XIV WORLD FORESTRY CONGRESS, Durban, South Africa, 7-11 September 2015

Using remote sensing for tree species discrimination in the narrow coastal forests of KwaZulu-Natal, South Africa.

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Abstract

Indigenous forests of South Africa occur in one of the smallest biomes covering less than 0.5% of the total surface area of the country. Regardless of the small and narrow extent of these forests, they offer a range of ecosystem services, such as fuel wood, construction material, food and medicine, especially for the poor. Mapping and monitoring these forests are crucial for their sustainability. Regular monitoring of vegetation composition and condition can be done through localised fieldwork, yet access may be difficult in mountainous terrain, or in swamp and mangrove forests, or where dangerous animals occur. Remote sensing technology offers a feasible alternative. The improved spatial and spectral resolution of space-borne sensors has enabled species mapping at canopy level, as well as assessing pigment and nutrients as indicators of vegetation health and condition. We studied six evergreen tree species found in the subtropical coastal, swamp and mangrove forests of the KwaZulu-Natal Province of South Africa over a period of four seasons: winter, spring, summer and autumn. We present the results and findings of our work, including: i) the ability to monitor pigments and nutrients over four seasons, using leaf-level data; ii) the ability to discriminate between these six species, using seasonal information at leaf level; iii) which bands were found to be important for these species over the four seasons; and iv) whether multispectral sensors, such as RapidEye, can be used to map these six species over four seasons. Our results indicate the importance of remote sensing in monitoring indigenous forests.

Keywords: remote sensing, forest monitoring, tree species discrimination.

Introduction, scope and main objectives

Indigenous forests of South Africa occur in one of the smallest biomes covering less than 0.5% of the total surface area of the country (Mucina and Rutherford 2006). Regardless of the small and narrow extent of these forests, they offer a range of ecosystem services, such as fuel wood, construction material, food and medicine, especially for the poor (Alongi 2002; Mucina and Rutherford 2006). Mapping and monitoring narrow-range forests or particular threatened tree species are crucial for their sustainability. Regular monitoring of vegetation composition and condition can be done through localised fieldwork, yet access may be difficult in mountainous terrain, or in swamp and mangrove forests, or where dangerous animals occur.

Remote sensing technology offers a feasible alternative to field surveys for extensive terrains which are difficult to access. The improved spatial and spectral resolution of space-borne sensors has enabled species mapping at canopy level, as well as assessing pigment and nutrients as indicators of vegetation health and condition. Mapping and monitoring vegetation types and condition with remote sensing, are enabled through the relationship found between biophysical and biochemical plant properties and absorption features or indices of the reflectance data (Curran 1989; Elvidge 1990; Mutanga and

Skidmore 2004; Cho and Skidmore 2006). While these plant properties are known to vary with phenology, the effect of the variation on tree species classification and condition is not well understood. Further work is therefore required to improve our understanding of the influence of phenology on the classification of tree species or narrow-range forests, prior to the implications for monitoring their condition.

This paper offers an overview of our research contribution to the improved understanding of how seasonality affects tree species classification. We used six evergreen tree species found in forested wetlands on the east-coast of South Africa in a protected area, over four seasons (winter, spring, summer and autumn) between 2011 and 2012. The following research gaps and aims were formulated:

- The uniqueness of pigment profiles were demonstrated by a few studies in the northern hemisphere (Gond *et al.* 1999; Cooke and Weih 2005), while the uniqueness of pigment profiles for evergreen tree species in the southern hemisphere has not yet been investigated.
- A number of studies showed that nitrogen and lignin or other plant properties would be valuable for tree species discrimination (Martin *et al.* 1998), however, the relationship between the foliar concentration and leaf reflectance varies across seasons, and co-varies with other plant properties (Zhang *et al.* 2007; Dillen *et al.* 2012). A better understanding is required on the changing relationship and which bands would be more reliable to use for tree species classification.
- The use of spectral bands, which relate to plant properties such as pigments, nutrients, foliage biomass, leaf water content and other organic constituents, to effectively reduce the dimensionality of the hyperspectral data, were also assessed for tree species classification.
- The best season for tree species discrimination was assessed, as well as the variation of the classification accuracy across seasons and which bands were most important for each season. We investigated whether combined seasons improved species classification compared to a single season.
- Lastly, we assessed how effective the RapidEye sensor is in classifying tree species across four seasons, and whether the combined information of four seasons improves the classification at image level, compared to a single season.

