Assessing the utility WorldView-2 imagery for tree species mapping in a South African subtropical forest patch and the conservation implications: Dukuduku forest patch as case study

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Abstract

Indigenous forest biome in South Africa is highly fragmented into patches of various sizes (most patches < 1 km^2). The utilization of timber and non-timber resources by poor rural communities living around protected forest patches produces subtle changes in the forest canopy which can be hardly detected on a timely manner using traditional field surveys. The aims of this study were to assess: (i) the utility of very high resolution (VHR) remote sensing imagery (WorldView-2, 0.5 to 2 m spatial resolution) for mapping tree species and canopy gaps in one of the protected subtropical coastal forests in South Africa (the Dukuduku forest patch (ca.3200 ha) located in the province of KwaZulu-Natal) and (ii) the implications of the map products to forest conservation. Three dominant canopy tree species namely, *Albizia adianthifolia*, *Strychnos* spp. and *Acacia* spp., and canopy gap types including bushes (grass/shrubby), bare soil and burnt patches were accurately mapped (overall accuracy = 89.3 ±2.1%) using WorldView-2 image and support vector machine classifier. The maps revealed subtle forest disturbances such as bush encroachment and edge effects resulting from forest fragmentation by roads and a power-line. In two stakeholders' workshops organised to assess the implications of the map products to conservation, participants generally agreed amongst others implications that the VHR maps provide valuable information that could be used for implementing and monitoring the effects of rehabilitation measures. The use of VHR imagery is recommended for timely inventorying and monitoring of the small and fragile patches of subtropical forests in Southern Africa.

Keywords: subtropical forest, tree species, remote sensing, WorldView-2

1. Introduction

Indigenous forest biome in South Africa is highly fragmented into patches of various sizes, most of which are less 1 km^2 in area (Eeley *et al.*, 1999). The biome consists of trees whose crowns are largely contiguous and is estimated to cover 0.56% of the total land area of the country (Eeley *et al.*, 1999; Lawes *et al.*, 2004). Over several decades, the forest has been converted to pasture, farmland and urban development (van Wyk *et al.*, 1996; Cho *et al.*, 2013; Eeley *et al.*, 2001). For example, Ndlovu et al. (2011) have reported a 29% loss of the Dukuduku forest patch, the largest indigenous coastal lowland forest patch in the province of KwaZulu-Natal between 1992 and 2005. In spite of its small area and fragmented nature, the indigenous forest biome supports a disproportionately high amount of biodiversity in South Africa (Eeley *et al.*, 1999). The negative impacts of forest fragmentation on biodiversity are well documented e.g. increased edge effects and decrease in ecological connectivity between patches which often result into loss of biodiversity (Fahrig, 2003; Bender *et al.*, 2003; Saunders *et al.*, 1991). It is therefore reasonable to recommend intensive management of remaining indigenous forest patches in South Africa to stop further biodiversity loss as it is a common paradigm that the smaller and more isolated the patches, the greater the risk of species extinction (Bender *et al.*, 2003; Zuidema *et al.*, 1996; Cook *et al.*, 2002). Lawes *et al.* (2007) showed that fine-grained species i.e. species capable of regenerating within their own canopy shadow are more vulnerable to afromontane forest fragmentation in South Africa than coarse-grained species i.e. species that typically regenerate over a large spatial scale.

About 44% of indigenous forest in South Africa is protected (Berliner, 2005). However, conserving state protected indigenous forest patches in South Africa is somewhat an uphill task as poor communities living around the forest patches depend on the forest for several goods and services including wood and non-timber products for craftworks and settlement construction, fire wood, food and medicine (Shackleton *et al.*, 2007; NFAP, 1997). In the 1990s, there were about 300000 traditional healers in South Africa who served about 27 million customers, with two-thirds of their plant medicines coming from forest and about 800000 people were involved in the craft industry, though not all depended on natural resources according to Shackleton *et al.* (2007). The above livelihoods activities produce subtle changes in the forest canopy including canopy dieback as result of bark ringing, gaps created by fallen trees or changes in species composition. These changes can be hardly detected on a timely manner using traditional field surveys over large areas because such surveys are generally point based, labour intensive and expensive. On the other hand, air or spaceborne remote sensing has been employed as a more cost effective alternative to field-based surveys to quantify ecosystem processes or functioning (Cabello *et al.*, 2012). Unfortunately, commonly available multispectral (few discrete wavebands) sensors such as Landsat (30m spatial resolution) or MODIS (250 - 500 m) lack both the spatial and spectral resolution to allow the detection of individual tree crown loss and changes in overstorey tree species composition (Nagendra and Rocchini, 2008; Prins and Clarke, 2007).

