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IDENTIFYING THE BEST SEASON FOR MAPPING EVERGREEN SWAMP AND MANGROVE SPECIES USING LEAF-LEVEL SPECTRA IN AN ESTUARINE SYSTEM IN KWAZULU-NATAL, SOUTH AFRICA

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ABSTRACT

Swamp and mangrove forests are some of the most threatened forest types in the world. In Africa, these forests are essential in providing food, construction material and medicine to people. These forest types have not sufficiently been mapped and changes in the extent or quality of these habitats can therefore not be effectively monitored. Compared to traditional surveying methods, remote sensing can be used to map these inaccessible areas over regional extents. This study investigated which season would provide the best discrimination of six evergreen tree species, associated with swamp (*Ficus Trichopoda*), mangrove (*Avicennia marina, Bruguiera gymnorrhiza, Hibiscus tiliaceus*), wetlands in adjacent woodlands (*Syzygium cordatum*) and coastal floodplain systems (*Ficus sycomorus*), using leaf-level hyperspectral data. Leaf spectra were collected from 113 trees for the winter, spring, summer and autumn months between the years of 2011-2012 in the subtropical estuarine system of the uMfolozi, uMsunduzi and St Lucia Rivers, on the east coast of KwaZulu-Natal, South Africa. The classification accuracy for each season was evaluated in the WEKA software using the Random Forest classification algorithm. When the data was upscaled to canopy-level, the results showed that all four seasons produced overall accuracies of > 90%. Spring, summer and autumn produced the highest overall accuracy of 94.7%, whereas the overall accuracy for winter was 89.5%. The results of the leaf-level analysis showed a decrease in accuracy of between 4 – 11% for the four seasons. Similar to other studies, our results showed that the simulated object-oriented approach showed a higher level in accuracy compared to the pixel-level approach. The results of this study showed that evergreen tree species around the uMfolozi, uMsunduzi and St Lucia Rivers in KwaZulu-Natal, South Africa, is highly separable over all four seasons. Further analysis will be done to assess whether the accuracies can be improved for certain species, for example *Ficus trichopoda*. Similar tests should be done on other tropical and subtropical regions of Africa, to assess whether these trends prevail for other species and regions.

INTRODUCTION

Mangrove swamp forests are considered to be one of the most threatened forest types in the world (Valiela et al. 2001). The exact percentage loss of mangrove forests over the past 50 years is globally estimated to range between 25% and 50% (Alongi 2002; Spalding et al. 2010). Losses are largely attributed to the clearance of forests for aquaculture and agricultural, and to a lesser degree to the impacts of climate change including sea-level rise, nitrification and drought (Alongi 2002; Mucina and Rutherford 2006). In Sub-Saharan Africa, where more than 48% of people live below the poverty line (http://data.worldbank.org/topic/poverty), mangrove forests provide essential ecosystem services, including livelihood resources such as construction material, fuel, food and medicine (Alongi 2002; Mucina and Rutherford 2006). Along other coastal, estuarine and riverine forests, mangroves also provide *inter alia* watershed protection, coastal erosion control, and habitats for some rare and endangered animal species (Alongi 2002). The World Atlas of Mangroves shows the extent and diversity of mangrove across the globe (Spalding et al. 2010). However, further work is required to acquire and monitor the distribution of other coastal forest types, which often co-occur alongside mangrove species in estuarine systems.

Coastal forests, such as mangrove and swamp forests, are however often difficult to access for traditional vegetation mapping surveys, owing to being waterlogged or occupied by dangerous animals (United States Department of Energy (US DOE) 2012). Remote sensing provides an alternative method to map these species at regional level and particularly for inaccessible areas. The advances of new sensors, such as RapidEye, Sentinel-2 and WorldView-2 and -3, offer increased spatial resolution to a level where individual tree canopies can be mapped. These satellite images remain expensive, particularly for developing countries, hence choosing the best season to discriminate between tree species associated with the different forest types, can allow for cost savings while enabling effective monitoring.

