Mangrove Species Discrimination in Southern Vietnam Based on in-situ Measured Hyperspectral Reflectance

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Abstract
The advances in hyperspectral imaging sensors offer unprecedented levels of detail to detect subtle reflectance differences between targets of study. This study assesses the spectral separability of canopies of common mangrove species in Southern Vietnam using a large sample-set of field measurements of hyperspectral reflectance. Although data collection has been conducted under consistent calibration and stable geometric set-ups, field spectroscopy deals with significant and multitudinous environmental noises compared to laboratory spectroscopic setups. Field measurements of canopies are however believed to hold greater relevancy for UAV, airborne and satellite remote sensing due a closer resemblance of real-world intra-specific variation and environmental determinants. The present study shows that the large sample-set of hyperspectral data recorded in the field provides a sound base for discrimination common mangrove species in Southern Vietnam – identifying the visible and red-edge as a key regions for species discrimination. This brings us a step further to a comprehensive spectral library for larger scale remote sensing applications of vegetation mapping and the monitoring of species distributions.

1. Introduction

Mangrove ecosystems globally are under pressure from the increasing impact of human disturbance perils as well as natural changes. A growing body of research acknowledges mangrove forests as one of the most productive ecosystems for carbon sequestration and resilient natural barriers for coastal protection (Clough, 2013, Manjunath and Kumar, 2013 and Siikamäki et al., 2012). Despite the acknowledgement of the ecological and economic importance of mangrove forests, studies report alarming rates at which the mangrove forests are degraded and converted driven by coastal urban expansion, land conversion to agriculture and coastal aquaculture as well as the unsustainable extraction of timber and firewood (Ajithkumar et al., 2008, Clough, 2013, Duke et al., 2007, Giri et al., 2011, Heumann, 2011 and Valiela et al., 2001). Detailed mapping and accurate monitoring of the health, state and dynamics of mangrove forests are therefore of key importance in sustaining the valuable ecosystems. Remote sensing techniques have been widely established as critical in accurate and efficient mapping and monitoring of mangrove ecosystems (Adam et al., 2009, Heumann, 2011 and Kuenzer et al., 2011).

Fundamental to remote sensing techniques is that each natural object reflects electro-magnetic energy in a unique way (Jensen, 2013). Theoretically, this provides the fundamental basis for surface classification. The advance towards hyperspectral sensors offers unprecedented levels of spectral detail to detect subtle differences between targets of study and their abundances and underlying biological and chemical processes as applied in various ecosystem studies (Adam et al., 2009, Govender et al., 2007 and Aspinall et al., 2002). In anticipation of the increased availability of hyperspectral sensors and data products from various platforms, the development of (regional) spectral libraries for ecosystem mapping is key to improving our capacity to understand, research and utilize the full potential of state-of-art remote sensing data. The development of high standard spectral libraries would be a way forward to facilitate this. It would compromise of a database of spectral curvatures of (pure) calibrated endmembers of interest as a basis to enable spectral matching techniques for classification and post-acquisition calibration (empirical line calibration) of remotely sensed data and can play an important role in enhancing current levels of mapping accuracy and detail (Zomer et al., 2009). For now, the limited availability of empirical field data, incomprehensive understanding of species-specific spectral properties and the missing richness of spectral libraries to map different vegetation remain to be limiting factors in detailed vegetation mapping (Schmidt and Skidmore, 2003, Sobhan, 2007 and Zomer et al., 2009).

Increased understanding of subtle differences of how solar radiation is reflected by the canopy of different common mangrove species will improve the ability to discriminate for detailed mapping of species distributions. Although no similar studies have been conducted in Vietnam so far, statistical analysis investigating spectral discrimination characteristics and quantification of separability of mangroves species using foliar samples under laboratory settings have been conducted in studies in Thailand, Malaysia, Panama and India (Kamaruzaman and Kasawani, 2007, Panigrahy et al., 2012, Prasad and Gnanappazham, 2014, Vaiphasa et al., 2005, Vaiphasa et al., 2007 and Wang and Sousa, 2009). These studies have been successful in statistical separation of mangrove species under laboratory settings using foliar samples of between three and sixteen different mangrove species – finding significant spectral differences at locations across the entire visible to infrared spectral range using parametric and non-parametric tests (Panigrahy et al., 2012, Vaiphasa et al., 2005, 2007 and Wang and Sousa, 2009).