High spatial resolution sensors are suited for mapping small targets such as tree canopies or gaps created by fallen trees but are not usually adequate for species level mapping (Nagendra and Rocchini, 2008; Cho *et al.*, 2012). On the other hand, high spectral resolution (hyperspectral) sensors have been used to characterise unique spectral profiles of tree species in various habitats (Cho *et al.*, 2012; Dennison and Roberts, 2003; Roberts *et al.*, 1998; Asner *et al.*, 2008; Carlson *et al.*, 2007). Hyperspectral data have also facilitated the mapping of biochemical diversity (e.g. chlorophyll, nitrogen, lignin, water) which has been found to correlate with species richness (Carlson *et al.*, 2007; Asner and Martin, 2009). However, the widespread use of hyperspectral data in tropical forest environment has been stymied by the high cost associated with hyperspectral image acquisition and processing (Nagendra and Rocchini, 2008; Ramoelo *et al.*, 2012).

Recent developments in very high resolution (VHR) multispectral imagery have pushed the frontiers of forest assessment beyond community level mapping to species level mapping. A new VHR multispectral sensor such as Worldview-2 (0.5 - 2 m, 8 bands) has shown great potential for species identification and mapping in a temperate forest in Austria (Immitzer *et al.*, 2012), urban trees (Pu and Landry, 2012) and plantation tree species (Peerbhay *et al.*, 2014). This has been made feasible due to the unique spectral features of WorldView-2. The sensor contains eight wavebands that are suitable for assessing vegetation characteristics that vary between species and hence adequate for species discrimination. WorldView-2 bands include: 400 – 450 nm (chlorophyll absorption), 450 – 510 nm (chlorophyll absorption), 510 – 580 nm (Green reflection), 585 – 625 nm (carotenoids absorption), 630 – 690 nm (chlorophyll absorption), 705 – 745 nm (sensitive to variation in chlorophyll and leaf mass), 770 – 895 nm (sensitive to variation in leaf mass and moisture content), 860 – 1040 nm (leaf mass and moisture content) (Ustin *et al*., 2009). Cho et al. (2012) used the eight WorldView-2 bands to improve the classification of savanna tree species when compared to the traditional blue, green, red and near infra-red bands of commonly available sensors.

The aims of this study were to assess: (i) the utility of WorldView-2 for mapping tree species and canopy gaps in a protected subtropical coastal lowland forest in South Africa and (ii) the implications of the spatial patterns of tree species and forest canopy gaps to conservation of subtropical lowland forest patches. (Cabello *et al.*, 2012) have argued that understanding the spatial distribution of species habitats is crucial for assessing the conservation status of populations, predicting species distribution and their responses to environmental change.

Insert Figure 1 here

2. Material and methods

2.1. Study site

The study was undertaken in the Dukuduku indigenous coastal forest located in KwaZulu-Natal, South Africa (28°38’33”S and 32°31’67” E) (Figure 1). The Dududuku forest covered more than 6000 ha of land in the early 1950s when it was declared a protected area (Karumbidza, 2005). However, deforestation has reduced the forest to barely 3 200 ha by 2011 (Cho *et al.*, 2013). Conversion of forest into squatter camps and small farms led to massive forest loss (29%) in the region between 1992 and 2005 (Ndlovu *et al.*, 2011). The current more or less intact and only protected part of the forest (label Dukuduku forest in Figure 1) is surrounded by intensive sugar and *Eucalyptus* plantations (on the western and southern borders), and villages (on the eastern edge) that practise subsistence farming. The area was chosen for the study because it is the largest remaining patch of indigenous forest on the north-eastern coastal shoreline of KwaZulu-Natal. It is part of the iSmangaliso Wetland Park (a UNESCO world heritage site) which also comprises the St Lucia estuary, the largest estuarine system in Africa (Whitfield and Taylor, 2009). van Wyk et al. (1996) sampled 110 species of shrubs (42 species, height < 5m) and tree (66 species, height ≥ 5m) in 200 sample plots in the protected part of the forest. The Dukuduku forest is recognised as harbouring the densest population of gaboon adder (*Bitis gabonica*) in South Africa (Kyle, 2003).

2.2 Image acquisition and pre-processing

A WorldView-2 image (DigitalGlobe, Inc) consisting of 8 multispectral bands at 2 m spatial resolution and a 0.5 m panchromatic band was acquired on the 1 December 2010. The image was geometrically corrected by the supplier (Updike and Comp, 2010). Some iconic points including road junctions and isolated tree canopies were located with an accuracy of ± 4m using a Garmin Vista Cx etrex handheld GPS (Geographic Positioning System). The image was corrected for atmospheric effects using ATCOR 2/3 version module (Berk *et al.*, 1998). The lower resolution (2 m) multispectral WorldView-2 image was enhanced to 0.5 m by fusing it with the high resolution panchromatic band (0.5 m) using Gram-Schmidt spectral sharpening or fusion technique (Aiazzi *et al.*, 2009). Feature extraction and classification have been found to benefit from image fusion (Bruzzone *et al.*, 2006). Gram-Schmidt tends to preserve the spectral information of the multispectral image (Ehlers, 2008; Klonus and Ehlers, 2009). We found a 99% correlation between the spectra extracted from the original and pansharpened image. Figure two shows the spectral profiles of three dominant tree species before and after image fusion (Figure 2).