This study investigated which season, amongst winter, spring, summer and autumn, would provide the best discrimination of six evergreen tree species, associated with swamp (*Ficus Trichopoda*), mangrove (*Avicennia marina, Bruguiera gymnorrhiza, Hibiscus tiliaceus*), wetlands in adjacent woodlands (*Syzygium cordatum*) and coastal floodplain systems (*Ficus sycomorus*), using leaf-level hyperspectral data. Species discrimination was assessed at leaf level, which is comparable to a per-pixel classification of an image, as well as at canopy level, which is similar to the object-orientation classification of tree species at image level. Leaf spectra were collected from 113 trees for the winter, spring, summer and autumn between 2011-2012 in the subtropical estuarine systems of the uMfolozi, uMsunduzi and St Lucia Rivers, on the east coast of KwaZulu-Natal, South Africa. The Random Forest (RF) classification algorithm has been proven successful in tree species classification (Adelabu and Dube 2014; Naidoo et al. 2012), and was therefore applied to assess the best season for discriminating amongst the six species.

MATERIALS AND METHODS

Study area

The iSimangaliso Wetland Park (28°S, 32°30'E) is situated in a sub-tropical climate zone on the east coast of South Africa in the KwaZulu-Natal province. Mean Annual Precipitation (MAP) ranges between 1 000 – 1 500 mm on the coast (Middleton and Bailey 2008). The mean temperatures in summer range between 23 – 30°C and are approximately 10°C in winter (Sokolic 2006). The channel of the uMfolozi have been artificially joined to the uMsunduzi Rivers, close to its estuary, while the St Lucia River estuary are located about 1 km north of the estuary of the other two Rivers (Figure 1).

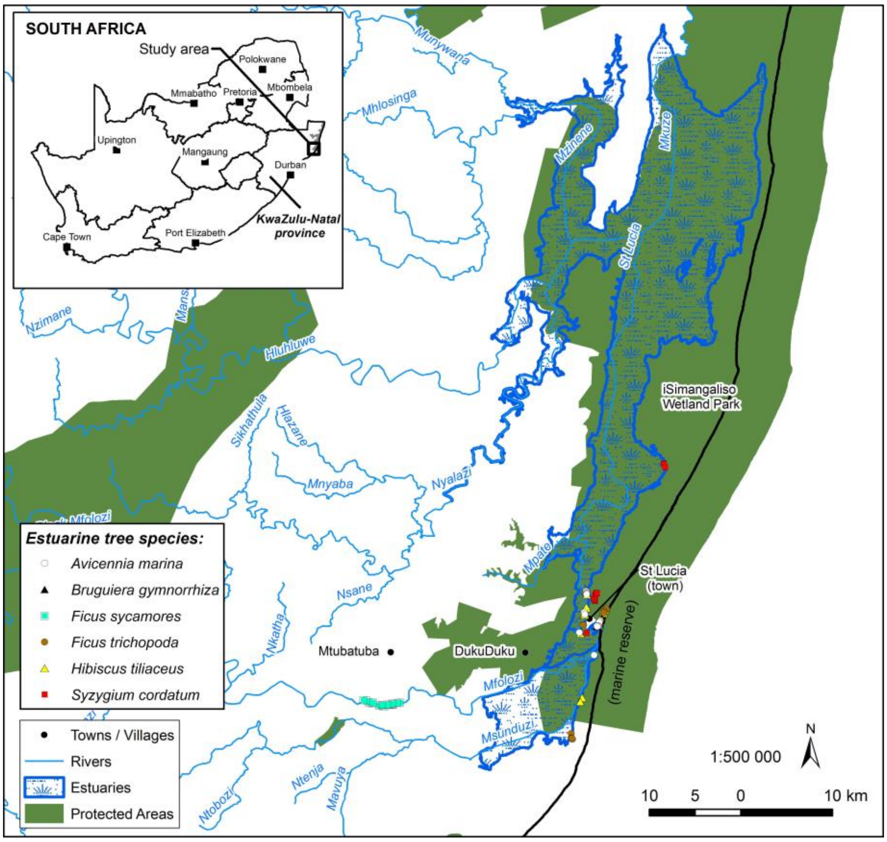

Figure 1: The estuaries of the St Lucia, uMfolozi and uMsundizu are located within 1 km of each other, and situated within the iSimangaliso Wetland Park on the east coast of South Africa.

