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Evaluating pixel and object based image classification techniques for mapping plant invasions from UAV derived aerial imagery: *Harrisia pomanensis* as a case study

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ABSTRACT

Invasive alien plants (IAPs) not only pose a serious threat to biodiversity and water resources but also have impacts on human and animal wellbeing. To support decision making in IAPs monitoring, semi-automated image classifiers which are capable of extracting valuable information in remotely sensed data are vital. This study evaluated the mapping accuracies of supervised and unsupervised image classifiers for mapping *Harrisia pomanensis* (a cactus plant commonly known as the Midnight Lady) using two interlinked evaluation strategies i.e. point and area based accuracy assessment. Results of the point-based accuracy assessment show that with reference to 219 ground control points, the supervised image classifiers (i.e. *Maxver* and *Bhattacharya*) mapped *H. pomanensis* better than the unsupervised image classifiers (i.e. *K-mediuns*, *Euclidian Length* and *Isoseg*). In this regard, user and producer accuracies were 82.4% and 84% respectively for the *Maxver* classifier. The user and producer accuracies for the *Bhattacharya* classifier were 90% and 95.7%, respectively. Though the *Maxver* produced a higher overall accuracy and Kappa estimate than the *Bhattacharya* classifier, the *Maxver* Kappa estimate of 0.8305 is not significantly (statistically) greater than the *Bhattacharya* Kappa estimate of 0.8088 at a 95% confidence interval. The area based accuracy assessment results show that the *Bhattacharya* classifier estimated the spatial extent of *H. pomanensis* with an average mapping accuracy of 86.1% whereas the *Maxver* classifier only gave an average mapping accuracy of 65.2%. Based on these results, the *Bhattacharya* classifier is therefore recommended for mapping *H. pomanensis*. These findings will aid in the algorithm choice making for the development of a semi-automated image classification system for mapping IAPs.

1. Introduction

Invasive alien plants (IAPs) not only pose a serious threat to biodiversity and water resources but also have impacts on human and animal wellbeing (Pimentel et al., 2005). IAPs alter the functioning of ecosystems by degrading the land, diminishing native flora, reducing farming and grazing potential, and/or by changing soil dynamics and ecosystem fire regimes (Richardson and van Wilgen, 2004; Van Wilgen, 2009; Vilà et al., 2011). An important step in IAPs management is to map their location (Evangelista et al., 2009; Clout and Williams, 2009; Wilson et al., 2016). Accurate spatial estimates are crucial because there is a strong correlation between the spatial extent of an invaded area and the effort required for clearing the plant invasion (Wilson et al., 2013). Spatial data is important in the process of generating simulation models for monitoring control programmes, assessing invasion risk and modelling eradication feasibility (Fox et al., 2009). Timely mapping and rapid delimitation of the spatial extent of IAPs can facilitate

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decision making regarding the feasibility and effectiveness of eradication and/or containment (Fox et al., 2009). Remote sensing has the potential to support the use of remotely-sensed observations for locating and managing IAPs (Müllerová et al., 2013).

There are two main optical remote sensing approaches for mapping and monitoring IAPs, namely, high spectral resolution with low spatial resolution and high spatial resolution with low spectral resolution (Underwood et al., 2003). In particular, the high spectral resolution approach entails the use of hyperspectral sensors for collecting hundreds of narrow bands (less than 10 nm bandwidth) in the visible, near infrared and shortwave infrared regions of the electromagnetic spectrum (Huang and Asner, 2009). For example, Ustin and Santos (2010) used field and spaceborne spectroscopy to distinguish between native and non-native plant species based on their spectral signatures. Huang and Asner (2009) fused Light Detection and Ranging (LiDAR) data and hyperspectral imagery to delineate the structural and functional properties of IAPs. Further, Williams and Hunt (2004) reported a 95% overall accuracy for mapping leafy spurge (*Euphorbia esula* L.) using the Airborne Visible/Infrared Spectrometer (AVIRIS) hyperspectral data. Notwithstanding these successful attempts, currently, using hyperspectral data in mapping IAPs has several limitations such as the high cost of satellite hyperspectral data, airborne and handheld sensors as well as the resultant large volumes of data that require high computing power for processing (Agjee et al., 2015).

The high spatial resolution approach usually makes use of spaceborne and/or airborne multispectral imagery as well as aerial photography. For instance, Ngubane et al. (2013) obtained 79.14%, 97.62% and 91.11% for the overall, user and producer accuracies, respectively, by using World-View 2 imagery at 2 m spatial resolution for mapping the invasive brackern fern in the KwaZulu Natal Province of South Africa. Even though canopy dominating IAPs as well as IAPs that are phenologically different from background vegetation can be mapped using spaceborne multispectral imagery, this technique performs poorly for mapping understorey IAPs (Fox et al., 2009). Moreover, low spectral resolution limits the application of multi-spectral satellite imagery in species specific monitoring of IAPs especially when the species of concern is phenologically invariant from its background vegetation (Peerbhay et al., 2016).