Insert Figure 2 here

2.3. Field survey

Two field surveys (July 2011 and August 2011) were undertaken to record data on tree species and canopy gaps. Seven line transects were randomly digitised on the pansharpened WorldView-2 image. Each transect had a minimum distance of 1 km. Tree crowns or vegetation clusters were numbered along the transects as shown by the example in Figure 3 because they were clearly visible on the pansharpened image. The coordinates of the numbered crowns were extracted and loaded into a handheld Garmin Vista Cx etrex GPS. With the help of the GPS device and printed true-coloured images, the tree crowns were located and identified in the field. We used the same simple and practical methodology in another study in the savanna landscape (Cho *et al.*, 2012). The field data collection was focused on dominant canopy (overstorey) tree species. In addition to the overstorey tree species, we also recorded canopy gap types such as grassland/shrubby patches (bushes), bare soil patches, and recently burnt areas (i.e. burnt scars) along each transect

2.4. Species and canopy gap classification and mapping

Only the three dominant overstorey tree species namely, *Albizia adianthifolia*, (65 canopies), *Strchynos* spp. (dominated by *S. gerrardii*) (77 canopies) and *Acacia spp*. (dominated by *A. karroo*) (61 canopies) were considered for classification (Figure 4). The canopy gap types included in the classification were; bushes (89 patches), bare soil (23 patches) and burnt areas (34 patches, mostly concentrated along the electrical power line that cuts through the forest). *A. adianthifolia* (family: fabaceae or mimosaceae) grows to about 25 m high and has a flat and wide-spreading crown (Boon, 1993). The tree is common on forest margins, colonises any clearing and grows rapidly in its early years (Boon, 1993; Boudreau and Lawes, 2005). The bark and roots of *A. adianthifolia* are used in traditional South African medicine (Risa *et al.*, 2004; Eldeen *et al.*, 2005). *S. gerrardii* commonly called Coast monkey-orange (family: strychnaceae) grow to 25 m. Its fruits are eaten by people, monkeys and antelopes (Lawes, 1991). *Strchynos spp*. which also included *S. decussata* and *S. henningsii* were the most dominant overstorey tree species in the study area and mainly in the most pristine part or central core of the forest as also reported by van Wyk et al. (1996). *A. karroo* (family: mimosaceae) is a fast growing deciduous tree (15 m) and is considered as a bush encroacher in the region (Boon, 1993). For example, van Wyk et al. (1996) reported thickets of *A. karroo* on old disbanded cultivated lands in the region. Gum from its wounds is eaten by people and monkeys and the hard wood is used for building and furniture. Most of the other overstorey tree species were mainly sampled close to the forest edges and the dominance of *Strychnos* spp. and *Acacia* spp. to a lesser degree increases with increasing distance into the forest.

Support vector machines (SVM) was adopted for the classification in this study because it has been shown to provide high accuracy for vegetation targets (Huang *et al.*, 2002; Pal and Mather, 2005). SVM was performed in ENVI 4.8 software with IDL (Exelis Visual Information Solutions, Boulder, Colorado). Image regions of interest (ROIs) were made over the tree canopies and canopy gaps after overlaying the field GPS points on the image. An iterative classification approach was adopted in this study because of the unequal sizes of the targets. Ten replicates of the training data, each consisting of ten ROIs were created by repeated sampling with replacement. The remaining ROIs of each iteration were used for the validation of the classification. The means and standard deviations of the producer's and user's accuracies were computed from the 10 bootstrapped replicates.

2.5. Spatial patterns of dominant tree species and canopy gaps and the implications for management and conservation of indigenous forest

Percentage cover maps of each dominant species and canopy gap type were computed on a 50 m scale grid to assess their spatial patterns. Descriptive analysis was then used to determine patterns of dominant species distribution and forest disturbance. Two stakeholders' workshops were organised on 20 February and 14 March 2014, in the Dukuduku forest office and office of the National Department of Forestry and Fisheries (DAFF) in Pretoria, respectively to present the map products, assess the utility of the maps to forest management and to raise awareness on the potential role of remote sensing in indigenous forest inventorying in South Africa. The 20 February workshop participants (n = 20) included the manager of the Dukuduku forest (n = 1), and representatives from the DAFF (n = 7), University of KwaZulu-Natal (n = 1), Dukuduku villages (n = 4), Department of Environmental Affairs (n = 1) and scientists from the Council for Scientific and Industrial Research (n = 6). There were 7 participants in the 14 March 2014 workshop at Pretoria. Other maps presented at the workshops included forest change maps (1960 to 2005) (Ndlovu *et al.*, 2011), *Chromolaena odorata* (an alien invasive species) distribution map (Malahlela *et al.*, In review) and foliar nitrogen map of the forest and surrounding land uses (Cho *et al.*, 2013).

