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Modelling the Above-Ground Biomass (AGB) of Eucalyptus Plantations using WorldView-2 Imagery in Sabah, Malaysia

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Abstract
Forest plantations are established not only to provide supply of demands, but also to help mitigate climate change. Satellite remote sensing can be used to estimate above ground biomass (AGB). This study was conducted in *Eucalyptus* plantations in Sabah, Malaysia. Satellite images from WorldView-2 were acquired as primary data. Allometric functions were used to calculate the AGB. The individual bands and vegetation indices were used as predictor variables. From the analysis, the 'best' predictive model for AGB was . The predictive model recorded an I^2=0.71, RMSE=0.44 tha^{-1} and p=0.001. The predicted AGB ranged from 4 to 225 tha^{-1}.

Keywords: Forest plantations; Above ground biomass (AGB); *Eucalyptus grandis; Eucalytus pellita*; predictive models; WorldView-2.

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1.0 Introduction

For many nations, forestry is crucial to the growth of their economies. Peninsular Malaysia's timber supply first showed signs of decline before becoming stable in 2010 at about 19.7 million m3 annually (MTC, 2012). This number clearly illustrates the lack of raw timber that the wood-based industry faces, and it may be necessary to address this deficit by establishing new forest plantations or using non-wood forest products made from sustainably harvested woody material. Due to consistent worldwide demand, Malaysia's timber exports for 2017 exceeded RM21.4 billion (Ching, 2018). In order to provide accurate information to predict the amount of timber to be collected from Eucalyptus plantations, this study on above-ground biomass (AGB) would be feasible and practicable.

AGB is defined as the above ground weight of solid wood and bark in living trees 1.0-inch DBH or larger from the ground to the tip of the trees, excluding all foliage. Consequently, biomass is defined as the total amount of above ground living organic matter in trees expressed as oven-dry tons per unit area (tree, hectare, region, or country) (Parresol, 2002). It is referred to as biomass density when expressed as mass per unit area. In Malaysia, there is inadequacy of reliable information and tabulation of data regarding the stand AGB for Eucalyptus plantations with almost no studies conducted (Whittinghill *et al*., 2013). Conventional inventory based on ground survey often incurred high cost, labour intensive, difficult and time consuming over larger areas.

Recently, a new generation of imagery acquired at high resolution, such as WorldView-2, opens a new era for environmental monitoring. Thus, the application of remotely sensed data for estimating forest AGB has widely explored (Hall *et. al*., 2006; Mäkelä & Pekkarinen, 2004; Mohammadi *et al*., 2011). Therefore, this work was conducted to study the relationships between spectral radiance and indices derived from WorldView-2 and AGB of Eucalyptus in Sabah, Malaysia and to establish predictive models for estimating AGB of Eucalyptus plantations using WorldView-2 imagery in the study area. This may be a useful function that will benefit many related

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parties that share the same interest to forecast and plan for forest plantation management. In addition, it provides sufficient information to indicate forest plantation sustainability and the availability of natural resources over time.

2.0 Materials and Method

2.1 Study area and field measurement

The study was conducted in forest plantations managed and owned by Sabah Forest Industries (SFI) in Sipitang, Sabah (Fig. 1). Sabah is a state in east Malaysia on the Borneo Island whereas Sipitang is located at the interior division in the southwest of Sabah. Sipitang is a parliamentary constituency with spans area of approximately 273,249.69 ha. In addition, it is located at the southwest of Sabah between latitude 4°7' and 5°10' North and between longitude 115°25' and 115°37' East. The elevation is at 45 to 1200 meter above sea level with average rainfall of 3584 mm. During monsoon, it frequently receives floods. This might be due to the geographical factors which surrounded with small hills and near to the coastal area. This topography has also influenced the rainfall distribution and temperature of the local area. Besides that, there are four main rivers crossing along the coastline of the district. There were four study areas selected for this study namely Sipitang, Mendulong, Ketanon and Basio.

