Estimating Mangrove Foliar Nitrogen using Spectroscopy and Remote Sensing

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by

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Abstract

Numbers of spectroscopic remote sensing methods have been developed for estimation of foliar biochemical at canopy level, but the successes of the estimation are restricted with site and ecosystem specifications. The research aimed to explore the potential of spectral reflectance (laboratory and airborne data) to estimate mangrove foliar biochemical (nitrogen and chlorophyll) at leaves and canopy level. Continuum removal and first-difference transformation methods were applied to reflectance spectra. Stepwise multiple linear regression and cross-validation analysis were employed to find relationships between the transformed spectra and mangrove foliar biochemical. For nitrogen concentration, the best predictive model obtained from first-difference transformation method applied to laboratory spectra (R^2cv = 0.58 and RMSEcv = 0.21%dry matter, n=60) and to hyperspectral HyMap data (R^2cv = 0.46 and RMSEcv = 0.27%dry matter, n=36). For chlorophyll content (used SPAD values as an indicator), although the best models achieved very high R^2cv (0.80 at leaves level, 0.83 at canopy level), but the models included too many number of wavebands (10). The wavebands selected in the regression model to estimated nitrogen concentration at leaves and canopy levels are related to known absorption features of chlorophyll and protein. High humidity and the forest physical structure such as wet soil, water and roots on the forest floor may have strong influence to mangrove canopy reflectance which would explain the slightly lower accuracy than the results from previous studies conducted on other ecosystems with HyMap data. The result models demonstrated a potential to estimate mangrove foliar biochemical. Although the accuracy of the models are slightly lower than the results from other previous studies, but the results are encouraging to applied another techniques to improve the accuracy of the estimation model for mangrove ecosystem.

Keywords: Spectroscopy, Hyperspectral, Nitrogen, SPAD, Mangrove

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1. Introduction

1.1. Background

Hyperspectral remote sensing has become a useful tool for forest ecological studies. Particularly, determination of foliar biochemicals leads to better understanding of spatial functioning and ecosystem processes (Chambers et al., 2007). Using the relation between reflectance spectra and foliar biochemical constituent of leaves, spectroscopic remote sensing demonstrated its capability to characterize forest canopy, communities and ecosystem (Asner and Martin, 2009; Kokaly et al., 2009).

Among a variety of foliar chemicals, nitrogen is the most common foliar chemical that has been extensively studied. An estimation of foliar nitrogen from spectroscopic data has been the subject for many research studies because of its importance in nutrient cycle of forest ecosystems. In a typical plant cell, nitrogen is a primary component of amino acids, nucleic acids, and chlorophyll, which are important for basic metabolism processes of plants cells. Additionally, nitrogen concentration and another biochemical constituent in leaves can be used as an indicator of vegetation quality (Mutanga et al., 2005). Furthermore, nitrogen concentration in plant foliage relates to biogeochemical processes and influences the diversity of ecological systems especially in tropical forests (Townsend et al., 2008).

Estimation of foliar nitrogen has been developed and successfully demonstrated from various source of spectroscopic data. Nitrogen concentration was shown to be well estimated from dried and ground leaves spectra (Kokaly and Clark, 1999). Spectroscopic methods have been further developed through up-scaling to the canopy level. Airborne imaging data such as HyMap has been used to estimate foliar nitrogen concentration of different types of vegetation at canopy level (Huang et al., 2004; Huber et al., 2008; Schlerf et al., 2010). However, the success of nitrogen estimation is still restricted with site specifications. For broader understanding of nitrogen estimation in wide range of forest ecosystems, research in different types of vegetation is suggested (Martin et al., 2008; Schlerf et al., 2010).

There are difficulties of estimating nitrogen in the transition from leaves to canopy level. This is due to the effect of biophysical factors such as canopy architecture and understory background on canopy reflectance spectra (Asner, 1998). Different transformation methods have been introduced and applied to reflectance spectra for enhancing sensitivity of biochemical absorption features in vegetation. The methods such as first-derivative of reflectance (Johnson and Billow, 1996; Schlerf et al., 2010) and

continuum-removal (Kokaly and Clark, 1999; Huang et al., 2004; Huber et al., 2008; Schlerf et al., 2010) were applied to reflectance spectra from leaves and canopy.

In addition to direct estimation, leaves and canopy nitrogen also have been predicted by its relationship with chlorophyll pigment. The chlorophyll pigments have shown to have a stronger correlation with spectra (Huber et al., 2008; Schlerf et al., 2010). However, in some ecosystems chlorophyll constituent has a weak correlation with leaf nitrogen (Asner and Martin, 2009).

Mangroves forests has been recognised to have important ecologial functions and economical values. Mangrove forests provide a habitat for many species of plants and animals (Nagelkerken et al., 2008). Mangroves also support diverse local fisheries and provide critical nursery habitat for marine productivity which supports wider commercial fisheries (Walters et al., 2008). Furthermore, it can be a natural barrier against natural disaster events such as Tsunamis and storm surges (Osti et al., 2009). However, mangrove forest in various areas especially in Asia are degraded (Blasco et al., 2001). Beside human activity which threat mangrove forest, nowadays climate change phenomena have such as rising of sea level become another problem (Gilman et al., 2008). Therefore, research that aims to detect and monitor ecological process of mangroves forest should be taking place.