Insert Table 1 here

3. Results

3.1. Classification of dominant overstorey tree species and canopy gap types

The classification of the dominant canopy tree species and canopy gaps types yielded an overall of 89.3±2.1%. Producer's accuracies of over 90% were observed for all three dominant tree species (Table 1). A low user's accuracy (66%) was observed for *Strychnos* spp. because of spectral confusion between this species and some bush spectra leading to misclassification of bush pixels as *Strychnos* spp. A lower overall accuracy was obtained (83.8±1.3%) when the classification was conducted using only the four traditional bands;

blue (480 nm), green (545 nm), red (660 nm) and near-infrared (835 nm) available in sensors such as Landsat, Quickbird and Systeme Probatoire d'Observation de la Terre (SPOT).

Insert figures 5 and 6 here

3.2. Spatial patterns of dominant canopy species and forest gaps

The dominant canopy species and gaps showed varying spatial distribution in the Dukuduku forest (Figure 5 and 6). Consistent with known patterns of *A. adianthifolia*, the species is predominantly found on the forest margins, along rivers and the eastern forest edge i.e. towards the Dukuduku village. It also showed a moderate abundance in areas dominated by bushes. *Strychnos* spp. occur mostly on higher ground with respect to river channels, thus forming several corridors in the forest. Its distribution is a bit scanty in the northern quarter of the forest and on the south eastern corner. *Acacia* spp. showed some association (co-occurrence) with *Strychnos* spp. in the main *Strychnos* corridors, but also some evidence of bush encroachment in the north western corner and central eastern edge of the forest. The bushes (grass/shrubby gaps) are concentrated in the riparian areas but can also be observed in moderate abundance in the northern quarter and south eastern corner of the forest. Bare soil areas are mainly concentrated on the eastern edge of the forest. Burnt scars (111,000 m^2) were mapped along the 22 kV power-line that cuts through the forest. The exact cause of the fire is not known. The power line cuts through two very dense *Strychnos* spp. corridors. We observed a high density of two invasive species (*Chromolaena odorata* and *Lantana spp*.) along the power line during the field campaign.

4. Discussion

In this study, we investigated the utility of WorldView-2 for mapping tree species and canopy gaps in the Dukuduku forest, a protected subtropical coastal lowland forest in South Africa. The dominant canopy tree species and the different forest canopy gap types were accurately mapped (overall accuracy = 89%) using the eight bands of WorldView-2. The results support other findings as to the suitability of WorldView-2 for tree species mapping (Immitzer *et al.*, 2012; Pu and Landry, 2012; Peerbhay *et al.*, 2014), a process which was only highly successful with hyperspectral data. In fact, the result of this study confirm our earlier findings in the savannah environment as to the superiority of the 8 WorldView-2 bands for species mapping when compared to the traditional blue, green, red and NIR bands (Cho *et al.*, 2012). The study was however only focused on the dominant tree species in the Dukuduku forest. It remains to be established if the non-dominant or rare overstorey tree species which are mostly located in the forest margins could be accurately mapped. The ability to accurately assess forest at tree species level using VHR imagery such as WorldView-2 expands the scope of forest inventorying with remote sensing beyond tree crown identification and delineation using hyperspatial imagery (Culvenor, 2002; Leckie *et al.*, 2003; Hirschmugl *et al.*, 2007).

The spatial patterns of the species and forest canopy gaps revealed subtle forest disturbances such as bush encroachment and edge effects resulting from forest fragmentation by roads and a power-line contrary to popular opinion of an undisturbed forest consisting of a contiguous layer of trees. The observed patterns of forest disturbance could have important implications for management, conservation and sustainability of the Dukuduku forest patch. Some of the identified effects such as bush encroachment by *Acacia* spp. and fire could cause irreversible damage to the forest biodiversity if not well managed. The following points represent the views/analysis of participants at the two stakeholders' workshops with regards to map products and the utility of the VHR remote sensing to Dukuduku forest management and indigenous forest patches in South Africa in general:

- Maps of dominant tree species and canopy gap maps should be used to (i) zone the forest into forest management units e.g. the *Strychnos* habitats, *Albizia* habitats, bush dominated habitats and riparian zones and (ii) control certain negative phenomena such as bush encroachment (e.g. *Acacia* encroachment needs to be monitored) and alien species invasion. The moderate to high density of *Albizia* (a secondary forest tree species) and bare soil patches along the eastern edge of the forest, i.e. towards the Dukuduku villages indicate more forest disturbance on the eastern part of the forest which might be attributed to its closeness to the villages. The villagers still graze their cattle in the forest and medicinal plant harvesting and wood craft activities are quite common in the region. Greater involvement of the local community in the conservation of the Dukuduku forest was recommended.
- The use of VHR products would provide information on changes to the forest and early warning for intervention and monitoring progress on rehabilitation.
- The maps provide valuable information for environmental impact assessment (EIA) of future developments such as road and power servitudes. All February 20, 2014 workshop participants agreed that it is highly probable that an alternative route for the power-line would have been chosen if the VHR maps of species existed at the time the decision to construct the power-line was made. The power-line cuts through dense *Strychnos* corridors. The power-line corridor provides a suitable habitat for invasive species propagation, thus creating suitable conditions for fire propagation as could be seen in the mapped fire scar (Figure 5). Workshop participants recommended persistent clearing of invasive species and other vegetation along the power-line to prevent the spread of fire into the forest from the power-line corridor.
- The map products should be used to create awareness and galvanize support for conservation amongst stakeholders and the public in general.
- Lastly, the maps could be important for field sampling design in forest inventorying of biodiversity.

