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Detection and mapping the spatial distribution of bracken fern weeds using the Landsat 8 OLI new generation sensor

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ABSTRACT

Bracken fern is an invasive plant that presents serious environmental, ecological and economic problems around the world. An understanding of the spatial distribution of bracken fern weeds is therefore essential for providing appropriate management strategies at both local and regional scales. The aim of this study was to assess the utility of the freely available medium resolution Landsat 8 OLI sensor in the detection and mapping of bracken fern at the Cathedral Peak, South Africa. To achieve this objective, the results obtained from Landsat 8 OLI were compared with those derived using the costly, high spatial resolution WorldView-2 imagery. Since previous studies have already successfully mapped bracken fern using high spatial resolution WorldView-2 image, the comparison was done to investigate the magnitude of difference in accuracy between the two sensors in relation to their acquisition costs. To evaluate the performance of Landsat 8 OLI in discriminating bracken fern compared to that of Worldview-2, we tested the utility of (i) spectral bands; (ii) derived vegetation indices as well as (iii) the combination of spectral bands and vegetation indices based on discriminant analysis classification algorithm. After resampling the training and testing data and reclassifying several times ($n = 100$) based on the combined data sets, the overall accuracies for both Landsat 8 and WorldView-2 were tested for significant differences based on Mann-Whitney *U* test. The results showed that the integration of the spectral bands and derived vegetation indices yielded the best overall classification accuracy (80.08% and 87.80% for Landsat 8 OLI and WorldView-2 respectively). Additionally, the use of derived vegetation indices as a standalone data set produced the weakest overall accuracy results of 62.14% and 82.11% for both the Landsat 8 OLI and WorldView-2 images. There were significant differences $\{U(100) = 569.5, z = -10.8242, p < 0.01\}$ between the classification accuracies derived based on Landsat OLI 8 and those derived using WorldView-2 sensor. Although there were significant differences between Landsat and WorldView-2 accuracies, the magnitude of variation (9%) between the two sensors was within an acceptable range. Therefore, the findings of this study demonstrated that the recently launched Landsat 8 OLI multispectral sensor provides valuable information that could aid in the long term continuous monitoring and formulation of effective bracken fern management with acceptable accuracies that are comparable to those obtained from the high resolution WorldView-2 commercial sensor.

1. Introduction

Invasive species encroachment into grass dominated landscapes has been observed in many parts of KwaZulu-Natal Province in South Africa (O'Connor, 2005). Bracken fern is one of the most common invasive species prevalent in KwaZulu-Natal province and other parts of the country (Singh et al., 2014). The fern has instigated severe environmental impacts, such as disturbing water distribution patterns (Ester and Al, 2016), being threat to biological diversity (Schneider and Geoghegan, 2006) and disturbance of ecosystem function. Research has revealed that bracken fern intercepts fifty percent of the rainfall, obstructing water from reaching the soil (Williams, 2011). The reduction in optimal water supply threatens productivity of indigenous plant species, particularly in areas that are already experiencing water shortages. Apart from its environmental impacts, bracken fern encroachment has long been unwelcome in farming areas (Turner et al., 2016; Berget et al., 2015; Schneider and Geoghegan, 2006). The emerging threats

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from uncontrolled spread of bracken fern in South Africa, particularly around the Cathedral Peak vegetation communities and its value as a World Heritage Site ascertains the necessity to quantify the spatial distribution and encroachment of bracken to improve appropriate intervention strategies. Lately, remote sensing technology has emerged as a reliable approach for invasive species mapping and monitoring. The need for consistent assessment of invasive species using remote sensing data has increased in recent years through developments in the understanding of vegetation spectral reflectance properties (Blackburn and Pitman, 2010).

Remote sensing technology offers better prospects in providing up to date spatial data required to understand the spread and spatial distribution of bracken fern species (Ngubane, 2014). Recent studies have revealed that high spatial resolution sensors can accurately classify bracken fern because of their improved spectral and spatial resolutions (Singh et al., 2014; Odindi et al., 2014; Ngubane, 2014). The applications of high spatial resolution satellite imagery, such as WorldView-2 in the detection and mapping of bracken fern has successfully yielded excellent accuracy results. For example the study by Odindi et al. (2014) reported a good overall accuracy of 84.72%. Similarly, Ngubane (2014) observed that the use of WorldView-2 data characterised by higher spatial resolution improved the accuracy of bracken fern mapping within eThekwini Metropolitan, KwaZulu-Natal, South Africa. Apart from its fine 2 m spatial resolution, WorldView-2 has strategically located spectral bands such as red edge, NIR2, coastal and yellow which could avail critical information required in discriminating vegetation (Mutanga et al., 2015). However, WorldView-2 sensor may not be an appropriate sensor for mapping invasive species in developing regions such as Southern Africa. This is due to its high acquisition costs, small swath width and a limited multi-temporal data which constrain continuous monitoring of the affected landscapes at a regional scale.