The majority of studies on mangrove species discrimination research the spectral signatures measured under a laboratory set-up. This offers a controlled environment and ensures stable light conditions while relying on foliar samples and quick processing to avoid spectral changes. Applying the findings of leaf spectroscopy conducted in a laboratory to satellite or UAV remote sensing imagery can however be problematic since the latter negotiates canopies, environmental noises, background scattering and intra-species variability. The research presented in this paper takes an approach different by using a large sample-set of spectral reflectance data collected in-situ of mangrove canopies. The rationale behind this study design is that by using in-situ field measurements of the spectral properties of different canopies, we hope to increase the relevance of understanding spectral differences between mangrove species and facilitate a feasible scaling up of the findings to UAV, airborne and satellite remote sensing.

Large intra-specific variation and environmental noises (changing light conditions, environmental noise, surroundings, and accessibility of canopies) inherent to in-situ measurements pose concerns for accurate spectral discrimination of different vegetation species (Cochrane, 2000). Prasad and Gnanappazham (2015) argue that for mangroves specifically, differences in canopy structure is a major limiting factor since structure of canopy is highly dependent on numerous natural dimensions including soil type, tidal inundation and salinity. Ultimately, the number of studies that examine the spectral discrimination of different mangrove species based on in-situ field spectral reflectance measurements remains limited, this applies for mangrove specifically (Manjunath and Kumar, 2013) and also other wetland ecosystems species (Prospere et al., 2014).

The Ca Mau Peninsula is home to Vietnam's largest and oldest remaining mangrove forests and therefore holds a pivotal role in national and regional mangrove forest conservation (Ha et al., 2014 and Van et al., 2015). The current paper focuses on the spectral properties of mangroves common across Southern Vietnam. During the field campaign of this study, mounted hyperspectral sensors have been used to collect spectral data for mangrove canopies of six common species in different states and ages, and sites to create an initial diverse spectral database for Ca Mau's mangroves. After the removal of anomalies and warped observations, the sample contains 609 canopy measures of six common mangrove species collected around 20 sites well-distributed across Ngoc Hien district in Ca Mau. An underlying hypothesis of the study is that a large sample of consistent measurements will result in per species reflectance that converge around the mean spectra that are indeed significantly spectrally separable despite intra-species deviations and environmental variabilities. The main questions address whether significant spectral differences in the narrow bands can be found to distinguish between species canopies and which narrowband regions contain the strongest discriminative power. The interpretation of spectral curvatures of different mangrove canopies and identification of consistent hyperspectral narrow bands to discriminate tree species accurately is analyzed by the implementation of parametric statistical tests and (step-wise) linear discriminant analysis, using both spectral reflectance and continuum removed curvatures to obtain optimal results.

2. Methodology

The study area comprises of coastal mangrove ecosystems in Vietnam's southernmost district, Ngoc Hien, Ca Mau province, in the Lower Mekong Delta of Vietnam (Figure 1). This area holds the largest share of Vietnam's remaining area of mangrove forests, at the same time the region is leading in terms of area and output of shrimp cultivation, contributing to about one-third of the nation's farmed-shrimp production (Ha et al., 2014). Specifically, Ngoc Hien district in Ca Mau is home to Vietnam's largest and last remaining old growth mangrove forests, including the recently acknowledged RAMSAR site of Mui Ca Mau (2012) and UNESCO Biosphere Reserve (2009) (Tue et al., 2014). It is bordered on the north by the Kien Giang and Bac Lieu provinces, on the west by the Gulf of Thailand, and on the south and east by the East Sea. It is the only place in the country where two different tidal regimes interact, creating favorable habitats for many species.

For the research, six common mangrove species dominant in this region, have been selected based on their importance, availability and accessibility for sampling, namely; Avicennia alba, Avicennia officinalis, Rhizophora apiculata, Bruguiera parviflora, Ceriops tagal and Nypa fruticans. MONRE (2010) and Tinh et al., (2009) confirm based on total individuals, number of occurrences, relative density that these mangroves dominate in the Ca Mau peninsula in that respective order. The spectral library comprises these common mangroves with the addition of the rarer Ceriops Tagal (important for conservation purposes) and economically important Nypa Fruticans (a palm not a true mangrove) (Table 1). For development of the spectral database, the canopies of these six dominant mangrove species in the study area, were taken during a 7-day field trip in April 2015. Measurements have been done using an Analytical Spectral Device (ASD) FieldSpec® Pro with a spectral range of 325nm - 1075nm and a field of view of 7.5degrees. Measurements have been conducted under natural conditions with the instrument positioned 1.5m (off-nadir) above target canopies. Each measure consists of an average of 10 readings to construct a mean radiance curve, 10 measures have been taken of each canopy.