So far, there has been no research applying spectroscopic remote sensing to study foliar biochemical of mangroves. Only little research has employed spectroscopic remote sensing to discriminate mangroves species or mangrove ecological zones (Held et al., 2003; Vaiphasa et al., 2005; Wang and Sousa, 2009). Additionally, research regarding the respond of mangrove foliar to spatial factors is restricted to local plots and they depend on laboratory analysis (Thong et al., 1993; Feller et al., 2002; Nandy et al., 2007). Thus, in this research spectroscopic remote sensing techniques were applied to broaden knowledge about mangroves foliar nitrogen estimation by spectroscopic remote sensing and provide a better understanding of spatial function of mangrove ecosystem

This research aims on estimating foliar nitrogen using spectroscopic remote sensing techniques and to investigate the spatial distribution of foliar nitrogen concentration in natural mangroves forest in Berau delta, East Kalimantan, Indonesia.

1.2. Research Objectives

This research was conducted to achieve the objectives as follows:

1. To explore possible relations between spectral transformations and foliar biochemicals (nitrogen, chlorophyll) at the leaf and canopy level.

2. To establish empirical predictive models of nitrogen concentration in leaves and canopy of the mangrove forest.

3. To investigate the possible spatial influence on mangrove foliar nitrogen.

1.3. Research Questons

The questions that were addressed by this thesis are as follows:

1. Does mangroves foliar nitrogen concentration has a relationship with SPAD values?

2. What is the relationship between foliar nitrogen concentration and continuum removed, first-difference and non transform spectra?

3. Which spectral transformation methods provide better accurate model of mangrove foliar nitrogen concentration?

4. Is there any spatial pattern in foliar nitrogen distribution in the Berau mangrove forest?

1.4. General workflow

The general work flow of this research is shown in figure 1. Spectral data from leaves and from the canopy were transformed by different spectral transformation methods. Then, stepwise regression was applied to find relationships between the transformed spectra and leaf nitrogen concentration and SPAD values (an indicator for leaf chlorophyll content).

