buffel grass (*Cenchrus ciliaris* L.) and birdwood grass (*Cenchrus setiger* Vahl), are also present and considered to be displacing the natives (van Vreeswyk et al., 2004).

### 2.2. WorldView-2 imagery

WorldView-2 (WV2) imagery was acquired for the study area in late October, 2010, during cloud-free conditions, to be contempo-