Although this study was focused on the Dukuduku forest patch, the results have broader implications to the conservation of indigenous forest patches in South Africa in particular and Southern Africa in general. The decreasing sizes of indigenous forest patches in Southern Africa increases their fragility to change and increased risk of ecosystem instability and collapse with the related loss of ecosystem services (Kemper *et al.*, 1999). Loss of the Dukuduku forest is causing changes the hydrological dynamics in the St Lucia estuary through increased deposition of sediment in the estuary (Whitfield and Taylor, 2009). The mapping methodology demonstrated in this study using VHR spaceborne imagery for the Dukuduku forest should form a basic set of core techniques that could be exported to other large subtropical indigenous forest patches in Southern Africa. VHR map products will allow for (i) more accurate evaluation of the effects of indigenous forest fragmentation as compared to *in situ* data only, (ii) defining detailed management plans for protected subtropical forest patches in the region and (iii) monitoring of the impact of rehabilitation measures.

5. Conclusions

The following conclusions could be drawn from the study:

- Three dominant canopy tree species namely, *Albizia adianthifolia*, *Strychnos* spp. and *Acacia* spp., and canopy gap types including bushes (grass/shrubby), bare soil and burnt patches were accurately mapped (overall accuracy = 89.3 ±2.1%) using WorldView-2 image and support vector machine classifier.
- The maps revealed subtle forest disturbances such as bush encroachment and edge effects resulting from forest fragmentation by roads and a power-line.
- The VHR maps provide valuable information that could be used for implementing and monitoring the effects of rehabilitation measures.
- The use of VHR imagery is recommended for timely inventorying and monitoring of the small and fragile patches of subtropical forests in Southern Africa.

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Table 1. Classification accuracy of dominant canopy (overstorey) species in the Dukuduku subtropical forest, South African

Class	Producer's accuracy		User's accuracy	
	Mean	Standard deviation	Mean	Standard deviation
Acacia spp.	94.5	5.7	92.4	3.2
Albizia adianthifolia	91.7	3.3	89.3	4.4
Strychnos spp.	91.9	5.1	66.1	5.6
Bushes	75.2	4.3	97.9	1.9
Burnt area	100	0	100	0
Bare soil	99	0.1	93.1	0.2