Moreover, Müllerová et al. (2005) used time series analysis to measure the spatial extent and the rate of areal spread of the *Heracleum mantegazzianum* (giant hogweed) in the Czech Republic using colour aerial photography. However, airborne multispectral sensors on board manned aircrafts may give inadequate spatial resolution for species specific detection of IAPs (Cochran, 2005). To address the problem of data acquisition costs and the insufficient spatial resolution in multispectral data and traditional aerial photography, use of Unmanned Aerial Vehicles (UAVs) can be made as this option allows for rapid acquisition of low cost ultra-high spatial resolution imagery (Lucieer et al., 2012).

The developments in UAV technology have afforded the remote sensing community the opportunity to map the environment at enhanced spatial resolutions. Use of consumer grade digital cameras with very high spatial but low spectral resolution in UAV remote sensing is often used due to the limited payload capacity on these systems (<50 kg) Laliberte et al., 2011. For example, in the Czech Republic, Dvořák et al. (2015) developed a rapid, repeatable and efficient UAV based method for the mapping and monitoring of IAPs from consumer grade digital cameras. Use of UAVs for producing high spatial resolution datasets has several advantages over the manned aircraft or spaceborne platforms for accurately mapping IAPs and these include flexible temporal resolution and low data acquisition costs (Dvořák et al., 2015). The high spatial resolution can be attributed to the fact that UAV systems allow for data acquisition at low flight altitudes of usually less than 150 m above ground level. The effect of high spatial resolution was demonstrated in Wan et al. (2014) whereby a 94% overall accuracy for mapping IAPs was obtained using 80 cm UAV-derived imagery. Furthermore, frequent IAPs monitoring efforts based on remotely sensed imagery may require development of semi-automatic image classification systems that are able to map, quantify and monitor the presence of IAPs in remotely sensed data (Peerbhay et al., 2016). Supervised or unsupervised (pixel, object based and hybrid) classification approaches are tested for mapping IAPs (Dvořák et al., 2015). In particular, iterative semi-automated object based classification approaches are tested for mapping IAPs such as *Heracleum mantegazzianum (*giant hogweed) from high spatial resolution UAV-derived data (Müllerová et al., 2016). For very high resolution imagery, the object-based image classification techniques have demonstrated improved performances over the pixel based approach (Chen et al., 2014). The first and critical step in object-based image classification is segmentation which encompasses grouping of similar pixels, according to some similarity threshold, into homogenous objects (Pham and Brabyn, 2017; Liu et al., 2012). Therefore, the object-based image analysis (OBIA) techniques do not only allow for the consideration of spectral information but also contextual, textural, shape and spatial relationships in image objects as opposed to single pixels (Pham and Brabyn, 2017; Hussain et al., 2013; Sebari and He, 2013). The objective of the current study is to evaluate pixel and object based image classifiers for mapping *Harrisia pomanensis* (The Midnight Lady), a particular plant invasion from ultra-high spatial resolution (5 cm) UAV derived imagery. The results of this evaluation shall then be used to guide the decision as to which image classifiers to be used when developing a semi-automated image classification system for mapping the target plant.

This study compared five image classifiers using two different interlinked evaluation strategies. The evaluation strategies used are point and area based accuracy assessment. The compared classifiers were unsupervised pixel based classifiers (*k-mediuns* and *Euclidian Length*), unsupervised object based classifier (*Isoseg*), supervised pixel based classifier (*Maxver*) and supervised object based classifier (*Bhattacharya*). The image classification for this study was done in the Spring open source software (Camara et al., 1996). The objective of this research is to contribute towards the development of a semi-automated image classification system for mapping IAPs.

2. Description of the study area, species and data-sets used

2.1. Study area

The study area is located near the Alldays town within Waterberg district municipality of the Limpopo province of South Africa (Fig. 1a). The area is characterised by a semi-arid climate and falls within the summer rainfall region which experiences average mid-day temperatures of 22.3 °C and 31.9 °C in winter (June to August) and summer (October to February) seasons, respectively (Mzezwa et al., 2010). The rainfall amount is estimated at 0 mm in winter and could escalate to a maximum of approximately 81 mm in summer (Mzezwa et al., 2010). Furthermore, the 872,000 m^2 spatial extent study area (Fig. 1b) is a flat terrain woodland with orthometric height values ranging from 800 m to 817 m.

2.2. Species description and mapping methods

Harrisia pomanensis, commonly known as the Midnight lady is a succulent cactus that belongs to the Harrisia genus (Fig. 2). *H. pomanensis* plants have jointed spiny fleshy stems with thorny spikes and when these stems touch the ground, they develop roots