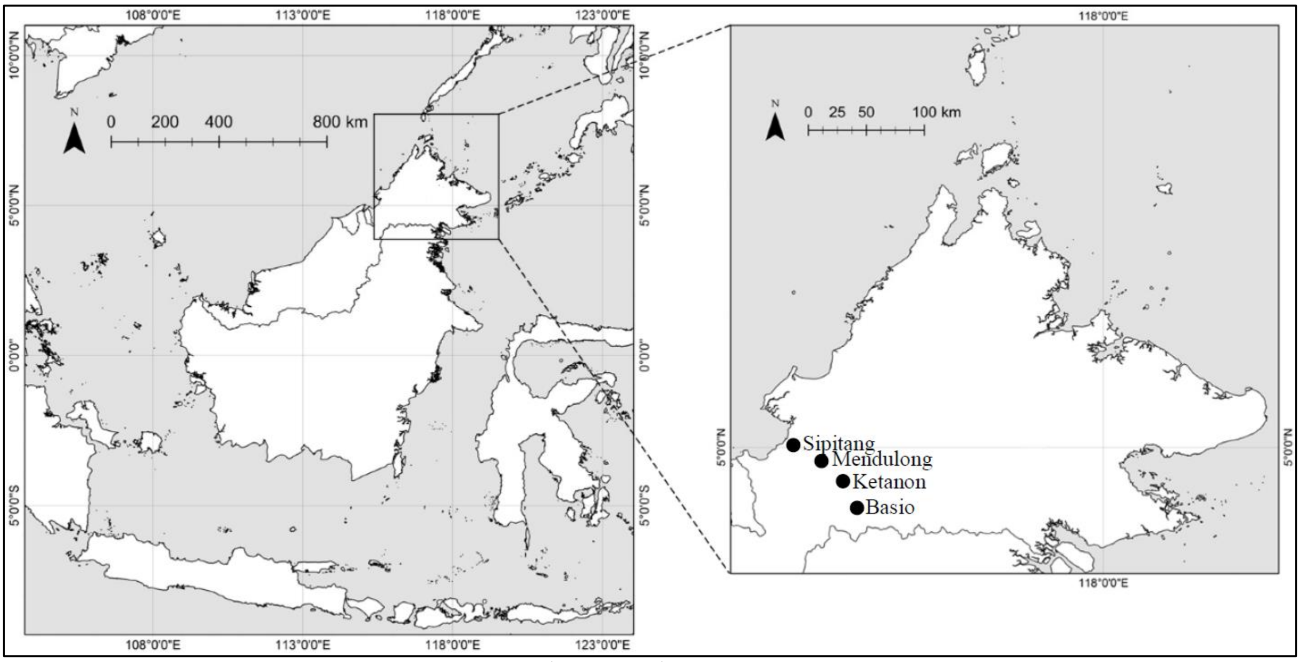

Fig. 1: Location of the study area

Data from field plots were collected from various age groups during March to April 2016 from a total of 65 plots. Each quadrat plot was 30 m × 30 m in size and were established based on random start using random number table. Age groups of plantations were 2 and 3 years for *E. pellita* and 4, 5, 6, 7 and 8 years for *E. grandis*. Data on plantations age were obtained from SFI management.

Within each plot, diameter at breast height (DBH in cm), total height (m), crown width (cm) and crown closure (%) were recorded. The DBH – 1.3 m from the ground level of all sampled trees was measured using DBH tape. Total tree height was measured using a hypsometer. The global positioning system (GPS) readings were taken at the corners of each plots using a GPS receiver and were recorded. The plot that represents 65 sampled stands were split using random method into two independent groups, with 42 stands for building the models, and the remaining 23 stands for validation of the model. Table 1 presents descriptive statistics of the data set used for model building and validation.