A number of indigenous forest patches are found around the estuaries. To the south of the uMfolozi and uMsunduzi estuaries are coastal dune forests stretching north-south along the coast. *Ficus sycomorus* is found on the floodplain system of the uMfolozi and uMsunduzi Rivers to the west of the estuaries as remnants between the sugarcane farms. Dryland coastal forests are situated near the St Lucia town with the largest patch remaining at the DukuDuku forest southwest of Khula village. In the swamp forests, located between the uMfolozi and uMsunduzi Rivers, *Ficus trichopoda* and *Barringtonia racemosa* species are found, whereas two mangrove species (*Avicenna marina* & *Bruguiera gymnorrhiza*), *Hibiscus tiliaceus* and *Syzyguim cordatum* is primarily found along the channels of the estuarine systems (Figure 2).

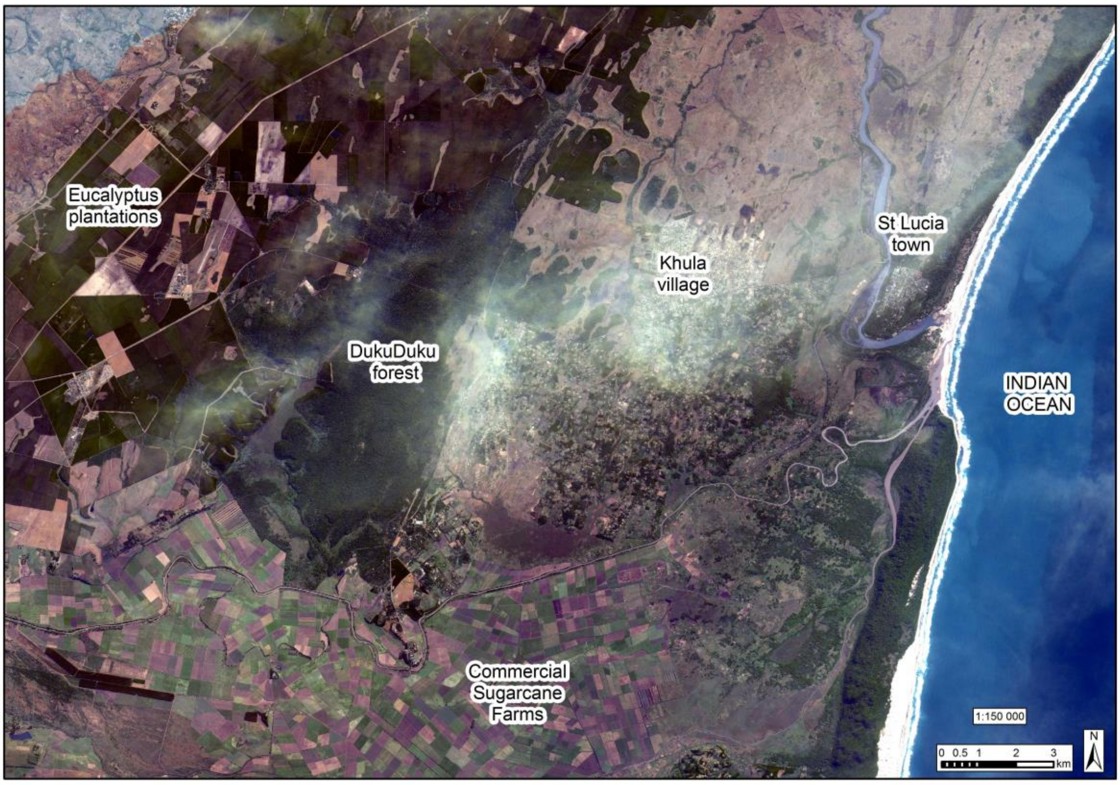

Figure 2: Distribution of coastal and inland indigenous forests, as well as other land uses, near the three estuaries of the St Lucia, uMfolozi and uMsunduzi Rivers (SANSA 2011).

Data collection

Six evergreen tree species, associated with the estuarine system, were sampled (Table 1) over four seasons (winter, spring, summer and autumn) between 2011 and 2012. Five green and fully expanded leaves were collected from across sun-exposed canopies of mature trees. The leaves were placed in zip-lock bags in a cooled container and transported back to the laboratory. One spectral measurement was recorded of the adiaxal surface of each of the five leaves using the leaf-clip device of an Analytical Spectral Device spectroradiometer (FieldSpec Pro FR, Analytical Spectral Device, Inc, USA.) within 3 to 5 hours of collection. The ASD covers the spectral range between 350 to 2500 nm with a 1.4 nm sampling interval between 350-1050 nm range, and a ±2 nm between 1 050 – 2 500 nm. Radiance was converted to reflectance against the scans of a spectralon reference panel. The reflectance spectra of the five leaves were averaged to a single reflectance signature per tree.