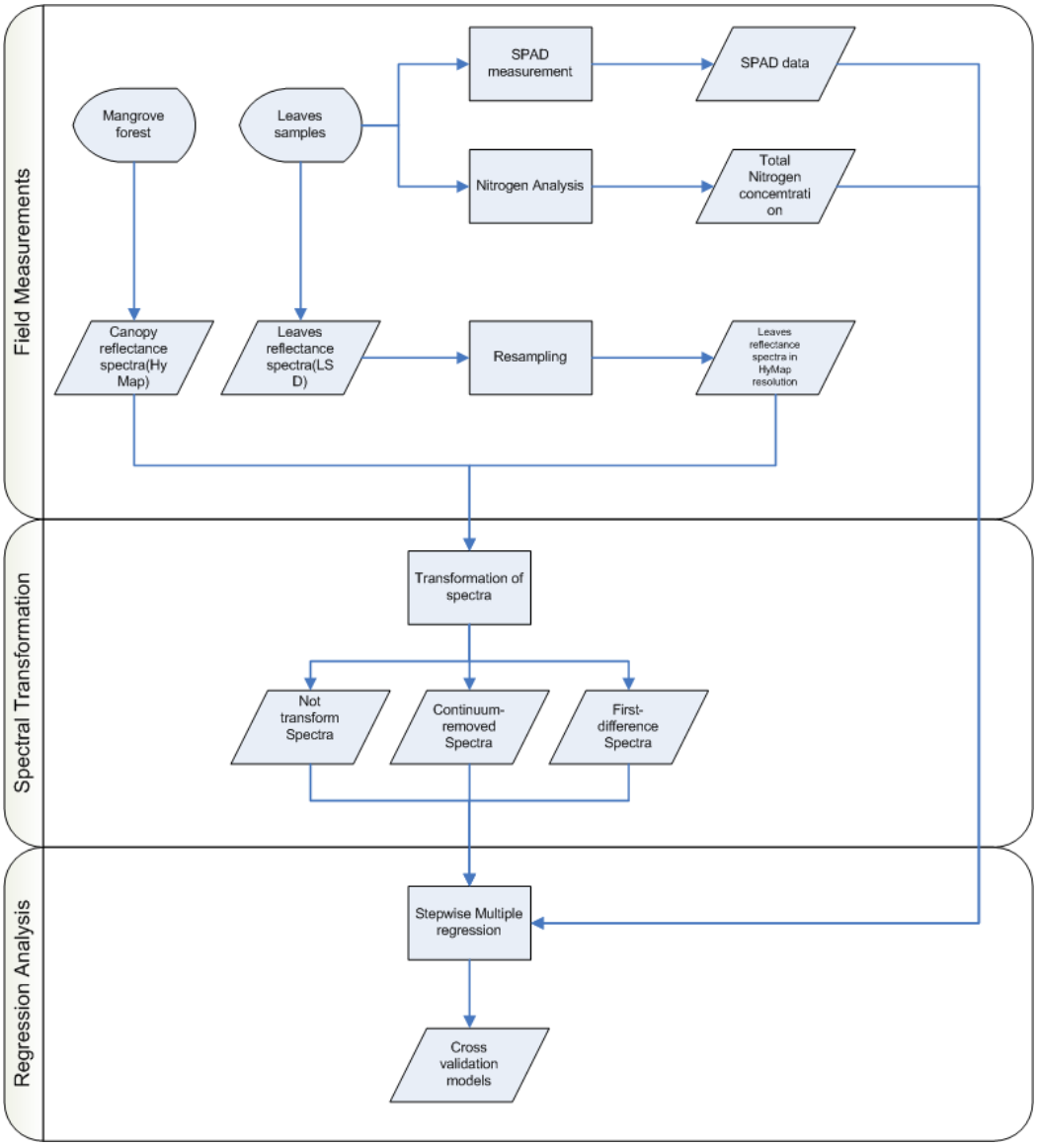

Figure 1.The general workflow of the research

2. Methodology

2.1. Study area

Study area: Berau delta, East Kalimantan, Indonesia

This study was carried out in the southern part of Berau Delta, East Kalimantan, Indonesia as shown in Figure 2. The mangrove forest is located on estuarine zone of Berau river. The forest is in undisturbed condition.

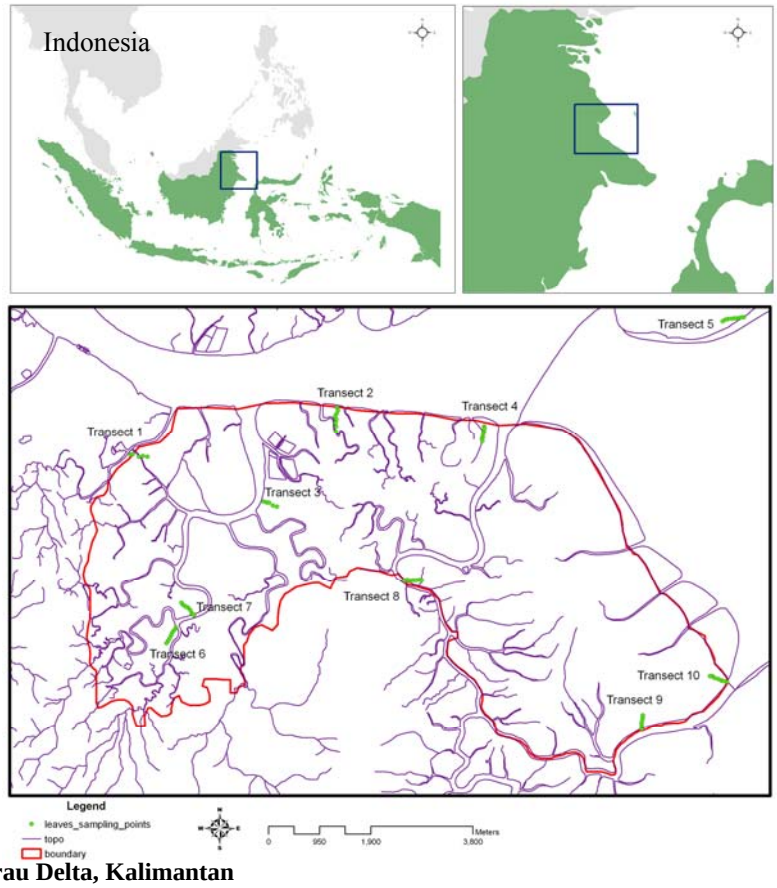

Figure 2 Map of Berau Delta, Kalimantan

2.2. Sampling design

Mangroves forest structure is influenced by estuarine environmental gradient. Many environmental factors such as inundation, salinity and nutrient availability influence distribution pattern of mangroves species (Krauss et al., 2008). The distribution pattern is known as zonation where each zone has

different forest structure. Mangrove zonation can be distinguished by tree high, density and species composition. In natural mangroves forest, zonation can be found across its environmental gradient from ocean fringe into inland area, such as an example study of India mangroves forest (Satyanarayana et al., 2002).

Nutrient availability in mangrove ecosystem varies across environmental gradient and mangrove zones. A study of estuarine mangrove forest in Florida indicated that soil nutrient availability along the river is related to mangrove forest structure (Chen and Twilley, 1999). In addition, variability of soil nutrients of small plots (200x300 m^2) were reported from a study in mangrove of Venezuela (Rivera-Monroy et al., 2004). It is presumable that nutrient variability in mangrove ecosystem can be found in both local and landscape scale.

There is a link between mangrove foliar nitrogen and nutrient availability in soil. Feller et al. (2002) reported different concentration of foliar nitrogen in difference mangrove zones where different soil nutrient availability was found. Thus we expected variability of leaf nitrogen concentration would be found across from seaward side to landward side and in different mangrove ecological zone of the study area.