Table 1: Descriptive statistics of data set used for model building and validation

Variables	Model-building data set					Validation data set				
	No. of stands	Mean	SD[a]	Min.[b]	Max.[c]	No. of stands	Mean	SD	Min.	Max.
AGB (t/ha)	42	53.22	44.73	1.02	142.35	23	46.36	36.50	7.85	135.48
Volume (m^3/ha)	42	0.89	0.81	0.01	2.97	23	0.74	0.63	0.11	2.16
Carbon (tC/ha)	42	25.48	22.46	0.43	77.08	23	21.88	17.69	3.52	65.26
DBH (cm)	42	10.92	4.95	2.50	20.32	23	10.83	3.26	5.69	18.18

Height (m)	42	11.31	4.44	3.43	18.54	23	11.52	3.08	6.97	19.11
Crown width (cm)	42	333.75	77.10	131.77	501.33	23	352.78	46.46	234.19	410.44
Crown Closure (%)	42	70.94	4.83	60.61	82.89	23	74.76	4.72	66.53	82.73
Band 1	42	324.25	19.81	299.94	353.55	23	322.52	17.94	300.99	352.97
Band 2	42	192.65	23.08	168.71	234.36	23	186.70	14.95	169.57	214.30
Band 3	42	250.62	34.05	196.36	306.70	23	239.55	27.03	195.45	282.93
Band 4	42	226.22	54.95	158.31	324.84	23	208.49	31.099	162.91	275.99
Band 5	42	152.42	34.40	109.20	220.70	23	143.30	23.26	111.84	191.22
Band 6	42	512.65	81.99	348.29	645.00	23	536.46	57.77	408.25	639.12
Band 7	42	903.25	200.04	496.30	1184.35	23	968.93	121.737	699.55	1178.65
Band 8	42	820.11	190.05	454.30	1100.11	23	869.57	122.73	609.51	1019.41

2.2 Allometric function

Allometric equation is often the preferred method when predicting AGB of forest or plantation as it provides a non-destructive and indirect measurement of biomass. This method does not consume much time and inexpensive. In order to develop an allometric equation, the sites specific allometric equations on the local level need to provide more accurate biomass estimates for forest as it takes into account the side effects (Rahman et al., 2015; Tewari & Singh, 2006). According to Food and Agriculture Organization (FAO) (2014), the development and use of country, biome, climate and species-specific equations improves accuracy, minimizes error propagation and reduces bias arising from the generalizations produced by using a generic equation. In this study, the allometric equations for *Eucalyptus* AGB used for this study was based on Onrizal et al., (2020). The establish equation to calculate biomass is as follow;

$$AGB = 0.0678D^{2.5794} (R^2 98.8\%)$$

Where, AGB = above ground biomass,
D = DBH and
R^2 is coefficient of determination in the regression.

2.3 Image Acquisition and Pre-Processing

The primary data source was purchased from the AAM Group Pte. Ltd. for the WorldView-2 imagery. Five WorldView-2 images were acquired to cover the four study areas. The images used were selected near to the field data collection date to ensure the images are under similar phenological conditions.

The images received were in very good quality since the interference from the cloud noise was less than 5%. Mosaic process was applied for Sipitang area. As for reference maps to study area, topographic maps obtained from SFI management were used. Erdas Imagine along with ArcGIS software were used for pre-processing by geometrically correcting the scenes of satellite imagery acquired. The specifications of the WorldView-2 image used in this study are as shown in Table 2.

Table 2. The specification of the WorldView-2 image

Image Specification	Information
Satellite image	WorldView-2
Date of image acquisition	13th April 2016
Pixel resolution	Panchromatic: 0.5 m Multispectral: 1.84 m
Spectral bands Band: Spectral range (nm)	Panchromatic: 450-800 Coastal (Band 1): 400-450 Blue (Band 2): 450-510 Green (Band 3): 510-580 Yellow (Band 4): 585-625 Red (Band 5): 630-690 Red Edge (Band 6): 705-745 NIR1 (Band 7): 770-895 NIR2 (Band 8): 860-900
Coordinate system	UTM 50N

The optical images underwent varied pre-processing procedures which include pan sharpen, geometric correction, radiometric correction, image enhancement and data extraction. These processes were common procedures when it involves satellite imagery and necessary to ensure the data for subsequent analysis are reliable.

Raw images were firstly pan-sharpened between panchromatic image (single band) and multispectral image. Pan sharpening is a shorthand of ‘panchromatic sharpening’ which technically using a panchromatic imagery to refine a multispectral image in order to increase its spatial resolution. Often time, panchromatic image provides higher spatial resolution imagery than a multispectral imagery while a multispectral imagery consists of a higher degree of spectral resolution. The image produced after pan sharpening procedure is fusion of sensor between multispectral imagery and panchromatic imagery. It will produce the best combination of both imagery in one image resulting in higher spatial and spectral resolution.