Data collection has been conducted in-situ under consistent calibration and stable geometric setups. Calibration using a white reference has been conducted immediately before every measure under stable weather conditions to minimize observation condition variability.

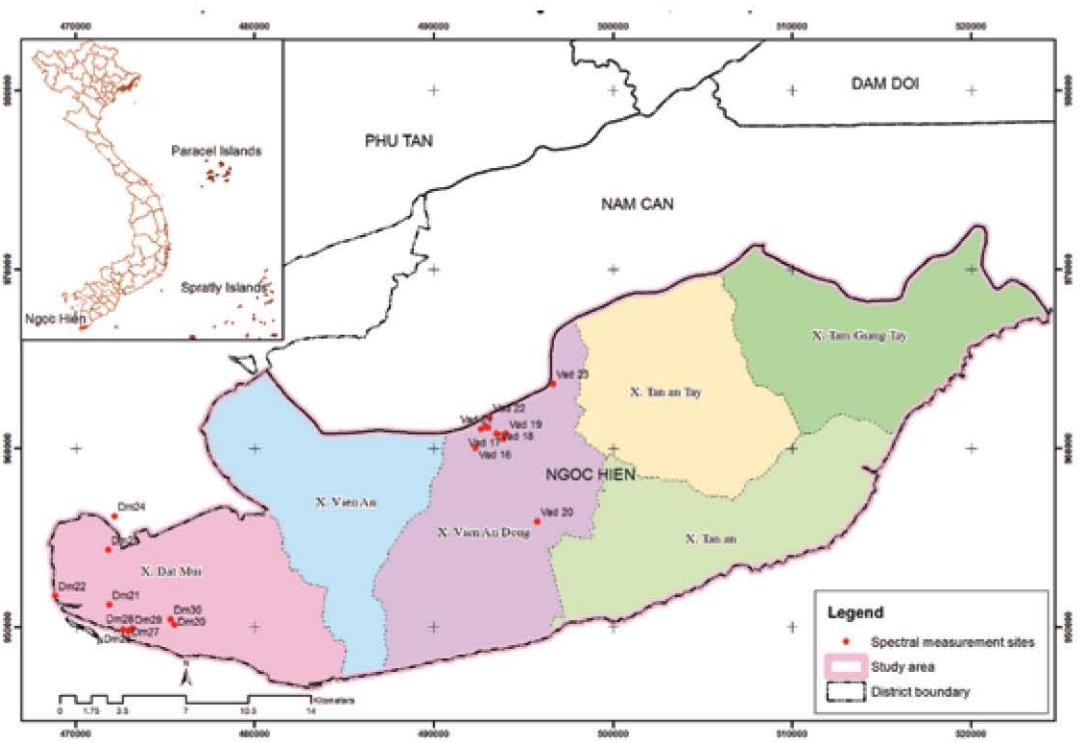

Figure 1: The field campaign has been conducted in Ngoc Hien district in Ca Mau and includes in total 20 different measurement sites at which different mangrove species have been measured. The study area and measurement sites are depicted in the map

Table 1: Number of field samples taken of six common mangrove species in Ngoc Hien district and the number of anomalies detected in a comprehensive outlier analysis

Mangrove species		Anomalies Removed	N
Latin Name	Vietnamese Name		
Avicennia Alba	Mắm Trắng	15	147
Avicennia Officialis	Mắm Đen	4	115
Nypa fruticans	Dừa Nước	12	48
Rhizophora Apiculata	Đước	32	225
Ceriops Tagal	Dà vôi	11	49
Bruguiera Parviflora	Vẹt	8	25
Total		82	609

The radiance was converted to a reflectance curve calibrated using a Spectralon reflectance panel and the correction of the in-built spectroradiometer dark current. Reflectance spectra obtained in the field using a handheld or mounted spectroradiometer are influenced by different pathways of solar illumination ending up in the field of view of the remote sensing instrument. Within this study, fixed viewing geometries have been applied from a stable platform - avoiding shadow and direct sun illumination (Jensen, 2013).

A large sample has been collected to converge reliable mean spectra to off-set some of the challenges of field spectroscopic measurements, environmental noises and account for intra-specific variation. Before further analysis, preprocessing of the data has involved; smoothing with a Savitzky-Golay filter to remove environmental noises, multivariate outlier analysis to detect anomalies (following methods by Filzmoser et al., 2008) and an applied correction for solar angle related to the time of measurement. In total, the spectral library consists of 609 canopy measurements of the studied mangroves in 20 different locations with different ages and different states.