During 4-16 September 2009, mangrove leaves were collected along 10 transect lines (figure1). The line transects cut through different mangrove zones where different concentration of leaf nitrogen were expected. . The length of transects varied from 250 to 350 meters due to differences transect accessibility. Along each transect, a tree was selected from the dominant species in the surrounding at every 50 meters. We considered trees which were possible to be climbed and had an exposed canopy. This allowed us to link ground leaves spectra to canopy spectra from airborne imagery. Branches of the selected trees were cut from the crown and several bouquets of leaves were collected and subsequently stored in a cool box for transporting them to the spectral laboratory. We selected 15 leaves from the bouquets of a selected tree, whereby only mature green leaves were considered and damaged leaves were avoided.

2.3. Analysis of leaves nitrogen

We randomly selected 5 leaves from each sample of 15 leaves and kept them in an envelope. Leaves samples were delivered to a laboratory of the Office of Agriculture Research and Development Region 1, Department of Agriculture, Thailand for dried nitrogen analysis using Kjeldahl technique. Kjeldahl technique is an internationally recognized method to determine nitrogen and chemical substance. This method not only gives a measurement of protein nitrogen but also non-protein nitrogen.

2.4. SPAD meaurement for chlorophyll

We used a Minolta SPAD-502 chlorophyll meter which measures the transmittance through a leaf at red (650 nm) and infrared (940 nm) wavelengths. This instrument provides comparative values which correlated with chlorophyll concentration of leaf and has been used for rapid field assessment of chlorophyll concentration (Bauerle et al., 2004). SPAD values have been widely used as an indicator for chlorophyll concentration in various vegetation studies.

2.5. Leaf spectral measurements

We measured leaf spectral reflectance using a field spectrometer (ASD FieldSpec Pro FR) connected to a contact probe. The contact probe has an internal light source which ensures that each measurement is done under similar illumination conditions. Individual leaf was placed on a black writing board, and then the contact probe was firmly attached to the leaf surface. The measurements were done at the centre of the leaves. A white reference spectrum measurement was made before each sample for the instrument calibration.

Spectral resolution of the spectra data obtained from the field spectrometer is 3 – 10 nanometers and the wavelength ranged from 350 to 2500 nanometers. This resolution is different from those obtained from airborne and space born sensors. In order to test if the spectral resolution of airborne sensor would be sufficient for estimation of foliar nitrogen, the data were resample to HyMap wavebands.

2.6. Airborne hyperspectral images

The hyperspectral HyMap sensor was flown over the study site on 19 October, 2009. The acquire images were geometrically corrected using parametric geo-coding and radiometrically corrected to top-of-canopy reflectance by HyVista, Sydney, Australia. Images have a spatial resolution of 3 meters. The images are partly covered with cloud and shadow.

Canopy spectra were extracted from HyMap images for each of 36 points from 6 transects (the rest are covered by cloud and shadow). The ground points of each sample which were recorded in the field were overlaid with the geo-coded images. Spectrum of four pixels surrounding the sampling points was extracted. There were 15 spectral channels identified as bad bands and were eliminated from 126 spectral channel of original HyMap data.

2.7. Spectral transformation

2.7.1. First-difference

First-difference of reflectance spectra using in this research was calculated by the formula (1) below.

$$FD = (S_i - S_{i+1}) / (\lambda_i - \lambda_{i+1}) \quad (1)$$

Where S_i is reflectance at particular waveband, S_{i+1} is reflectance at the next waveband, λ_i and λ_{i+1} are wavelengths of S_i and S_{i+1} respectively. First-difference of reflectance is similar with the first derivative by mean of calculating difference in reflectance spectra between adjacent wave bands (Schlerf et al., 2010).

2.7.2. Continuum removal

Continuum removal is a spectral transformation method which reduces effect of background absorption feature and allows each individual absorption feature can be comparing from the same baseline. This method was introduced for vegetation studies by Kolaly and Clark (1999) which applied continuum removal to dried leaves spectra. Furthermore, continuum removal have been wildly applied with imaging spectroscopic data for obtaining canopy biochemical prediction with accurate results (Huang et al., 2004; Mutanga et al., 2005; Huber et al., 2008). In this research, continuum removal was applied using ENVI 4.5 software package.

2.8. Regression Analysis

This research applied stepwise multiple linear regressions to the transformed spectra from laboratory and canopy in order to find relationship between foliar biochemical and transformed spectra. The stepwise multiple linear model has the advantages of simple application to explain predictors variable. Cross-validation (leave-one-out) was used to assess the accuracy of the resulting models according to limitation of the sample size (Huang et al., 2004; Schlerf et al., 2010). The p-values were set at 0.05 for entry of bands and 0.10 for removal to control the number of bands in the model. For model assessment, three parameters from the cross validation result which are coefficient of determination (R^2cv), root mean squared error (RMSEcv) and number of bands were used.