Overall accuracy = 89.3±2.1%, kappa = 0.87±0.02%

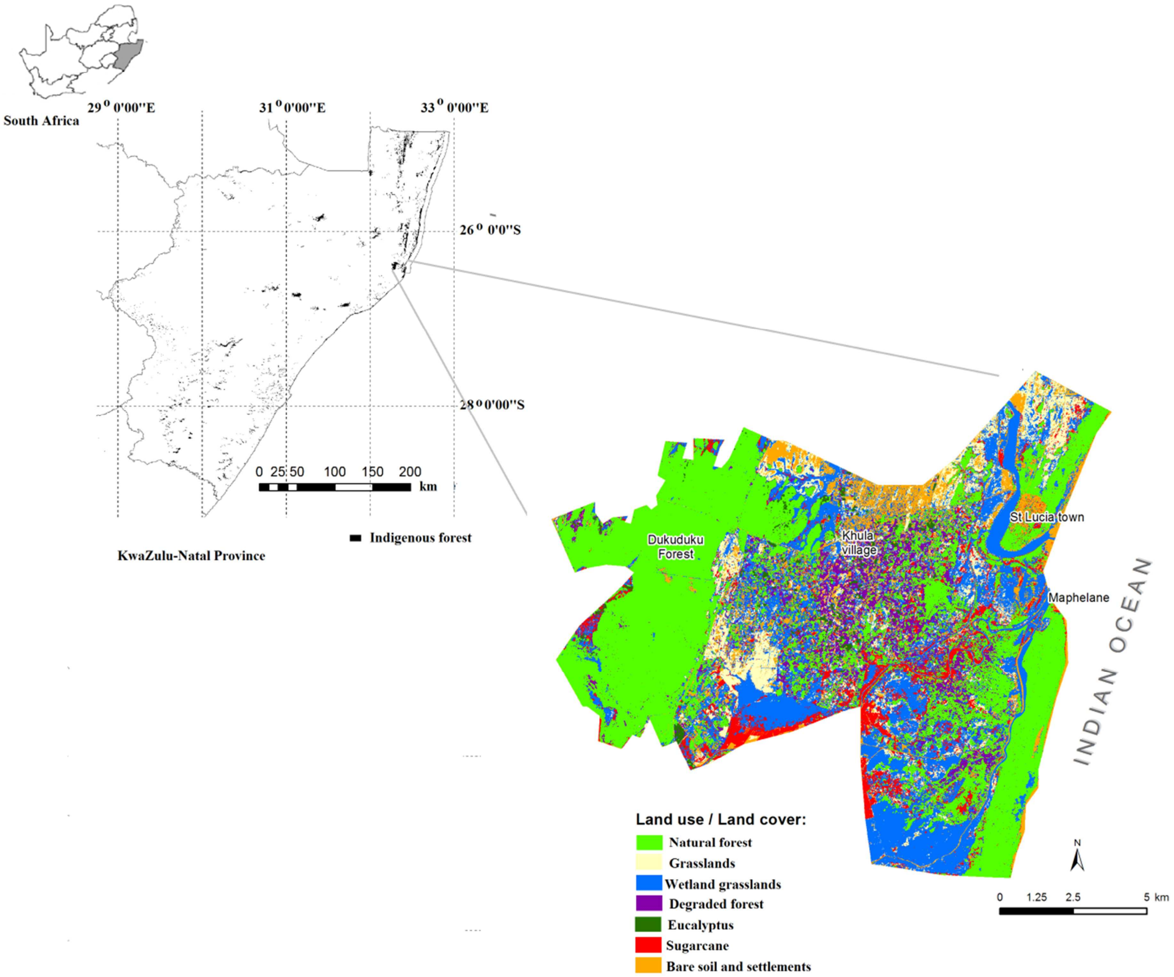

Figure 1. Indigenous forest patches in the province of KwaZulu Natal South Africa and land use/ land cover map of 2011 for Dukuduku lowland coastal forest (Cho et al. 2013). The study was limited to the protected part of the forest labelled, Dukuduku forest.

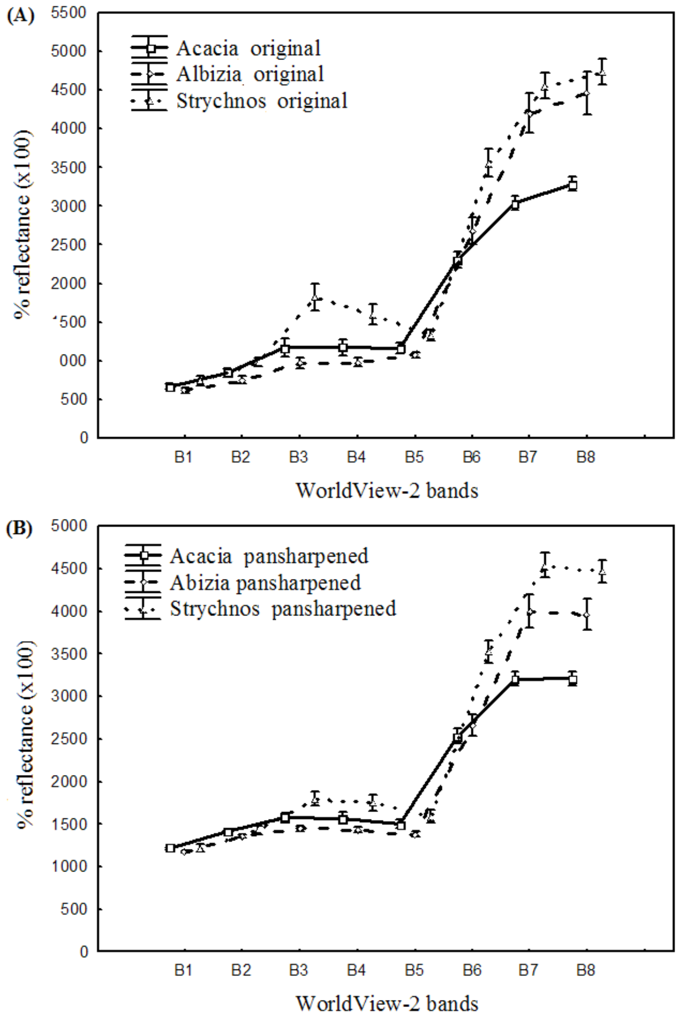

Figure 2. WorldView-2 spectral profiles of three dominant canopy species in the Dukuduku subtropical forest in South Africa, before (A) and after pansharpening for the 2 m 8 band multispectral image using the 0.5 m panchromatic band.

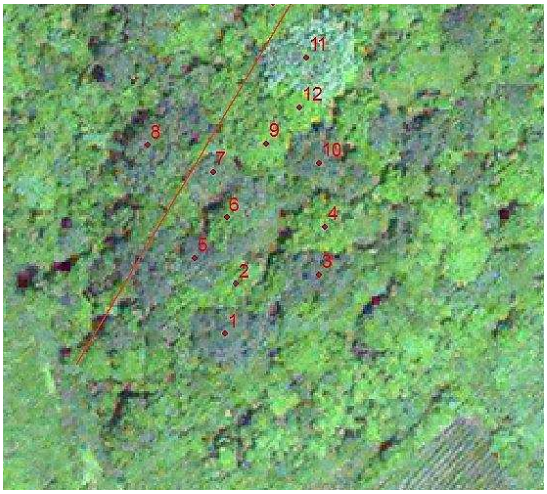

Figure 3. Example of true colour print used during field survey to identify dominant canopy species and canopy gaps