By using ERDAS Imagine 9.1 satellite imagery software tools, Malaysia Rectified Skew Orthomophic (MRSO) projection system was applied to the images to geometrically corrected the imagery with root mean squared error (RMSE) of less than 0.5 pixels (Hexagon, 2018). The process was carried out to join the images and object from provided coordinate system into a specific map coordinate system and datum. The data was geometrically re-projected from WGS1984 to UTM50N coordinate system using the application of ArcGIS 10.1 software.

2.4 Above ground biomass modelling

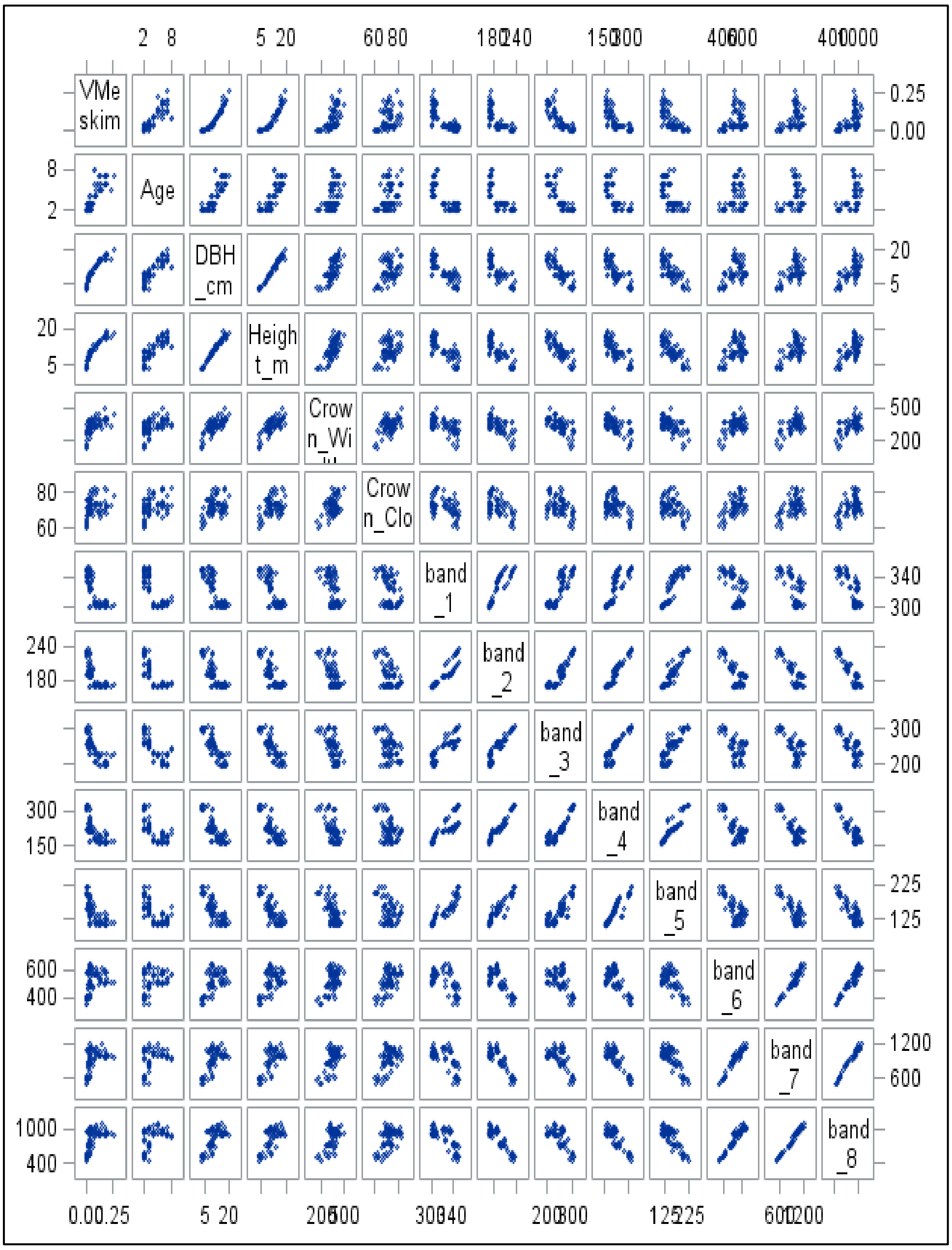

Fig. 2. Scatter plot matrix between AGB versus WorldView-2 variables for model building dataset (N=42 stands)

