ASM Sc. J., 14, Special Issue 1, 2021 for ICSTSS2018, 118-125

Modelling of Stand Volume of Eucalyptus Plantations using WorldView-2 Imagery in Sabah, Malaysia

Ahmad Farid Mohsin[1], Mohd Nazip Suratman[1,2*] and Shaikh Abdul Karim Yamani Zakaria[3]

[1]*Faculty of Applied Sciences, Universiti Teknologi MARA, Malaysia*

[2]*Institute for Biodiversity and Sustainable Development, Universiti Teknologi MARA, Malaysia*

[3]*Universiti Teknologi MARA Pahang, Bandar Tun Abdul Razak Jengka, Pahang, Malaysia*

Eucalyptus is one of forest plantation species established to provide sustainable timber supply for meeting market demands and mitigating climate change. However, managing an extensive area can be labour intensive and time consuming. Thus, remote sensing technology is utilised as it could provide estimates of forest parameters. Therefore, a study on the relationship between spectral radiance and indices derived from WorldView-2 imagery and stand volume of two Eucalyptus species in Sabah, Malaysia was conducted. From the study, predictive models for estimating stand volume of Eucalyptus plantations were developed. Field inventory and data analysis were conducted to provide ground data for *Eucalyptus grandis* and *E. pellita*. Randomly selected quadrat plots measuring at 30 m × 30 m were established. Within each plot, diameter at breast height (DBH in cm), total height (m), crown width (cm) and crown closure (%) were recorded. Satellite imageries from WorldView-2 were acquired as primary data. The spectral bands were extracted and several published indices were used as predictor variable candidates. Published allometric function developed for this species was used to estimate the stand volume. The best predictive model for estimating stand volume of Eucalyptus plantations was $\hat{v} = [-3.77 + 1435.76(rb1) + 355.98(rb3) - 484.26(rb6) - 6.64\,(pWVBI)]^2$ ($p \leq 0.05$, R^2=0.86). This analysis is expected to provide crucial insights into the ecosystem functions of forest plantations in sequestering carbon.

Keywords: biomass; forest plantation; modelling; WorldView-2

I. INTRODUCTION

Forestry is extremely important to the development of economies to many countries. In Peninsular Malaysia, the supply of timber showed a declining trend and eventually steady at around 19.7 million m^3 per year in 2010 (MTC, 2012). This number is a clear figure to represent that wood-based industry is fall short of raw timber and this shortage might require to be replaced with the sustainable resources from readably available woody material from other alternatives such as from the establishment of forest plantations or non-wood forest products. Nowadays, forest plantation enhances the creation of resources to meet demand for wood and wood product, development of a flexible resource able to produce variety of products for internal and external markets. Malaysia's timber exports for 2017 had exceeded RM21.4 billion as global demand remains stable (Ching, 2018). Rapid necessary actions are essential to confront the emerging challenges of the forest plantation industries. Therefore, this study on the stand volume would be practical and realistic to sufficiently supply information to the estimate timber stand volume to be harvested from Eucalyptus plantations.

Stand volume is the basic unit in data collection, management planning and forest operations (Mäkelä & Pekkarinen, 2004). It is also to enable formulation in monetary term to evaluate the value productions, asset and

*Corresponding author's e-mail: nazip@uitm.edu.my

services the forests could be yield to society (Edakunle *et al.*, 2013). In addition, stand volume is required as parameter to quantify estimation of ecosystem services such as carbon sequestration and biomass estimation. In Malaysia, there is inadequacy of reliable information and tabulation of data regarding the stand volume for Eucalyptus plantations with almost no studies have been conducted (Whittinghill *et al.*, 2013). Conventional inventory based on ground survey often incurred high cost, labour intensive, difficult and time consuming over larger areas especially for forest plantation.

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 stand volume has been 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 stand volume of Eucalyptus in Sabah, Malaysia and to establish predictive models for estimating stand volume of Eucalyptus plantations using WorldView-2 imagery in the study area. This predictive model may be a useful function that will benefit many related parties or individual that share the same interest of study to forecast and plan for forest plantation management. In addition, it provides sufficient information needed to indicate forest plantation sustainability and the availability of natural resources over time.

II. MATERIALS AND METHOD

A. Study Area and Field Measurements

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 south west of Sabah. It is a small township which also represents a district area. Sipitang is a parliamentary constituency with spans area of approximately 273,249.69 ha. In addition, it is located at the southwest portion 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 or raining season, it frequently receives flood. This might due to the geographical factors which are surrounded with small hills and located 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 namely, Padas, Lukutan, Mengalong and Sipitang rivers. There were four study areas selected for this study namely Sipitang, Mendulong, Ketanon and Basio.