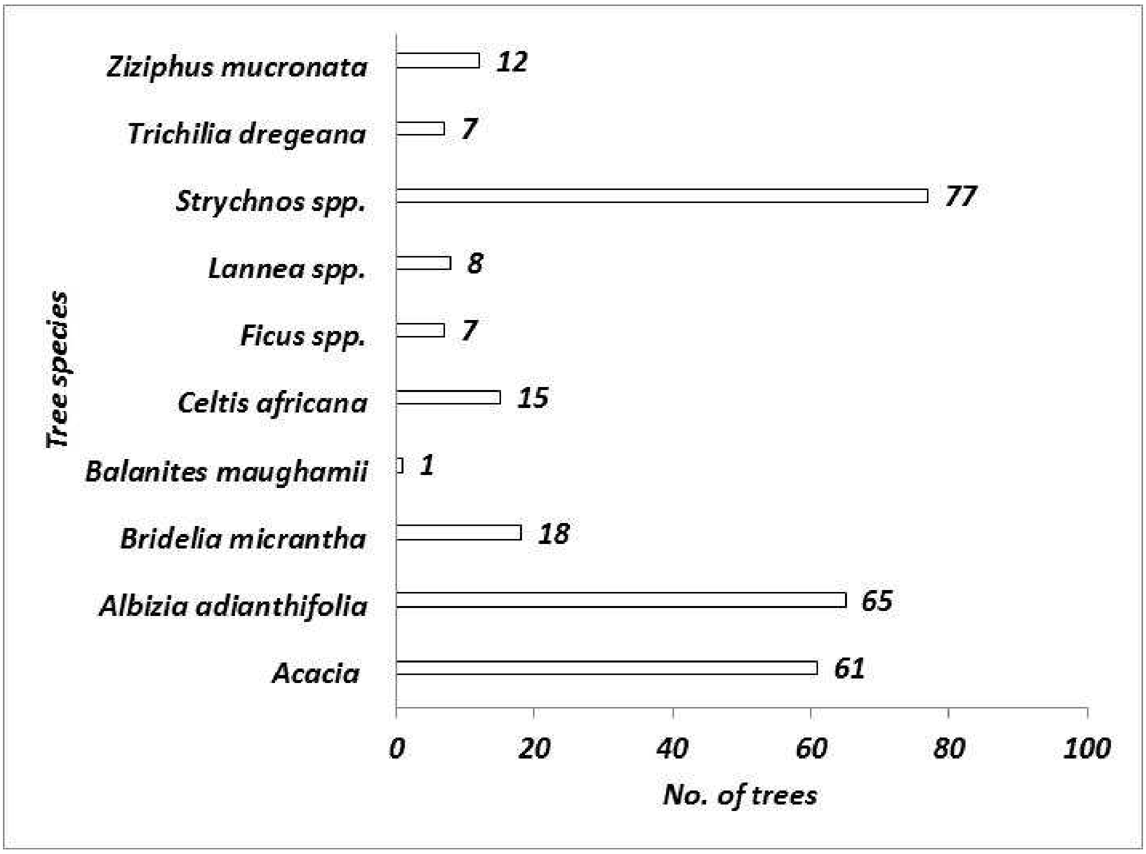

Figure 4. Statistics of dominant canopy tree species sampled in the Dukuduku forest