Table 1. Number of tree species sampled for each season. The number of trees is derived as the average of the number of usable leave spectra in brackets.

Tree species	Common name	Acronym	Winter (*n*)	Spring (*n*)	Summer (*n*)	Autumn (*n*)	Total number per species (*n*)
Avicennia marina	White mangrove	AM	21 (105)	21 (104)	21 (104)	21 (105)	84 (418)
Bruguiera gymnorrhiza	Black mangrove	BG	19 (95)	19 (94)	19 (95)	19 (94)	76 (378)
Ficus sycamores	Sycamore fig	FSYC	15 (75)	15 (75)	15 (75)	15 (75)	60 (300)
Ficus trichopoda	Swamp fig	FT	11 (55)	11 (55)	11 (55)	11 (55)	44 (220)
Hibiscus tiliaceus	Lagoon hibiscus	HT	30 (150)	30 (150)	30 (150)	30 (150)	120 (600)
Syzigium cordatum	Waterberry	SC	17 (85)	17 (85)	17 (85)	17 (85)	68 (340)
Total per season:			113 (565)	113 (563)	113 (564)	113 (564)	***452*** ***(2 256)***

Statistical Analysis

In order to establish the applicability of parametric methods for modelling the relevant spectra, the distribution assumptions of the spectra were assessed using a variety of tools. Firstly, graphical methods such as *histograms* and *quantile-quantile* (Q-Q) plots were used and showed departures from normality. Further, numeric tools including Mardia's and Henze-Zirkler's tests were also performed and indicated that the relevant spectra did not meet the multivariate normality assumption. Therefore, a non-parametric classifier, Random Forest (RF) (Breiman 2001), which has been proven successful in handling a large number of factors for classification, has therefore been chosen to assess the species separability (Grossmann et al. 2010; Prasad et al. 2006). For each season, the dataset was split into 66% training ($2/3^{rds}$ of the data) and 34% validation ($1/3^{rd}$ of the data) for the leaf-level classification, using the WEKA software (Waikato Environment for Knowledge Analysis v 3.6.11, 1999-2014, The University of Waikato, New Zealand, available from http://www.cs.waikato.ac.nz/~ml/weka/). The default settings of WEKA were maintained in the analysis for the number of trees (10) and features (12). Thereafter, the average of the five leaves was calculated to simulate canopy level, and classification repeated in a similar manner. The overall classification accuracy, kappa statistic and user's and producer's accuracies were calculated for each species in each season.

RESULTS

The results of the leaf-level assessment showed that all four seasons produced overall accuracies of > 84% (Table 2). In spring the classification accuracy was the highest (88%), compared to the summer season which had the lowest accuracy (83%). The producer's and user's accuracy for all species in spring was > 78%, whereas the other three seasons had accuracies below 75%. In summer, *Ficus trihopoda* was also classified as *Hibiscus tiliaceus* and *Syzygium cordatum* (results are not shown), resulting in producer's and user's accuracy of 47%. A large number of *Ficus trihopoda* was incorrectly classified as *Hibiscus tiliaceus* in autumn too (producer's accuracy = 54%). *Syzygium cordatum* also had producer's accuracies between 63-65% in winter, and a user accuracy of 63% in summer.

Table 2: Classification accuracies of the six evergreen tree species at leaf-level.

	Winter		Spring		Summer		Autumn	
Overall accuracy (%)	85.4		88.0		83.3		86.5	
Kappa statistic	0.82		0.85		0.80		0.83	
Accuracy (%)	Producer	User	Producer	User	Producer	User	Producer	User
Avicennia marina	89.1	97.6	81.1	90.9	91.1	100.0	95.2	97.6
Bruguiera gymnorrhiza	95.8	79.3	100.0	88.9	97.1	97.1	94.3	97.1
Ficus sycamores	95.8	95.8	85.7	94.7	77.8	87.5	90.5	79.2
Ficus trichopoda	75.0	75.0	78.6	91.7	47.1	47.1	54.2	76.5
Hibiscus tiliaceus	87.0	87.0	91.7	84.6	87.0	81.6	85.4	83.7
Syzigium cordatum	62.5	65.2	88.0	81.5	73.9	63.0	90.9	74.1