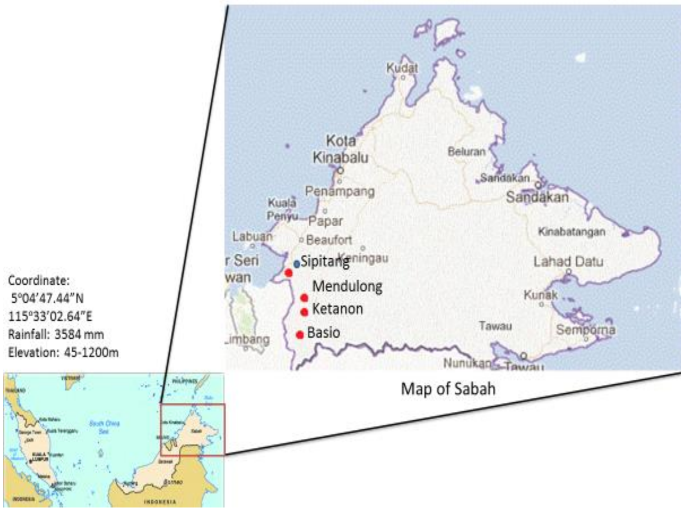

Figure 1. Location of the study area

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 the plots 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.
Volume (m^3/ha)	42	0.89	0.81	0.01	2.97	23	0.74	0.63	0.11	2.16
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

B. Allometric Function

Volume equation for *E. grandis* developed by Meskimen and Franklin (1978) was used for calculating the tree volume in this study. The stand volume was calculated based on the mean calculated from the plot volume. The calculated volumes were converted into metric units for further analysis.

$$V = D^2 + (0.001818H + 0.0136) \quad (1)$$

where, V = volume in cubic feet

D = diameter at breast height in inches (outside bark)

H = total height in feet

This equation interprets the tree as a cylinder from ground level to DBH and as a cone from DBH to tip (Meskimen & Franklin, 1978).

C. 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 specifications of the WorldView-2 image used in this study are as shown in Table 2.

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.

Table 2. The specifications of the WorldView-2 image

Satellite image	WorldView-2
Date of image acquisition	13th April 2016
Pixel resolution	Panchromatic: 0.5 m
	Multispectral: 1.84 m
Spectral bands	Panchromatic: 450-800
Band: Spectral range (nm)	B1 - Coastal : 400-450
	B2 - Blue : 450-510
	B3 - Green : 510-580
	B4 - Yellow : 585-625
	B5 - Red : 630-690
	B6 - Red Edge : 705-745
	B7 - NIR1 : 770-895
	B8 - NIR2 : 860-900

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 involve 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.

D. Stand Volume Modelling

Analysis of basic relationship between ground parameters and WorldView-2 data is fundamental in modelling steps. 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 (stand volume) were useful to determine the behavioural nature, the trend and strength of the bivariate relationship that were established between each of X and Y variables.

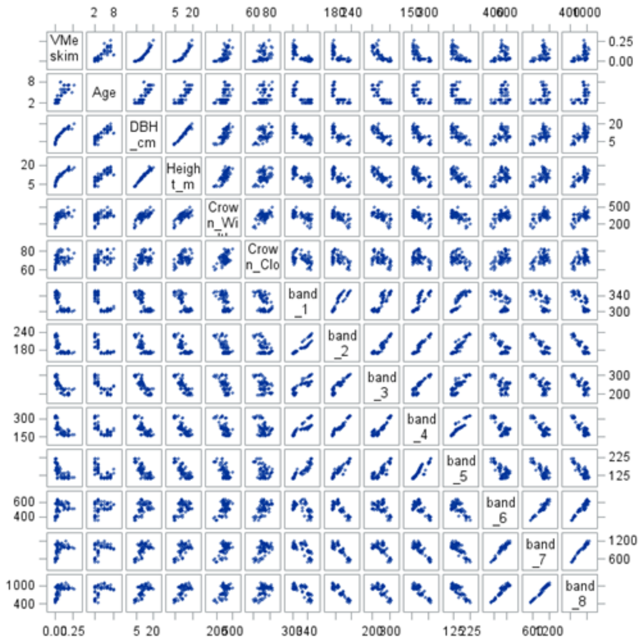

Figure 2. Scatter plot matrix between stand volume versus WorldView-2 variables for model building dataset (N=42 stands)

Modelling procedures to estimate stand volume for the Eucalyptus plantation underwent multiple linear regression technique. The function of $\sqrt{V}$ was used, where

$$\hat{v} = [-3.77 + 1435.76(rb1) + 355.98(rb3) - 484.26(rb6) - 6.64\,(pWVBI)]^2 \quad (p \leq 0.05, R^2=0.86)$$

as a result 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 analysis. 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 (SE_E) 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 test 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.