The rate at which bracken fern spreads globally is still not clearly understood partly because of the scarcity of high spatial resolution sensors with a regional swath width. These limitations have of late resulted in a shift towards the use of free-and-readily available broadband multispectral sensors offering spatial data at a global footprint (large swath width) and a higher repeated coverage, such as the Landsat series datasets (Dube and Mutanga, 2015). Moreover Landsat datasets permit repeated regional scale mapping and monitoring (Matongera et al., 2016). For instance, Dube and Mutanga (2015) concluded that the Landsat 8 OLI sensor's 16 day temporal resolution it one of the key primary data sources highly suitable and practical for regional applications especially in resource-limited areas. It is upon this background, that considering their accessibility at a global scale, Landsat series products have the potential to provide indispensable data sources for continuous detection and mapping of invasive species over time and space. In this regard, an affordable, efficient and repeatable method of surveying bracken fern invasion enables its monitoring at a regional scale.

The capability of the recently launched Landsat 8 OLI sensor with improved collection of spatial, spectral, temporal and radiometric resolutions combined with its post-launch calibration is hypothesized to offer a great potential in bracken fern mapping. Landsat 8 OLI imagery delivers an improved spectral range of certain bands that are critical for distinguishing vegetation spectral responses across the near infrared (NIR) and panchromatic band. The sensor's enhanced radiometric resolution from 8 bits to 12 bits is crucial in the characterization of different seasonal phenological patterns of vegetation (Dube and Mutanga, 2015; El-Askary et al., 2014). Landsat 8 OLI has a total of 11 spectral bands captured at a 16 day interval, hence providing a continuous seasonal coverage of the global landmass at a spatial resolution of 30 m. Additionally, a significant advancement in the sensor design has also enriched substantial improvements in signal to noise ratios (SNR), almost twice as good as Landsat 7 Enhanced thematic mapper plus (Dube and Mutanga, 2015; Irons et al., 2012). Landsat 8 OLI data set has been successfully used in various remote sensing studies including water resources management (Shoko et al., 2015a,b), biomass studies and crop yield (Dube and Mutanga, 2015; Hurley et al., 2014; Crippen, 1990). The successful application of Landsat 8 OLI sensor in different studies has also been largely accomplished by the use of vegetation indices, such as the normalized difference vegetation index (NDVI) computed from the red and near infrared bands (Mutanga et al., 2012). The above mentioned indices respond to the difference in the chlorophyll absorption levels as a result of multiple scattering effects in the near infrared (Thenkabail et al., 2000). However, the same approach of combining derived vegetation indices and spectral bands can also be tested in bracken fern mapping using the medium spatial resolution Landsat 8 OLI sensor.

Therefore, considering the sensor's performance in vegetation mapping, due to the aforementioned sensor's improvements, it is hypothesized that the freely available Landsat 8 OLI sensor with its improved sensor characteristics have the potential of detecting and mapping the spatial distribution of bracken fern at acceptable accuracies that are comparable to the high spatial resolution WorldView-2 sensor. To assess the performance of Landsat 8 OLI data in mapping the invasive bracken fern, we compared its classification performance to that of high resolution WorldView-2 sensor. WorldView-2 data was used to bench-mark the performance of Landsat 8 OLI in this study due to its proven track record of high accuracy in detecting and mapping bracken fern (Odindi et al., 2014; Ngubane, 2014). To the best of the researcher's knowledge, no study has compared the performance of the medium spatial resolution Landsat 8 OLI with a high resolution sensor, such as WorldView-2 in bracken fern mapping. In this study, for the first time the researcher assessed the utility of the Landsat 8 OLI sensor in detecting and mapping the spatial distribution of bracken fern species at Cathedral Peak, South Africa.

2. Materials and methods

2.1. Description of the study area

The research was conducted at Cathedral Peak nature reserve, in KwaZulu-Natal Northern Drakensberg mountain range, South Africa (Fig. 1). The study site is located at NW, Lat = −28.97360039, NW Long = 29.20739937, SE Lat = −29.01429939; SE, Long = 29.2670020.The study area has 15 catchments delineated for research management purposes. The Cathedral Peak nature reserve occupies approximately 32,000 ha. At an altitude of 3482 m, the Drakensberg is the highest mountain range in South Africa, extending its mountain ranges to a distance of about 1, 000 Km from south-west to north-east (Rosen et al., 1999). The mountains being further away from the equator, characterize cooler habitats at lower altitudes than most mountain ranges in southern Africa (Condie and Kröner, 2008). The area is characterised by a diversity of habitats which are split between moderately undulating Drakensberg Moist Foothill and grassland plateau (at roughly 1750 m asl) leading to densely forested (Fig. 2) south and east facing slopes. The area is characterised by homogenous basalt formations of stormberg series (Killick, 1963). The climate of the area is mainly subtropical, with humid and warm summers, mild winters, and a relatively high amount of rainfall of approximately 950 mm per annum. Mean temperatures in summer are around 17 °C whilst winter is normally around 9 °C. Approximately, 70 different types of ferns have been documented in the Drakensberg region (Sycholt, 2002). Bracken fern (*Pteridium Aquilinum*) is the most common fern at the Cathedral Peak which is often found in grasslands and along forest margins in the montane and sub-alpine belts. With the abundance of vegetation