After pre-processing the data, mean spectra have been calculated. In addition to the reflectance curves which represent the reflectance amplitude of radio magnetic energy, the continuum removal has been calculated and included in the analysis. Continuum removal normalize amplitudinal effects of the reflectance spectra and allows for a direct comparison among absorption features from a common baseline, thereby minimizing the effect of different scales or observation conditions (Schmidt and Skidmore, 2003).

In order to gain statistical insight on the significance of observed spectral differences between the mangrove species, one-way ANOVA (Analysis of Variance) and post-hoc analysis for pairwise comparisons through Tukey HSD test are tested across all available spectral locations. The analysis of between group and within group heterogeneity is key as concerns have been raised related to the high similarity of reflectance curvatures of different vegetation species, while simultaneously large variation due to differences in plant architecture, age, seasons, soil characteristics, precipitation, topography and a host of other environmental factors and stress factors could hamper the ability to distinguish mangrove species consistently based on spectral properties (Adam et al., 2009, Cochrane, 2000, Milton et al., 2009 and Prospere et al., 2014).

The hyperspectral data collected across the Visible and NIR range provides a wealth of potential discriminating variables. Linear discriminant analysis provides a statistical tool to portend group memberships from (a set of) predictors and assess separability of groups. Running a linear discriminant analysis, while entering all predictors in the equations at once, gives an indication of what proportion can be classified correctly using the full spectral information of the dataset. In addition, an alternative method of classification with a simple k-nearest neighbors (K-NN) algorithm has been added. The K-NN procedure plots the data on a high-dimensional plane and the cases are classified by a majority vote of its neighbors. Step-wise discriminant analysis (SDA) is implemented to gain insight in which subset of narrow bands retains the highest separability between the researched mangrove species while maintaining minimal informational redundancy. Ultimately, the SDA process aims to produce an optimal set of discriminating variables with minimal informational overlap between the selected variables.

The step-wise procedure starts by selecting the individual narrowband with the highest univariate discrimination based on the Wilks's Lambda statistic and the partial F ratio. The Wilks's Lambda is an informative measure for group separability as it takes into consideration both the differences (between-group) as well as the cohesiveness (within-group). The procedure continues by looking to add variables to establish a combination which produces maximum discrimination and continues until all possible unique variables have been selected and the remaining variables do not contribute a sufficiently significant increment.

3. Results

3.1 Mean Spectra

Mean spectra and standard deviations have been calculated for each of the tree species (see Figure 2). All selected species do follow rather similar spectra curves - prototypical to photosynthetic vegetation. The primary chlorophyll associated bands occur between 0.45-0.5 and 0.65-0.66 μm as also appears in the plots from the field data of this study (Figure 2). Low reflectance values in the visible range characterize pigments in the plant leaves, whereas in the Red-edge plateau and Near-Infrared range (0.75 to 1.3 μm) we observe high reflectance values around 50%, much of which is presumed to be determined by canopy density and canopy structures (Jensen, 2013, Manjunath and Kumar, 2013 and Schmidt and Skidmore, 2003).

From the mean spectra, initial differences between species can be identified visually. Avicenna Alba and Officinalis follow similar curves across the visible range while its shape is relatively distinct from Rhizophora apiculata, Ceriops Tagal and Brugeira, all three being part of the larger Rhizophoraceae family. Ceriops Tagal right bound prolongation of the reduced green absorption explains its typical yellow-green leafs. Dense canopies of Avicenna Alba and Officinalis and Rhizophora apiculata dominating large parts of Ngoc Hien district in Ca Mau explain higher near-infrared reflectance. Nypa Fruticans characteristically shows low reflectance in the visible range from its dark green branches, and low reflectance in the near-infrared range by the relatively low leaf area index of the palm. Standard deviation increases in line with the amplitude of the spectral reflectance curves. Values range between 0.01-0.03 and 0.11-0.13 in the visible and NIR range respectively.