A short overview of our results of the relevant studies follows.

Methodology/approach

Six evergreen tree species from the subtropical coastal, swamp and mangrove forests in the iSimangaliso Wetland Park, South Africa, were sampled over four seasons (winter, spring, summer and autumn) between 2011 and 2012 (Fig. 1, Table 1). The extent of the Park as well as the high prevalence of wetlands and dangerous animals, limits the possibility of monitoring tree species through fieldwork surveys. As such, the management authority will greatly benefit from the capability of remote sensing tools, particularly in identifying the location and extent of protected tree species and threatened forest types such as mangroves. The Park is situated in a sub-tropical coastal region with mean annual precipitation ranging from 1000 to 1500 mm on the coast, to below 1000 mm inland (Middleton and Bailey 2008). In summer, temperatures range from 23 – 30°C and can decrease to about 10°C during the winter (Sokolic 2006).

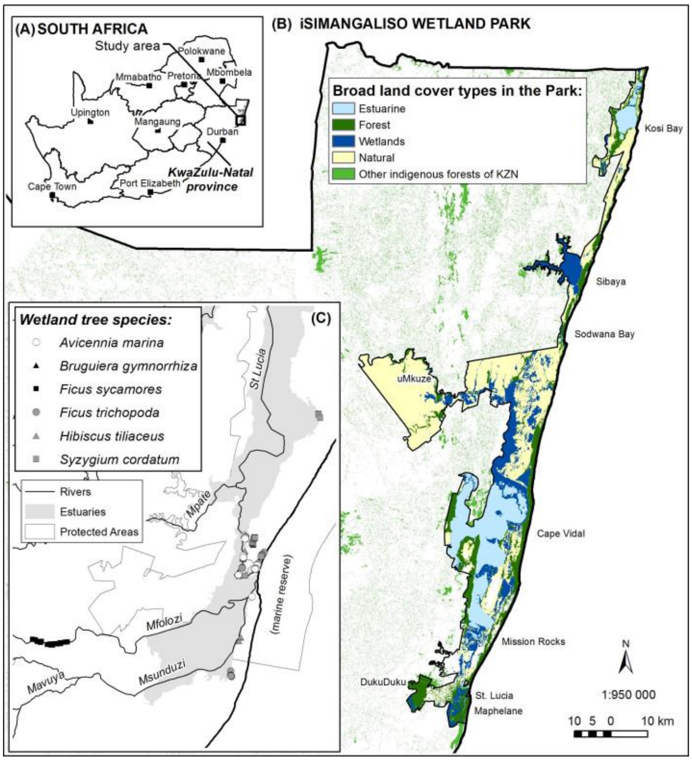


Fig. 1: The study area is located in the iSimangaliso Wetland in the KwaZulu-Natal Province of South Africa (Inset A). The Park stretches along the coast with broad vegetation and land cover comprising natural thicket and grassland, forests and wetlands (Inset B). Six tree species were sampled along the Msunduzi, Mfolozi and St Lucia estuarine systems (Inset C).

Table 1: Number of tree species sampled across four seasons in the iSimangaliso Wetland Park, South Africa*.

Tree species	Common name	Acronym	Trees Winter (*n* =)	Trees Spring (*n* =)	Trees Summer (*n* =)	Trees Autumn (*n* =)	Total number of trees per species (*n* =)
Avicennia marina	White mangrove	AM	23 (21)	23 (21)	22 (21)	22 (21)	90 (84)
Bruguiera gymnorrhiza	Black mangrove	BG	20 (19)	19	20 (19)	20 (19)	79 (76)
Ficus sycamores	Sycamore fig	FSYC	15	15	15	15	60
Ficus trichopoda	Swamp fig	FT	12 (11)	11	11	11	45 (44)
Hibiscus tiliaceus	Lagoon hibiscus	HT	31 (30)	31 (30)	30	30	122 (120)
Syzygium cordatum	Waterberry	SC	17	17	17	17	68 (68)
Total per season			118 (113)	116 (113)	115 (113)	115 (113)	464 (452)

** Species and number of trees were equalised for regression and classification purposes.*

Five leaves were sampled from the sun-exposed canopy of mature trees which are more than 2x2 m in size. Spectral measurements were taken from each leaf using an Analytical Spectral Device spectroradiometer (FieldSpec Pro FR, Analytical Spectral Device, Inc, USA.) according to the procedures previously published (Van Deventer *et al.* 2013; Van Deventer *et al.* 2015b).