Analysis of basic relationship between ground parameters and WorldView-2 data is fundamental in modelling. Therefore, Pearson's correlation coefficient (r) and scatter plots were analysed using 'proc corr' command in SAS Software (SAS, 2018). A scatter diagram was used to show the values of two variables, X parameter and Y parameter (Fig. 2). Scatter plots of each of WorldView-2 bands (X) versus response variable (AGB) were useful to determine the behavioural nature, the trend and strength of the bivariate relationship that established between X and Y variables.

Modelling procedures to estimate AGB for the Eucalyptus plantation underwent multiple linear regression technique. The function of exponential was used, where

$$\widehat{AGB} = e^{-4.57+792.95\ (rb3)-0.21\ (RDVI)+14.06(WVVI)}$$

from transformation in order to achieve the best fit model as described in model building procedure. 'Good' model candidates were selected based on common practices in statistical regression for modelling. It includes data set performed from the analysis of usefulness of predictor variable in prediction. The predictor variables selection procedure such as forward selection, backward selection and stepwise regression was applied to produce best of fit combination of predictor variables. Statistics such as R^2, Adjusted R^2 (Adj R^2), Standard Error of Estimate (SEE) and significant level (α = 0.05) were used to determine the best model candidates. The value of R^2 and Adj R^2 should be comparable to each other which represent models' consistency in prediction.

Normality test was conducted to examine whether the trends of residuals were normally distributed using Shapiro-Wilk test and histogram to illustrate the residuals as well as P-P plots to show cumulative frequency of predicted value against cumulative frequency of residuals (Shapiro & Wilk, 1965). Any possible remaining trends were continuously diagnosed using the predicted versus residual plots. Set of tests were applied to the models to analyse the accuracy and root mean squared error (RMSE) was calculated using predicted value against actual value. The calculation on Mallow Cp (MCp) criterion was taken to make selection easier and practical. The model with small MCp values has a small total mean squared error (MSE). Hence, if the MCp value is close to the number of parameters or variables used in a model, it tells the bias represented in that model is minor.

3.0 Results and Discussion

3.1 AGB Estimation using allometric function

The mean AGB per ha from this study is 44.73 tonnes with the range of 1.02 to 142.35 tonnes per ha. The values were low most probably due to the ability of the allometric equation which did not cover the small DBH size collected in this study. In addition, the plantations were not well maintained, resulting in high mortality in the stands. Many trees were observed fall-off due to beetle attacks and strong wind in monsoon season. As comparison, a study in North Sumatera, Indonesia found out that average AGB class was 0-50 t/ha with 16.59 ha and smallest area has greater than 300 t/ha with 0.09 ha of Eucalyptus plantations (Latifah *et al.,* 2018). This indicates a comparative AGB of Eucalyptus plantation can be observed from both in Sabah, Malaysia and North Sumatera, Indonesia.

3.2 Relationship of Eucalyptus AGB with stand attributes and spectral reflectance

A correlation matrix table (Table 3) was generated to summarise the relationships establish that exist between stand attributes. Statistically strong and significant correlations among stand attributes were found, as can be expected.

Table 3. Correlation matrix between Eucalyptus stand attributes (N = 42 stands)

Stand Attributes	AGB (t/ha)	DBH (cm)	Height (m)	Crown Width (cm)	Crown Closure (%)
AGB (t/ha)	1.00				
DBH (cm)	0.96[a]	1.00			
Height (m)	0.94[a]	0.99[a]	1.00		
Crown Width (cm)	0.72[a]	0.80[a]	0.82[a]	1.00	
Crown Closure (%)	0.46[c]	0.55[b]	0.56[b]	0.64[a]	1.00

[a, b, c,] and [d] are significant at the <0.001, 0.001, 0.01 and 0.05 significance levels, respectively.