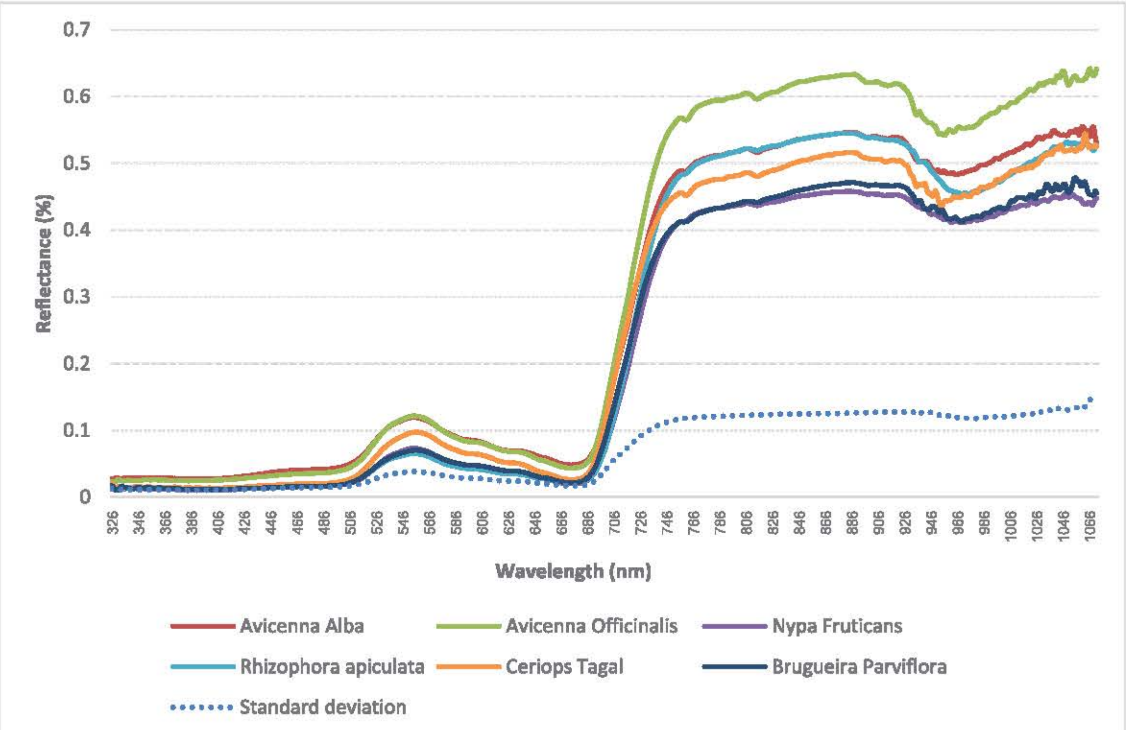

Figure 2: Calibrated and processed mean spectra of six mangrove species studies in Ngoc Hien District, Ca Mau (N=609)

3.2 Significance of Differences between Mangrove Species

The one-way Analysis of Variance (ANOVA), carried out across all bands between 325nm and 1072nm with the six vegetation species as the grouping factor, enables assessment of the significance of spectral differences between groups. The F-test assumes a null-hypotheses stating that the different groups are in fact part of the same sample rather than significantly different. ANOVA is carried out for each of the wavebands within the measurement range finding significant heterogeneity across the entire spectrum of measured spectral reflectance (P = 0.01). As presented in Figure 3, significant differences are found contiguously across wavelengths (2nm) with few exceptions in the outer ranges of the measured spectral range. These findings imply that at least one of six vegetation species deviates significantly from others at every spectral location. Post-hoc analysis conducted through Tukey's HSD analyzes pair-wise comparisons for all 15 possible combinations. The compound line in figure 3 reveals the number of significant pairs (P = 0.01) for each of the possible spectral reflectance positions (2nm). Peaks are found in the green visible spectrum and the red-range with 11 significantly different pair-wise combinations. In total, the NIR range between 900-1000nm yields the lowest number of significant pairs.

Similar to a reversed ANOVA procedure, Linear Discriminant Analysis provides a statistical tool to predict vegetation species from the measured spectral wavebands. To assign cases into groups, linear classification equations are developed for each vegetation species. Cases are assigned to the vegetation species for which it has the highest classification score. The classification procedure has been run for original reflectance data as well as continuum removed dataset. Consequently, the yielded accuracy of predicted group membership can be found in Table 2. Classification using a simple k-means nearest neighbor procedure is added for comparison. The field data provides enough between group variability in relation to within group heterogeneity to yield relatively high classification accuracy. Continuum removal supports a slightly higher accuracy in classification of vegetation species based on spectral reflectance values. Differences between LDA and K-NN classification methods are relatively small. Classification accuracy ranges between 88.2 and 93.6 percent for the two datasets. The classification matrix in the lower section of table 2 elaborates on the classification patterns and errors found for LDA per species. Very high classification accuracy is found for the Nypa Fruticans which indeed is a palm and very distinct from the analyzed mangrove species. Incorrect predications are found higher for the related Avicennia Alba (AA) and Avicennia Officialis (AO) species, the former yielded the lowest classification accuracy at 79.6 percent (Table 2).