The pigment concentrations of each leaf were determined using the Datt1998 index for carotenoids and Vogelman3 index for chlorophyll (Van Deventer *et al.* 2013). The foliar concentration of nitrogen and phosphorus were extracted for each season (Van Deventer *et al.* 2015b).

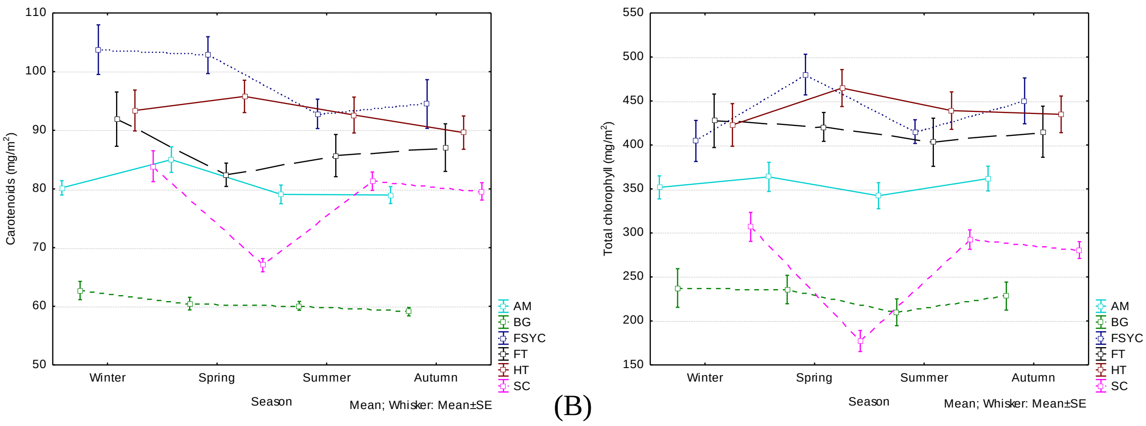
One-way ANalysis Of VAriance (ANOVA), with a post-hoc Tukey Honest Significant Difference (HCD) multiple comparisons test, were undertaken to assess whether pigment concentrations differed significantly between seasons and species. The uniqueness of the mean seasonal pigment profile of species was assessed visually and with two similarity measures, including the Spectral Angle Mapper (SAM) and Sum of Euclidian Distances (ED). Thereafter we assessed whether seasonally-combined content of either carotenoids or chlorophyll improves the number of separable combination above a single season.

The varying relationship between nutrients and reflectance data was assessed through a linear regression between nutrient concentration and an NDVI-based vegetation index (Van Deventer *et al.* 2015b). The maximum coefficient of determination (R^2) for bands, which represent either the centre of known absorption features or established indices of plant properties, were compared between seasons to assess how the relationship changes, and how the nutrients co-vary with other plant properties. The selected bands were then used for tree species classification, using a random forest (RF) classification algorithm, and comparing the accuracies of untransformed, as well as Principle Component Analysis (PCA) and Partial Least Square (PLS) transformations (Van Deventer *et al.* In Press). RF was also used in assessing the best season of all the bands (Van Deventer *et al.* 2014), as well as assessing the classification accuracies across seasons when using only selected bands (Van Deventer *et al.* 2015a). The importance of the selected bands was determined with RF for each of the seasons, with subsequent analysis of the accuracies of the band combinations according to importance rank (Van Deventer *et al.* 2015a).

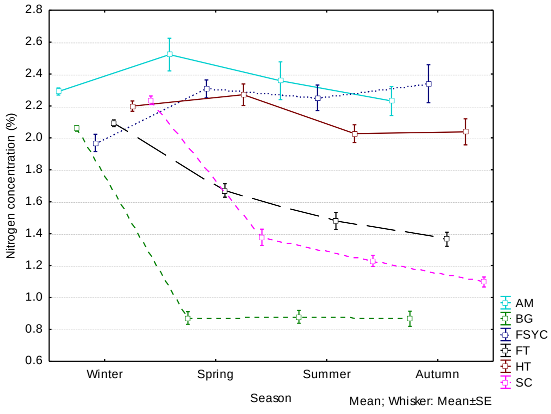
Lastly, four RapidEye images were collected over four comparative seasons between 2011 and 2012: March 2011, July 2011, October 2011 and January 2012. The images were atmospherically corrected prior to classification in ENVI.