2.9. Selection of spectral regions

Following approaches was adopted from the previous work of (Kokaly and Clark, 1999; Huang et al., 2004; Schlerf et al., 2010). Five broad regions were extracted from laboratory and canopy spectra

(Table 1). The spectral transformation methods were applied to these selected regions spectra. For comparison, the full range spectra were also applied.

Relation to chemical	Start (nm)	End (nm)	Known absorption bands (nm)
Chlorophyll a + b	558	761	640, 660
Lignin, water	1077	1277	1120, 1200
Protein	1686	1784	1690, 1730
Protein	2099	2206	2130, 2180
Protein	2241	2371	2240, 2300, 2350

Table 1 Selected five regions of spectra used in regression analysis (modified from Schlerf et al., 2010)

3. Results

3.1. Nitrogen concentration and SPAD values

Over all sixty one leaf samples were analyzed for nitrogen and for seventy leaf samples SPAD values were obtained (Table 2).

	Unit	Min	Average	Max	Std
Nitrogen (n=61)	% of dry weight	0.73	1.4	2.99	0.38
SPAD (n=70)	Arbitrary	40.03	53.77	64.35	5.42

Table 2 Summary of percentage of nitrogen concentration and SPAD values

The original data of nitrogen concentration was not normal distributed while the SPAD value was normal. There was an outliner present in the nitrogen concentration data set. However after the outliner was removed, the data set returned normal distributed at 90 % confidence (p-value = 0.003364, Shapiro-Wilk normality test). Linear correlation coefficient between leaves nitrogen concentration and SPAD values show a very weak relation (r= 0.188).

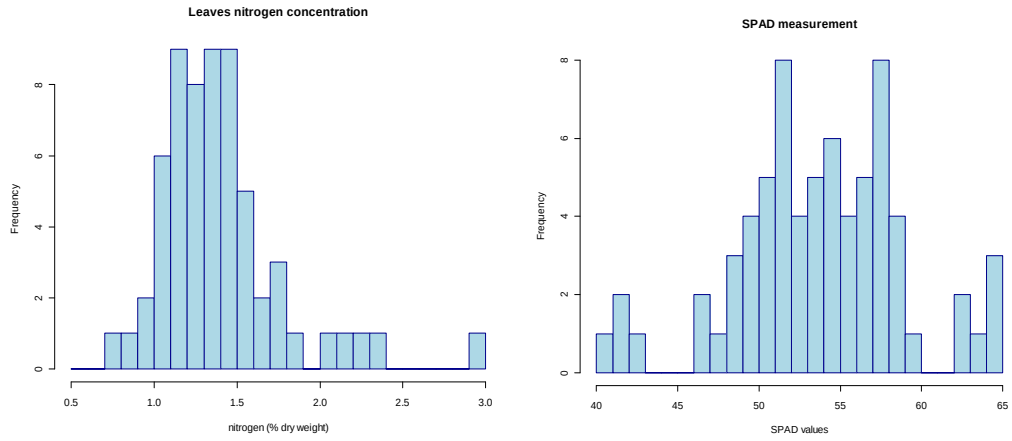

Figure 3 The original data of nitrogen concentration and SPAD values show an outliner and not normal distribution of nitrogen data set, left: leaves nitrogen concentration, right: SPAD values

3.2. Difference of nitrogen concentration and SPAD values between line transects

Figure 4 shows the averages of nitrogen concentration and of SPAD values of each line transect. Result from one-way ANOVA with Fisher's least significant difference (LSD) post-hog test show that mean of leaf nitrogen concentration in transect 4 and 5 are distinctly higher than others at 95 % confidence. Differently, the SPAD values do not show similar pattern although there were significantly different among them.

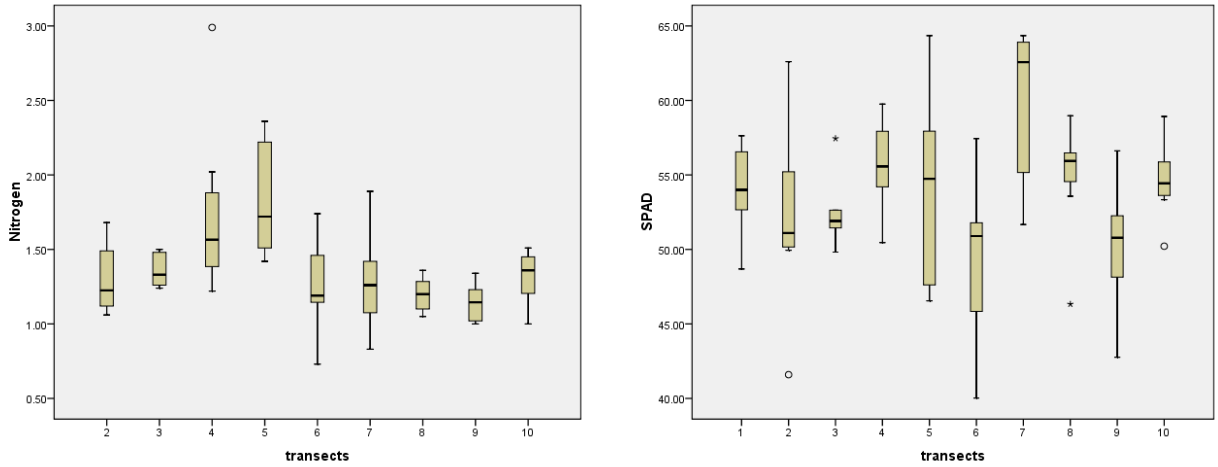

Figure 4 Average values per transect of leaves nitrogen concentration (% dry matter) and SPAD values. Left: nitrogen, right: SPAD.