Particularly, there were significantly positive high correlation between AGB and DBH (r=0.96, p≤0.001). The relationship between AGB and height was also significantly strongly positive. Both DBH and height result in high correlation as it directly related to tree size. In addition, crown width increases as AGB, DBH, height and crown closure increased (r=0.72, 0.80, 082 and 0.64, respectively). However, a moderate correlation trends were shown between crown closure and AGB, DBH, height and crown width (r=0.46, 0.55, 0.56 and 0.64 respectively). Crown closure relationships were moderately correlated probably due to tree mortality and poor field maintenance by the plantation management. It could also due to the health condition of the trees which experienced defoliation.

Means of DBH and height were strongly inversely correlated with several of the WorldView-2 bands (bands 1 to 5) (Table 4).

Table 4. Correlation between stand attributes and WorldView-2 spectral bands (n=42 stands)

	DBH (cm)	Height (m)	Crown Width (cm)	Crown Closure (%)
Band 1	-0.88[a]	-0.86[a]	-0.67[a]	-0.43[c]
Band 2	-0.87[a]	-0.86[a]	-0.68[a]	-0.54[b]
Band 3	-0.88[a]	-0.88[a]	-0.66[a]	-0.50[b]
Band 4	-0.84[a]	-0.84[a]	-0.64[a]	-0.52[b]
Band 5	-0.85[a]	-0.85[a]	-0.67[a]	-0.48[b]
Band 6	0.57[a]	0.61[a]	0.59[a]	0.61[a]
Band 7	0.67[a]	0.70[a]	0.61[a]	0.59[a]
Band 8	0.73[a]	0.75[a]	0.64[a]	0.58[a]

, [b], [c], and [d] are significant at the <0.001, 0.001, 0.01 and 0.05 significance levels, respectively.

These indicated that as stand attributes increased the spectral reflectance decreased as reported in many findings in previous studies (Ahern *et. al*., 1991; Ripple *et. al*., 1991; Ardö, 1992; Gemmell, 1995; Suratman *et al*., 2004). However, they are consistently positive and highly correlated with bands 6, 7 and 8. The same trends were found in the relationship between crown width and crown closure, and WorldView-2 bands at a moderate strength of the correlation. The strongest correlation appeared between DBH and band 1, DBH and band 3, and height and band 3 at r = -0.88 (p<0.001). The lowest value of r was found in the correlation between crown closure and band 1 at r = -0.43 (p=0.01). Generally, significant relationships exist between stand attributes and WorldView-2 spectral bands that allow for further analysis for modelling.

AGB prediction models were developed using 'proc reg' commands in SAS and was tested with all modelling methods and procedures. There are six candidate models that were selected for comparison and all final candidate of regression models were statistically significant (p<0.000) (Table 5).

Table 5. Comparison of models fitted to AGB (n=42 stands)

Model	**Predictor Variable for LnAGB =**	***p***	**R^2**	**Adj R^2**	**M*Cp***	**SE_E**
1	rb3, MTVI2	2	0.82	0.81	0.80	0.60
2	rb3, SARVI	2	0.82	0.81	2.16	0.61
3	rb3,RDVI, WVVI	3	0.83	0.82	1.63	0.60
4	rb3 pMSAVI2, RDVI	3	0.83	0.82	1.61	0.60
5	rb3, rb6, RDVI, WVVI	4	0.84	0.82	2.35	0.60
6	rb2, rb3, MTVI2, RDVI	4	0.84	0.82	2.21	0.59

Notes: p is number of predictor variables in the model, Adj. R2 is adjusted R2, MCp is Mallow's Cp, SE_E is standard error of estimate, b1 is WorldView-2 band 1, b3 is WorldView-2 band 3, 4 is WorldView-2 band 4, b5 is WorldView-2 band 5, b6 is WorldView-2 band 6, b8 is WorldView-2 band 8, RDVI is Renormalized Difference Vegetation Index, WVVI is WorldView Vegetation Index, DVI is Brightness, SAVI is Soil Adjusted Vegetation Index and WVBI is WorldView Built-up Index

All models recorded VIF values below 10 to control multicollinearity and met the regression assumption in which the residuals were normally distributed and uncorrelated, variances between the variables were constant and the expected values of the variables were zero.