Results

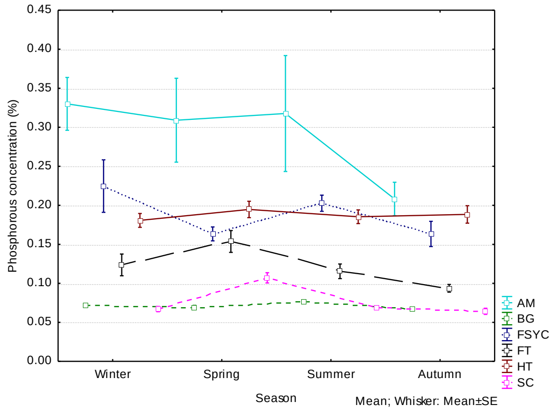
The concentration of carotenoid and chlorophyll varied across the seasons for species (Van Deventer *et al.* 2013). While many species showed similarities of pigment profiles, exceptions were noted for some species. The black mangrove species, for example, showed distinctly low levels of pigments compared to the other tree species (Fig. 2). Visually, the mean seasonal profile of the pigments of each species was unique (Fig. 2), yet the similarity measures attained accuracies <52%. The combination of the pigment content of all four seasons, showed an improvement in species separability of between 27 and 29% compared to a single season (Van Deventer *et al.* 2013). Spring showed the highest percentage of separability for the concentration of pigments, whereas the combined seasons improved separability for carotenoids (Table 2).



(A) (B)



(C)



(D)

Fig. 2: Mean seasonal profiles per species over four seasons for (A) carotenoids, (B) chlorophyll, (C) nitrogen and (D) phosphorous. Abbreviations of tree species: AM = *Avicennia marina*; BG = *Bruguiera gymnorrhiza*; FSYC = *Ficus sycamores*; FT = *Ficus trichopoda*; HT = *Hibiscus tiliaceus*; SC = *Syzygium cordatum*.

Table 2: Percentage of comparable pairs that are significantly different (*p* < 0.003 Bonferroni corrected for 15 comparable pairs) between the foliar chemical content of six tree species across the four and combined seasons.

Season:	Carotenoids	Chlorophyll	Nitrogen	Phosphorous
Winter	47	27	40	53
Spring	67	67	73	20
Summer	40	47	67	20
Autumn	40	47	60	53
Combined	73	67	73	60

Foliar nutrient content also showed a high variability among the species (Figure 2), similar to the pigments. Similar to the pigments, the foliar nitrogen content showed the highest separability in the spring season and the highest seperability of >60% for the spring, summer and autumn seasons, compared to the foliar pigments and phosphorous content (Table 2). The combined-seasonal data improved the separability for both foliar nutrients (Table 2). Twenty-two bands were selected which represented pigments, nutrients, foliage biomass, leaf water content, starch, lignin, tannins, pectin, protein and cellulose plant properties (Van Deventer *et al.* 2015b). Across seasons, the winter season showed the highest mean N content and lowest variability, whereas the other three seasons showed lower mean nitrogen values, and an increase in variability. In contrast, foliar P showed no significant differences between seasons (Van Deventer *et al.* 2015b). The relationship between foliar nutrient concentrations and N was lowest in the winter season, and highest for spring for many regions associated with co-varying organic constituents (Van Deventer *et al.* 2015b). The highest R^2 for N was recorded in the shortwave infrared (SWIR) for the band combination 2130 and 2240 nm. Across the seasons, P showed very low R^2 values, with the highest value recorded in autumn ($R^2 = 0.38$, $p < 0.01$) (Van Deventer *et al.* 2015b).

The classification of tree species using only the 22 bands (untransformed) at leaf level in spring resulted in an accuracy of 84%, a mere 2% less than the accuracy attained by 421 hyperspectral bands (Van Deventer *et al.* In Press). The optimisation of the data through transformation and component reduction, showed the PLS-RF to outperform the PCA-RF model for both the overall and individual accuracies of the tree species (Van Deventer *et al.* In Press).