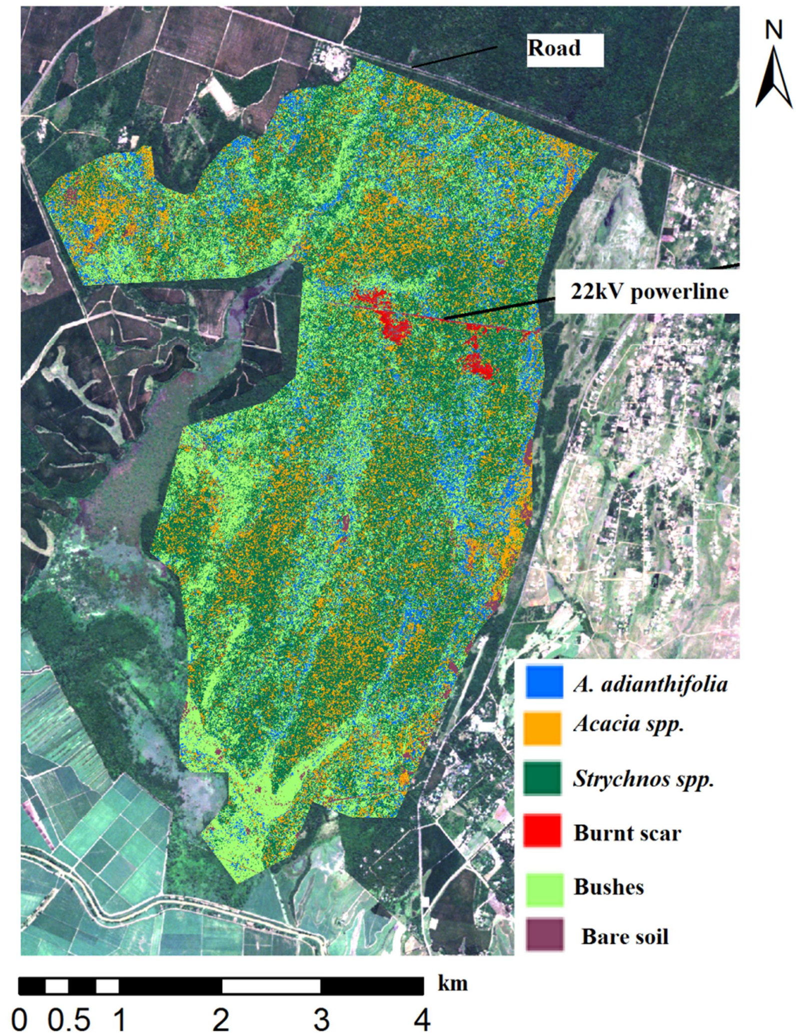

Figure 5. Dominant canopy (overstorey) tree species and canopy gap types following classification of WorldView-2 image using support vector machine classifier

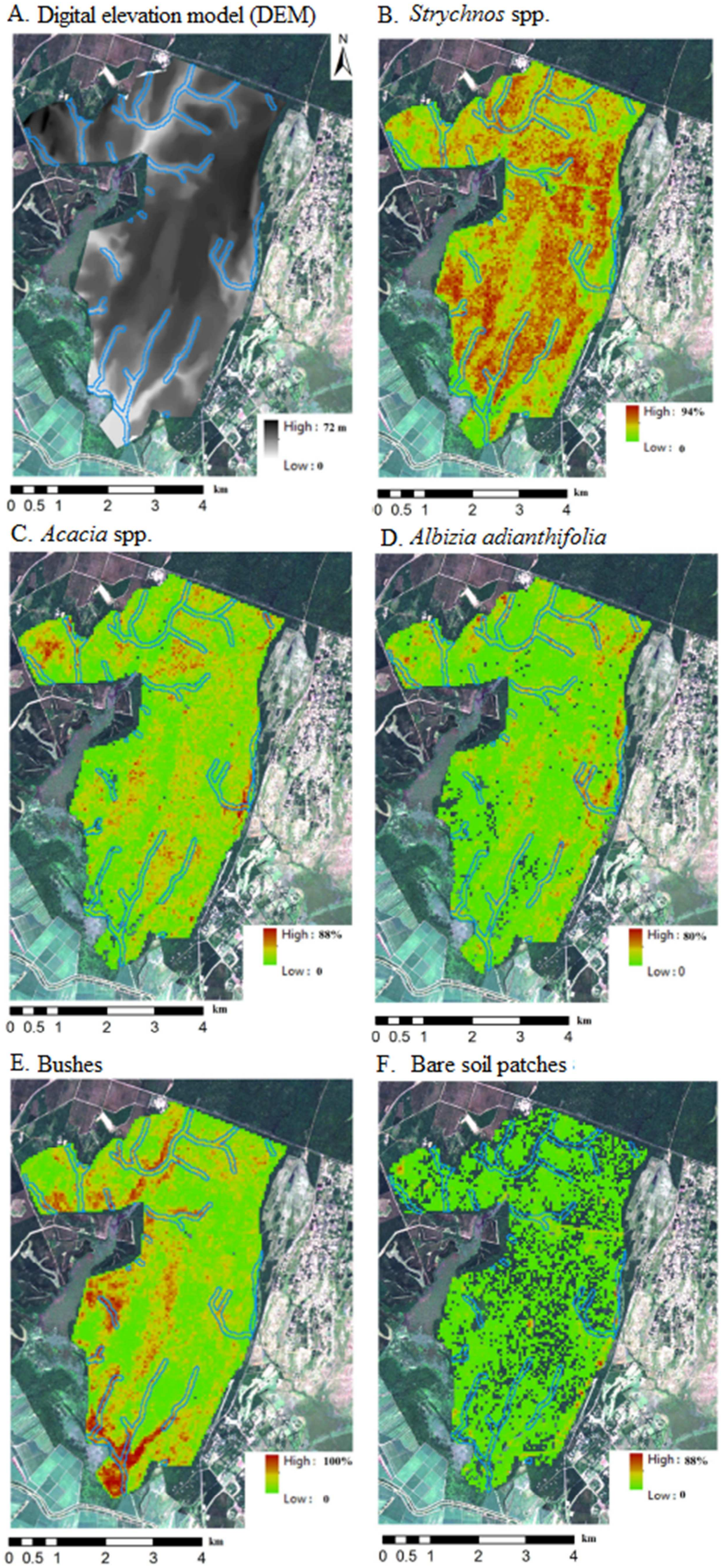

Figure 6. Percentage cover maps of dominant overstorey species and canopy cover types in the Dukuduku coastal forest, KwaZulu-Natal, South Africa.