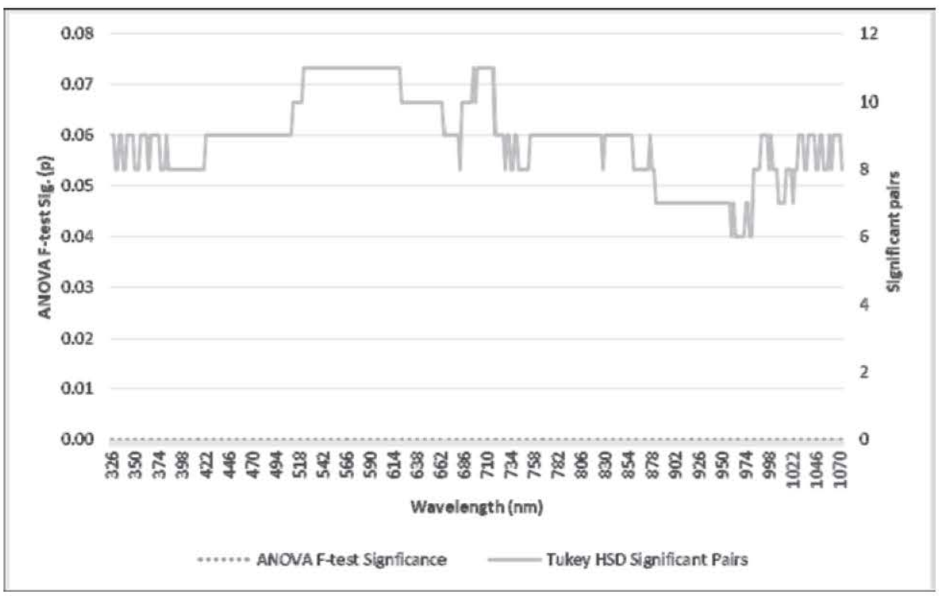

Figure 3: ANOVA and Tukey's HSD to assess the overall and the pair-wise significance of spectral reflectance differences among six studied mangrove species. ANOVA F-test Significance Values around found to be below p = 0,001 across all spectral locations studied

Table 2: a) Classification accuracy of spectral canopy reflectance signatures (325-1075nm) of six studied mangroves using LDA and K-NN classification methods for both the reflectance dataset and the continuum removed dataset b) elaboration of the classification results of the LDA method per species

a)

Spectral resolution	Dataset	Correctly Predicted Species Membership	
		LDA Accuracy (%)	K-NN Accuracy (%)
2 nm	Reflectance	88.2	92.0
	Continuum Removal	93.5	93.6

b)

	Mangrove Species	Predicted species membership						Totals	
		AA	AO	NF	RA	CT	BP	Correctly predicted (%)	N
Observed	Avicennia Alba (AA)	117	21	0	8	0	1	79.6	147
	Avicennia Officialis (AO)	6	103	0	5	0	1	89.6	115
	Nypa fruticans (NF)	0	0	48	0	0	0	100.0	48
	Rhizophora Apiculata (RA)	0	9	6	203	3	4	90.2	225
	Ceriops Tagal (CT)	0	0	1	4	44	0	89.8	49
	Bruguiera Parviflora (BP)	0	0	2	1	0	22	88.0	25

Table 3: Overview of the wavebands selected through Stepwise Linear Discriminant Analysis (SDA) as tested for both the reflectance dataset and the continuum removed dataset

Dataset	Steps	Wavebands selected			Wilk's λ
		Visible	Red-edge	NIR	
Reflectance (2nm)	6	500, 588, 596	712, 716, 748	-	0.117
Continuum Removed (2nm)	17	396, 404, 440, 454, 528, 568, 600, 634, 648, 678	690, 730, 754	890, 968, 974, 1056	0,007

3.3 Feature Selection

A step-wise discriminant analysis (SDA) selects the most important spectral regions for separating the six mangrove species in a gradual approach that aims to achieve maximum discriminative power with minimal informational redundancy. The stepwise procedure seeks to select bands containing unique information to maximize group distances based on Wilks' Lambda. The model omits redundant bands focusing on a combination of key discriminative wavelengths. Wilks' Lambda is indicative of the separability or discriminative power of (a set of) spectral wavebands. The lower the value of Wilks' lambda, the greater the separability between two classes. The stepwise methods implies at each step, the variable that contributes most to the discriminatory power of the model is entered or the variable already in the model that fails to meet the F-criterion to stay is removed. The process stops once no significant improvements in the model are achieved. At 2nm, a maximum of 620 steps are possible.