Among the four seasons, the spring season was the best season to use for species discrimination (Van Deventer *et al.* 2015a). The highest overall accuracy was attained for spring, and the lowest for winter (Van Deventer *et al.* 2015a). The improvement of the overall accuracy was visible when the combined seasons were used. Further results on the most important bands and best band combinations, will be presented at the conference.

The image classification was in progress at the time of submission of this paper, the results will be presented at the Forest Symposium however.

Discussion

The influence of vegetation phenology on species classification is not well understood. We addressed this gap through assessing the separability of six evergreen tree species in a subtropical region of South Africa, across four seasons (winter, spring, summer and autumn). Our study investigated a number of aspects, including the uniqueness of pigment profiles of the species, the variability of nitrogen and phosphorous across the four seasons, the importance of plant-property bands for data reduction and classification, and whether combined seasonal data improves tree species classification above a single season.

Our results suggest that tree species may be more separable when many plant properties, other than pigments, are also considered. Both the foliar chemical data and classification of reflectance data indicated that nitrogen, lignin, protein, starch, cellulose, waxes, pectin, tannins, foliage biomass and leaf water content may contribute more to the separability of tree species compared to carotenoids or chlorophyll only. Many other studies also suggested that the SWIR region, which relate to leaf structural components, have value in tree species classification (Van Deventer *et al.* 2015a).

All four seasons attained a high percentage of overall accuracy > 83%, with the spring season attaining the highest overall accuracy and winter the lowest. A study in Hong Kong, which also showed varying classification accuracies for 25 subtropical trees over four seasons, showed the highest overall classification accuracy for the autumn season, and the lowest for the summer season (Fung *et al.* 2003). Although the climate and some species were comparable to our study, the variation across seasons was different.

The combination of seasonal data showed improved accuracies in tree species classification. The overall and individual accuracies of the seasonally-combined data of tree species were significantly higher when combined-seasonal data were used, compared to the winter and summer seasons, when leaf-level reflectance data were used. The combination of data across phenological phases, may therefore capture unique phenological or growth patterns of species. Our study was however limited in spatial and temporal extent, the climatic region represented as well as in the number of species sampled.

The overall and individual accuracies of the image classification using RapidEye, is expected to show lower results compared to the leaf-level data. Although RapidEye has a sufficient spatial resolution (6 m) for the detection of individual tree canopies or narrow-range forests, it offers no bands in the SWIR region. As a result, it may not offer the same level of separability compared to the leaf-level data where a larger number of plant properties were considered in assessing the separability of the six evergreen tree species. In contrast, Sentinel-2 offers a wider number of SWIR bands, yet at a spatial resolution insufficient for individual tree canopy detection. Regardless, further work is essential to improve our understanding of phenology on tree species classification across the globe, and to shape the spectral resolution and regions of future sensors.

Conclusions/outlook

The influence of phenology on tree species classification has thus far been limited. Our study assessed how the variation of plant properties across four seasons influenced the classification of six evergreen tree species for a subtropical region of South Africa. We found many plant properties to contribute to the separability of tree species, that a larger combination of these plant properties improved the classification accuracy and that the combination of seasonal data improved the separability of species above a single season. Further work is essential to assess how phenological trends vary across the globe for different climatic zones and species.

Acknowledgements

This work was funded by the South African Department of Science and Technology (DST), the National Research Foundation (NRF), the Council for Scientific and Industrial Research (CSIR) and the Water Research Commission (WRC). We thank the iSimangaliso Wetland Park Authority and Ezemvelo KwaZulu-Natal (KZN) Wildlife for granting access and logistical support. Dr Ricky Taylor, former ecologist at Ezemvelo KZN Wildlife for guidance and advice. We are grateful to the following fieldwork assistants: Mr S. Gumede, Dr F. Durand, Ms R. van Deventer, Mr A. van Deventer, Mr S. Mfeka, Dr E. Adam, Mr T. Colins, Mr K. Barker, Mr O. Malahlela and the iSimangaliso bursary students Ms N. Nkosi, Ms T. Sibiya, Ms N. Gumede, Mr B. Mdamba, Mr B. Gumbi. Dr Eatwell for proof reading.

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