Table 6. Summary of regression model validation results for AGB (n=23 stands)

Model	**Predictor Variable for LnAGB =**	***p***	***I^2***	**RMSE**
1	rb3, MTVI2	2	0.74	0.44
2	rb3, SARVI	2	0.74	0.44
3	rb3, RDVI, WVVI	3	0.77	0.44
4	rb3 pMSAVI2, RDVI	3	0.76	0.44
5	Rb3, rb6, RDVI, WVVI	4	0.75	0.45
6	rb2, rb3, MTVI2, RDVI	4	0.77	0.44

Where, p is number of predictor variables, I^2 is Correlation Index Square, RMSE is Root Mean Squared Error, rbx is $(Band\ x)^{-1}$, DVI is Difference Vegetation Index, RDVI is Renormalized Difference Vegetation Index, SAVI is Soil Adjusted Vegetation Index, WVBI is WorldView Build-Up Index and WVVI is WorldView Improved Vegetation Index

Strong and good relationships were found between AGB and WorldView-2 imagery data. These could be explained from the R^2 values that ranged from 0.82 to 0.84 which indicate the prediction ability of the models are 82 to 84 % to estimate AGB of Eucalyptus plantation. In addition, the Adj R^2 values were ranged from 0.81 to 0.82 consistently near to R^2 value. Based on the criteria for selecting the 'best' model, model 3 was found to be the most promising for predicting AGB as compared to the other models. This is caused by the high R^2 = 0.83 and Adj R^2 = 0.82, as well as the MCp = 1.63 which is lower and near to the number of predictor variables, p=3. Despite model 5 and model 6 slightly higher in R^2=0.84, model 3 was chosen due to the simplicity of indices in terms of future model application. Many factors could play a direct influence that affecting the growth and health of Eucalyptus plantation. The factors might be due to planting age, type and quality of soils, topography, micro-climate, plantation management and natural environment. Some of these factors will then accumulate to affect the yield of logs production. A study of Eucalyptus AGB using Landsat TM data in Brazil obtained R^2 = 0.32 comparatively lower due to low resolution. The analysis results of the validation data set for estimating AGB of Eucalyptus are shown in Table 6.

Generally, there were very small differences in predictive performance among Models 1 – 6. The I^2 and RMSE values of these models ranged from 0.74 – 0.77 and 0.44, respectively. The I^2 statistic describes the percentage of variation across studies that were due to heterogeneity rather than chance (Higgins & Thompson, 2002; Higgins *et al*., 2003). Upon validation, model 3 maintained its high predictive ability by achieving a high I^2 value (0.77) and RMSE (0.44 t/ha). Therefore, model 3 is preferred over other models as it provides a good balance between practicality, predictive ability, and simplicity with a potential time-saving in computation. A study in North Sumatera Province, Indonesia by Latifah *et al*. (2018) was conducted to develop prediction model of Eucalyptus plantation using spatial analysis. The result shows a strong relationship was established between all attributes to produce high correlation of determination, R^2 = 0.90, for predicting AGB. The selected model was rerun using all data set of 65 stands to produce the final model.

4.0 Conclusion

The best predictive model for estimating AGB of Eucalyptus plantation is model 3, as follows;

$$\widehat{AGB} = e^{-4.57+792.95\,(rb3)-0.21\,(RDVI)+14.06(WVVI)}$$

The final predicted model as developed in this research contributes to application of statistical in forestry industries which merging dataset from field-ground measurements and extraction of satellite imagery dataset.

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Paper Contribution to Related Field of Study

This method is believed to provide convenient way to estimate Eucalyptus plantation and as a useful tool for any practitioners in the industries especially for making resource forecasting purposes. In addition, it has the potential to assist policymaker in planning and decision making for a better overview for future recommendation to extend the utilisation of Eucalyptus benefit. Finally, this might help in assessing indicators of sustainability and provides a platform for further research in the future.

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