3.3. Difference of nitrogen concentration between land ward and sea ward side

Data from line transects where located close to the sea or close to the main river (transect 2, 4, 5, 10) were combined into seaward category while data from line transects where located in the landward area (transect 1, 3, 6, 7, 8, 9) were combined to landward category. To test a difference of values between the two categorizes, t-test was applied. There is significantly different of leaves nitrogen concentration in the seaward side and the landward side (t-test, $p = 0.025$), but the SPAD values do not show significantly different between categorizes (figure 5).

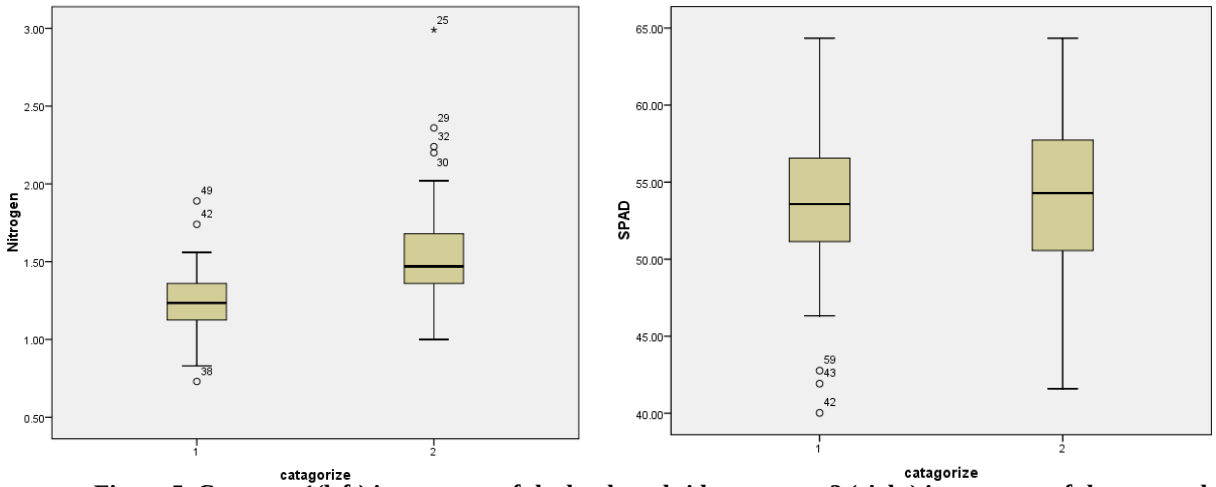

Figure 5 Category 1(left) is transects of the landward side, category 2 (right) is transects of the seaward side. Nitrogen concentration (% dry matter) of the seaward side was higher than landward side. SPAD values from both sides were not different. Left: nitrogen, right: SPAD.

3.4. Estimation of nitrogen concentration and SPAD values

3.4.1. Laboratory spectra

Different spectral transformations were applied to full range and selected regions of the laboratory spectra. The results of the estimation model were compared (Table 3).

Spectral Transformation		**Nitrogen(n=60)**		**SPAD(n=70)**	
		Full	**selected**	**Full**	**selected**
Reflectance spectral	R^2cv	0.37	0.54	0.49	0.80
	RMSEcv	0.26	0.22	3.72	2.33
	Number of bands	4	5	4	10
First-difference	R^2cv	**0.58**	**0.58**	**0.75**	**0.76**
	RMSEcv	0.21	0.21	2.60	2.55
	Number of bands	3	3	9	7
Continuum removal	R^2cv	0.40	0.41	0.32	0.32
	RMSEcv	0.25	0.25	4.29	4.29
	Number of bands	4	4	1	1

Table 3 Cross-validated R^2 between measured and estimated of nitrogen (%dry matter) and SPAD values from different spectral transformations

Cross-validated R^2 between measured and estimated nitrogen concentration for the spectral transformation are between 0.37 – 0.58. The best predictive model was obtain from first-difference transformation method which has highest R^2cv (0.58) and lowest RMSEcv (0.21 % of dry matter).

For the SPAD values estimation, the best predictive model was obtained from non-transformed spectra. Cross-validated R^2 between measured and estimated SPAD values of the best model is 0.80 and RMSEcv is 2.33.