Running the SDA procedures for the reflectance and continuum removed datasets at 2nm spectral resolution yields respectively 6 and 17 information-rich discriminative bands selected in the different datasets (Table 3). The untreated reflectance data contains bands selected by the SDA procedure in the Visible, specifically (Green; 500nm and Yellow; 588nm, 596nm) and the Red-Edge (712nm, 716nm and 748nm) ranges of the electromagnetic spectrum. The dataset treated by continuum removal yields a larger number of bands to achieve maximum separability with minimum amount of informational redundancy. The selection from the continuum removed dataset achieves a lower Wilk's lambda which indicates greater separability between the mangrove species has been achieved with the selected set of bands. In total, 10 of out 17 bands are selected from the visible range emphasizing the importance of this spectral range in discriminating the different mangrove species.

4. Discussion

The extensive field campaign in Ngoc Hien district, Ca Mau, resulted in a large database of spectral measurement of the canopies of the six selected mangrove species. After pre-processing procedures, the mean reflectance spectra have been compiled and these show similar curvatures over the 325-1072nm spectral range at first sight. Typical to evergreen vegetation, all six mangrove species record high absorption in the visible range and a diminished absorption peak in the green wavebands, and high reflectance in the NIR regions. The value of this compiled hyperspectral library critically relies on the separability of the spectral canopy reflectance characteristics of different mangroves for accurate species classification.

The results from the statistical analysis of the case-study in Ca Mau, Vietnam indicate the feasibility of in-situ field measurements for spectral discrimination. The analysis shows that group differences are significant despite the variability of environmental conditions and sites encountered in a field campaign. ANOVA tests carried out across the entire spectral range of measured wavebands (325-1072nm) show that all spectral locations contain significant differences for at least one of the mangroves species. Pairwise comparison of significant separability of the six mangrove species with the Tukey's HSD tests yields the highest results in the green and red-edge wavebands with peaks 11 significantly different pair-wise combinations in some wavebands whereas lowest significant pair-wise combinations are found between 875nm and 975nm. Laboratory studies have been equally consistent in distinguishing foliar characteristics of common mangrove species in India, Malaysia, Thailand and Panama (Kamaruzaman and Kasawani, 2007, Panigrahy et al., 2012, Prasad and Gnanappazham, 2015, Vaiphasa et al., 2005, 2007 and Wang and Sousa, 2009). This study however shows the feasibility of in-situ field measurements for spectral discrimination of mangrove canopies.

The ability to predict mangrove class membership is assessed by two simple classification methods, Linear Discriminant Analysis (LDA), as well as K-means Nearest Neighbor. Species membership prediction based on these methods achieves 88.2 and 93.6 percent of correctly classified cases making use of the full spectral information available. The dataset treated with a continuum removal (CR) achieves slightly higher accuracies. The CR procedure removes the impact of amplitude and draws stronger attention to the shape of the spectral curvatures. Furthermore, CR reduces noise caused by amplitudinal effects of the environmental factors (sun angle and cloudiness in particular) that still remain after the calibration efforts. CR possibly results in higher distinctiveness found among different wavelengths which can benefit the spectral discrimination.

Spectral regions differ in their relative importance for species differentiation. Different aspects of mangrove canopy anatomy and structure are unequally liable for reflectance and absorption intensity of available light across different parts of the spectrum. For mangrove species discrimination in the Ca Mau peninsula, the Tukey's HSD test as well as step-wise linear discriminant analysis (SDA) are carried out as key methods to give insight in the most discriminative bands and spectral regions. The number of significant pairs in the Tukey's HSD analysis reaches peaks in the green (520-620nm) as well as red-edge range (700-716nm) using reflectance data. None of the narrow bands has been able to discriminate all 15 possible pairings. Hence, a multivariate approach is necessary.

Step-wise discriminant analysis is used to select a discriminative set with maximum separability as well as orthogonality. The SDA procedure for reflectance data ultimately selected a model of six narrow bands (2nm). The bands (500nm, 588nm, 596nm, 712nm, 716nm, 748nm) are clustered around the green inhibited absorption peak and the red-edge. Repetition of the SDA for the continuum-removed data set has resulted in a selection of 17 narrow bands. Selected bands are mainly found in the visible range peaking at the red-edge range, with relatively fewer bands are selected in the NIR regions. The continuum removed dataset achieves a lower Wilk's lambda statistic indicating a greater degree of separability that has been achieved with the subset. This could be attributed to the larger number selected narrow bands which in turn could be due to a larger distinctiveness of spectral information as amplitudinal effects have been removed.