In comparison to the leaf-level results, the upscaled canopy-level results showed an overall improvement in accuracy by 5% (Table 3). The spring, summer and autumn seasons also produced a much higher overall accuracy of 94.7%, compared to the varying results of the leaf-level analysis (83-88%). The canopy-level results also indicated that the winter season had the lowest overall accuracy (90%) of all four seasons, whereas the season with the lowest overall accuracy for the leaf-level results was in summer. Most species showed producer’s and user’s accuracies above 75% at the canopy-level analysis, except for *Ficus sycamorus* in spring, where the producer’s accuracy was 66.7%. *Ficus trihopoda* showed the lowest user’s accuracies for winter, spring and autumn at 50%. A small number of *Ficus sycamores* have been misclassified as *Ficus trichopoda* in spring (results are not shown), resulting in a producer’s accuracy of 67%.

Table 3: Classification accuracies of the six evergreen tree species at canopy level.

	Winter		Spring		Summer		Autumn	
Overall accuracy (%)	89.5		94.7		94.7		94.7	
Kappa statistic	0.87		0.94		0.94		0.94	
Accuracy (%)	Producer	User	Producer	User	Producer	User	Producer	User
Avicennia marina	88.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Bruguiera gymnorrhiza	100.0	85.7	100.0	100.0	100.0	100.0	100.0	100.0
Ficus sycamores	100.0	75.0	66.7	100.0	75.0	75.0	80.0	100.0
Ficus trichopoda	100.0	50.0	100.0	50.0	80.0	100.0	100.0	50.0
Hibiscus tiliaceus	83.3	100.0	100.0	100.0	100.0	90.0	100.0	100.0
Syzigium cordatum	83.3	100.0	100.0	100.0	100.0	100.0	83.3	100.0

DISCUSSION

A number of studies used multispectral Landsat and SPOT imagery to map mangrove species in Africa: in Ghana (Mensah 2013), Kenya (Brakel 1984; Gang and Agatsiva 1992), Senegal (Conchedda et al. 2008) and Tanzania (Wang et al. 2003). We could not find published work on hyperspectral studies done in Africa in species discrimination of mangrove or estuarine tree species. Hyperspectral species discrimination studies done in Africa included those on other wetland vegetation (Adam and Mutanga 2009; Mafuratidze 2010) or savanna trees (Naidoo et al. 2012).

This study is the first study which assessed the separability of evergreen tree species associated with estuarine systems on the east coast of South Africa, in the KwaZulu-Natal province. The selected tree species are associated with mangroves, swamps, floodplain and other estuarine species. The results of this study showed that evergreen tree species around the uMfolozi, uMsunduzi and St Lucia Rivers in KwaZulu-Natal, South Africa, is highly separable at leaf spectral level over all four seasons (>89%). At canopy level the accuracy of classification increased by 5% for the spring, summer and autumn seasons (95%), compared to the winter season (90%).

The upscaled canopy-level analysis produced higher accuracies across all seasons, improving the classification between 4 – 11%. The canopy-level results also showed fewer accuracies below 75%, and none < 50%. These findings concur with the findings of other species discrimination studies where improvement in accuracies was found at object level, compared to the individual pixel-level classification (Kamal and Phinn 2011). The use of object-oriented classification of mangroves using SPOT imagery also resulted in accuracies > 75% (Conchedda et al. 2008; Vo et al. 2013).

Further analysis can include the assessment of specific regions of the spectrum which contributed significantly to the classification, and assessing whether the classification accuracy remains high if degraded to the spectral resolution of the bands of commercially available space-borne sensors. This study will also be extended in future to assess whether these species are separable using RapidEye images for four seasons. The work can also be extended to include more tree species of this estuarine environment and elsewhere in Africa.

CONCLUSIONS

This study found that six evergreen tree species, associated with estuarine forests in the east coast of South Africa, were highly separable at individual canopy level (95%) over three of the four seasons (spring, summer and autumn). The accuracy of the classification was slightly less in the winter (90%). The results of the leaf-level analysis showed a decrease in accuracy of between 4 – 11% for the four seasons. Similar to other studies, our results showed that the canopy-level analysis, which is comparable to an object-oriented approach, showed a higher level in accuracy compared to the pixel-level approach.

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