The results of cross-validation generally showed slightly better performance of selected regions spectra than the full range spectra for both nitrogen concentration and SPAD values. The approach of spectral selected regions show a large influence on non-transformed spectra where the R^2cv increases from 0.37 to 0.54 for nitrogen and from 0.49 to 0.80 for the SPAD value.

3.4.2. Canopy spectra

The model of nitrogen prediction obtained from continuum-removed spectra (R^2cv=0.47) and the model obtained form first-difference spectra (R^2cv = 0.46) have similar accuracy (RMSEcv=0.27 % of dry matter). Considering number of bands in the models, the model obtained from first-difference spectra has two wavebands while the model obtained from continuum-removed spectra has three (table 4). This indicated that the model obtained by first-difference spectra is better.

For SPAD values, the best model predictive was obtained from first-difference transformation applied to the full range spectra which was archived very high R^2cv (0.83) while others provided low R^2cv especially the reflectance spectra.

Spectral		**Nitrogen(n=36)**		**SPAD(n=36)**	
Transformation		**Full**	**selected**	**Full**	**selected**
Reflectance spectra	R^2cv	0.38	0.33	0.06	no model found
	RMSEcv	0.29	0.30	5.92	
	Number of bands	2	2	1	
First-difference	R^2cv	**0.46**	**0.46**	**0.83**	0.40
	RMSEcv	0.27	0.27	2.51	4.72
	Number of bands	2	2	10	3
Continuum removal	R^2cv	0.43	**0.47**	0.21	no model found
	RMSEcv	0.28	0.27	5.42	
	Number of bands	2	3	1	

Table 4 Cross-validated R^2 between measured and estimated of nitrogen and SPAD values from different spectral transformations at canopy levels.

3.4.3. Selected wavebands

For nitrogen estimation, selected wavebands of each transformation methods are difference. Whit laboratory spectra (leaves level), more number of wavebands were selected in to models when compare to the canopy spectra (Table.6).

For the best model of nitrogen prediction at leaves level obtained form first-difference spectra, three wavebands were included. The first two waveband are 1669 and 1706 nanometres which are close to 1690 nm (within 20 nm) were related to lignin, starch, protein and nitrogen (Curran, 1989). Anther waveband included in the model at 2115 nm is close to a protein absorption feature at 2130 nanometres.

At canopy level, it is consistent that less number of waveband was selected into the modes for all transformation methods. Two wave bands selected into the best model (obtained from first-difference spectra) are 558 and 2099 nanometres which is close to 570 and 2010 nanometres where related to chlorophyll and starch absorption feature.

		Selected wavebands	
Levels	**Spectral Transformation**	**full range spectra**	**selected regions spectra**
leaves	Reflectance spectra	503 656 731 1089	656 731 1669 1755 2097
	First-difference	1669 1706 2115	1669 1706 2115
	Continuum removal	747 918 2150 2305	563 716 731 1706
canopy	Reflectance spectra	528 675	558 675
	First-difference	558 2099	558 2099
	Continuum removal	675 1121	587 675 1121

Table 5 Selected wavebands of nitrogen estimation models at leaves and canopy levels.

Fore SPAD values estimation, there are comparatively large numbers of the waveband selected in the best models. At both leaves and canopy level, there are 7 - 10 wave bands selected to the best model. Some of the selected wavebands are related to known absorption feature of chlorophyll, protein nitrogen and starch.

Levels	Spectral Transformation	Selected wavebands	
		full range spectra	**selected regions spectra**
leaves	Reflectance spectra	549 563 981 1134	549 563 716 1148 1207 1236 1250 1669 1731 1949
	First-difference	747 823 965 1192 1657 2254 2305 2321 2418	702 747 1089 1192 1743 2254 2305
	Continuum removal	731	731
canopy	Reflectance spectra	1461	no model found
	First-difference	455 618 762 888 1249 1610 1636 2118 2242 2310	1178 2118 2241
	Continuum removal	1062	no model found

Table 6 Selected wavebands of nitrogen estimation models at leaves and canopy levels.

3.4.4. Predictive equations

The model obtained from first-difference spectra (FD) is the most accurate for nitrogen concentration at leaves level (Table 3.). The model is described as the equation 2.

$$N_{leaves} = -322.954(FD_{1669}) + 161.522(FD_{1706}) + 100.472(FD_{2115}) + 1.852 \quad (2)$$

Where N_{leaves} is the estimated nitrogen concentration at leaves level.

At canopy level, the most accurate model also obtained form first-difference spectra. The relationship is described as the equation 3.

$$N_{canopy} = 221.37(FD_{558}) + 247.404(FD_{2099}) + 2.663 \quad (3)$$

Where N_{canopy} is the estimated nitrogen concentration at canopy level.

The scatter plots (figure 7) show linear relationships between measure and estimated mangrove foliar nitrogen at leaves and canopy level.