The relative high importance of the visible spectral range for species discrimination is supported by studies of Sobhan (2007). These findings underline the importance of foliar characteristics since these dominate the reflectance properties in the visible range. Three selected (information-rich) bands (712, 716, 748) located close to each other implies the importance of the red-edge range for spectral discrimination. These findings are similar to the spectral discrimination study by Kamaruzaman and Kasawani (2007) using laboratory hyperspectral reflectance data collected in Malaysian mangrove forests. Their stepwise discriminant analysis revealed that the five mangrove species were most spectrally separable at five wavelengths (693, 700, 703, 730, and 731 nm) located in the red-edge zone. Similarly, the results from Prasad and Gnanappazham (2014) emphasize the importance of the red-edge region (680 nm – 720 nm) for mangrove species discrimination in India. Vaiphasa et al., (2007) conclude that red-edge slope is particularly meaningful for separating mangrove species based on different leaf pigments, internal leaf structure and water.

In comparison to studies by Manjunath et al., (2013), Wang and Sousa (2007) and Vaiphasa et al., (2007) the NIR region is strongly underrepresented to discriminate mangrove species. Possible explanation lies in the relationship of the NIR region and canopy density (minimum exposure of background) (Manjunath and Kumar, 2013). The collected data consists of a wide variety of different ages at different locations with different forest density. The variation in age and environment of the collected spectroscopic measurement results in a relatively higher amount of noise and spectral deviation and thereby limits the discriminative power of the NIR region. Stratification of the data in different age groups is an interesting option for further analysis.

The study shows that relatively significant discrimination of the studied mangrove species is possible with the hyperspectral canopy data collected in-situ. Relatively accurate classification is achieved with as few as 6 narrow bands. Ultimately, the value and application of the spectral reflectance data is tied to its purpose for mangrove species mapping and the availability of remotely sensed imagery such as EO-1 Hyperion and the expected EnMAP satellite (2017) (Belward and Skøien, 2015). The hyperspectral library of the six mangrove species is of further importance to study intra-specific variation, for calibration of remote sensing instruments and to build prior constraints guide the inversion of radiative transfer models that could enable to study of plant characteristics and traits of the selected mangrove species. Key variables that underlie the further application of the hyperspectral library are the reliability of spectral measurements, comprehensiveness of the library, transferability of spectral library (seasonality, vegetation phenology, variation), multi-functionality of applications and the availability of relevant remote sensing data (Rocchini et al., 2013 and Zomer et al., 2009).

5. Conclusion

Mangrove mapping based on reflectance of sunlight emitted electromagnetic radiation can greatly benefit from improved understanding on how the top of the canopy of different mangroves interacts with radiation in distinctive ways. Accurate field measurements capturing canopy spectra are there for highly relevant in the context of scaling up the knowledge and understanding of spectral properties derived from handheld spectrometers to satellite and UAV remote sensing. Thus far, studies on the spectral discrimination of different mangrove species have predominantly been conducted with a focus on foliar characteristics and analysis has mainly taken place within laboratory settings. The controlled laboratory environment ensures stable light conditions while relying on foliar samples and quick processing to avoid spectral changes. Nevertheless, satellite and UAV remote sensing methods for vegetation mapping require understanding of the spectral characteristics of plant canopies in their natural environment – taking into consideration a wide range of environmental determinants that influence variability in plant canopies as well as consideration of intra-specific variation. The current study has taken an in-situ field measurement approach to capture the spectral signatures of the canopies of six common mangrove species found in Southern Vietnam.

The study contributes to the conclusion that the high spectral resolution of hyperspectral sensors contains rich information that provides a strong foundation for discrimination at species level using in-situ field measurement of mangrove canopies. Field spectroscopy has to deal with changing environments, poor lighting conditions and other noise, whereas laboratory setups can control these factors. This study nevertheless shows that the large sample-set of hyperspectral data recorded in the field provides a sound base for discrimination common mangrove species – identifying the red-edge and narrow bands surrounding the green inhibited absorbance peak as a key region for species discrimination. This brings us a step further to larger scale remote sensing application in detailed mangrove vegetation mapping and the monitoring of mangrove species distributions in Southern Vietnam.

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