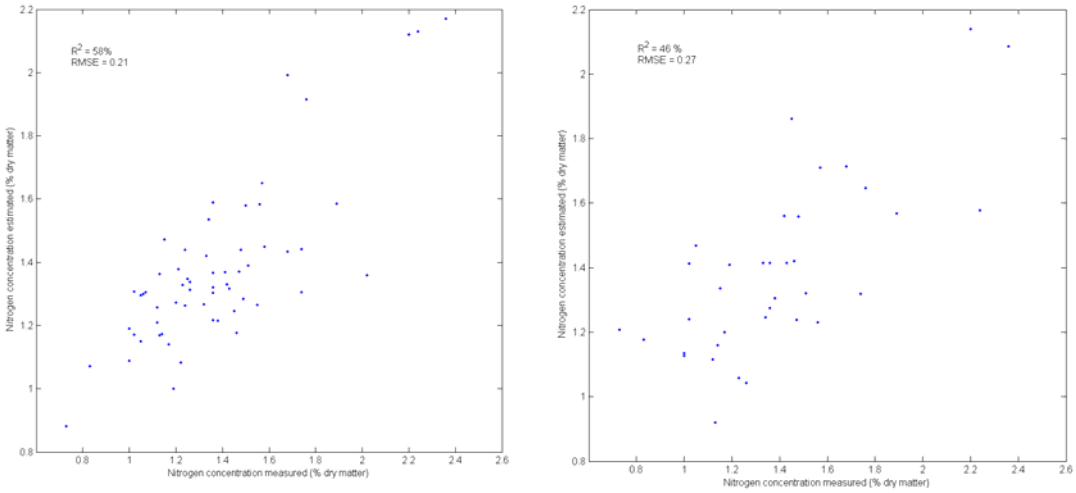

Figure 6 Scatter plots of estimated and measured nitrogen using laboratory spectra (left) and image spectra (right)

4. Discussions

4.1. Bichemical data

Differences of nitrogen concentration in the leaves sample are due to the differences of the transect location. The line transects which are closed to the main river or the sea show higher leaves nitrogen concentration (figure 4.) than landward transects. The experimental research conducted by Feller et al. (2002) show that leaves nitrogen increased when additional nitrogen was added to soil. This suggests that the river or the sea bring additional nutrients to the mangrove forest. In contrast, SPAD values reveal no similar pattern. Probably, chlorophyll content of mangrove leaves is less related to soil nutrient availability.

4.2. Nitrogen estimation models

At leaf level, the result show that transformed and not transformed spectra can predict nitrogen concentration of mangrove foliar with moderate accuracy with R^2cv from 0.41 – 0.58 % (table. 2). This result is close to the results from Schlerf et al. (2010) which applied the same methods to fresh needle leaves of Norway spruce (R^2cv from 0.47 – 0.59 %). However, the RMSEcv of the models in this study are higher (lower accuracy) which may be explained by characteristic of mangrove leaves that contain a lot of water. Kokaly and Clark (1999) demonstrated that nitrogen prediction can be achieved to 85 – 94 % from dried and ground leaves spectra. Additionally, the same research indicated that increasing of leaf water content resulted in greater RMSE of nitrogen prediction.

At canopy level, the transformed spectra can predict nitrogen concentration of mangrove foliar better than not transformed spectra (table 3.). This results show the effect of the transformation methods on canopy spectra. Asner (1998) indicated that variability of canopy spectra is influenced by biochemical and biophysical such as canopy architecture, soil and understory background. This could explain that only about half of the nitrogen variability is explained by the best model. In the study area of this research located in mangrove forest understory tree layer is usually absent, but wet soil, water and mangrove roots may have a strong influence on the measured mangrove canopy reflectance. Additionally, high humidity of tropical mangrove forests may cause problems due to atmosphere water vapour. These would be explained why cross-validation R^2 obtained from first-difference and continuum removed spectra in this study are slightly lower than the results from previous studies which studied other ecosystems with HyMap data (Huang et al., 2004; Huber et al., 2008; Schlerf et al., 2010).

4.3. Relations of transformed spectra and SPAD values

The SPAD values show very strong relation with transformed spectra at both leaves and canopy level (table 2 and table3). This may indicate that chlorophyll content of mangrove canopy can be estimated and achieves high accuracy. However, the reliable and accurate method for chlorophyll measurement is required. This is due to, although, the SPAD values estimation models archived very high R^2 (more than 80%), but the models are included to many wavebands to explain the SPAD values. In addition, some of selected bands are unknown to any particular chemical absorption features.

5. Conclusion

In this research, we demonstrated the potential of applying spectral transformation methods to laboratory and canopy spectra to estimate mangrove foliar biochemical (nitrogen and chlorophyll) concentration. The main objectives of this study were to explore possible relations between spectral transformations and foliar biochemical, to establish empirical predictive models of nitrogen concentration in leaves and canopy of the mangrove forest and to investigate the possible spatial influence on mangrove foliar nitrogen. The main conclusions are summarized below.

Foliar nitrogen concentration of Berau mangrove forest has very weak relationship with SPAD values.

The best empirical predictive models of nitrogen concentration in leaves and canopy can be archive by first-difference transformation method.

Leaves nitrogen concentration of the seaward side is higher than the landward side in Berau mangrove forest.

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