III. RESULTS AND DISCUSSION

A. Stand Volume Estimation using Allometric Function

The mean stand volume per ha from this study is 0.82 m^3 with the range of 0.01 to 2.97 m^3 per ha. The values were very 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 stand volume class was 0-50 m^3/ha with 16.59 ha and smallest area has greater than 300 m^3/ha with 0.09 ha of Eucalyptus plantations (Latifah *et al.,* 2018). This indicates a comparative stand volume of Eucalyptus plantation can be observed from both in Sabah, Malaysia and North Sumatera, Indonesia.

B. Relationship of Eucalyptus Stand Volume 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. Particularly, there were significantly positive high correlation between stand volume and DBH (r=0.92, p≤0.001). The relationship between stand volume 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, stand volume, carbon, DBH, height and crown closure increased (r=0.72, 0.60, 0.64, 0.80, 082 and 0.64, respectively). However, a moderate correlation trends were shown between crown closure and AGB, stand volume, carbon, DBH, height and crown width (r=0.46, 0.25, 0.25, 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.

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

Stand Attributes	Volume (m3/ha)	DBH (cm)	Height (m)	Crown Width (cm)	Crown Closure (%)
Volume (m^3/ha)	1.00				
DBH (cm)	0.94^a	1.00			
Height (m)	0.92^a	0.99^a	1.00		
Crown Width (cm)	0.68^a	0.80^a	0.82^a	1.00	
Crown Closure (%)	0.46^d	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.

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

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]

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

Stand volume 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). All models recorded VIF values below 10 to control multicollinearity. Apart from that, all models 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.

Strong and good relationships were found between stand volume and WorldView-2 imagery data. These could be explained from the R^2 values that ranged from 0.82 to 0.87 which indicate the prediction ability of the models are 82 to 87 % to estimate stand volume of Eucalyptus plantation. In addition, the Adj R^2 values were ranged from 0.81 to 0.85 consistently near to R^2 value. Based on the criteria for selecting the ‘best’ model, model 6 was found to be the most promising for predicting stand volume as compared to the other models. This is caused by the high $R^2 = 0.86$ and Adj $R^2 = 0.84$, as well as the MCp = 3.08 which is lower and near to the number of predictor variables, p=4. Despite model 5 and model 6 share the same number of predictor variables, p=4, model 6 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 due to planting age, type and quality of soils, variation of genetic, topography, micro-climate, plantation management ecosystem, and natural environment of the plantation. Some of these factors will then accumulate to affect the yield of logs production from the plantation. A study of Eucalyptus volume stand using Landsat TM data in Brazil obtained $R^2 = 0.32$ comparatively lower due to low resolution of spectral imagery.

The analysis results of the validation data set for estimating stand volume 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 0.71 – 0.76 and 0.18, 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 6 maintained its high predictive ability by achieving a high I^2 value (0.75) and RMSE (0.18 m^3/ha). Therefore, model 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 stand volume.

The selected model was rerun using all data set of 65 stands to produce the final model.

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

Model	Predictor Variable for $\sqrt{V}$	p	R^2	Adj R^2	MCp	SE_E
1	rb1, rb3	2	0.84	0.83	5.07	0.19
2	rb3, rb5	2	0.82	0.81	9.50	0.20
3	rb1, rb3, rb4	3	0.84	0.82	6.88	0.19
4	rb3, RDVI, WVVI	3	0.85	0.83	4.32	0.19
5	rb3, rb8, lnDVI, SAVI	4	0.87	0.85	1.72	0.18
6	rb1, rb3, rb6, pWVBI	4	0.86	0.84	3.08	0.18

Where, p=number of predictor variables, R^2=Coefficient of determination, Adj R^2=adjusted R^2, MCp=Mallow's Cp, SE_E=Standard Error of Estimate, Rbx = (Band x)$^{-1}$, DVI=Difference Vegetation Index, RDVI=Renormalized Difference Vegetation Index, SAVI=Soil Adjusted Vegetation Index, WVBI=WorldView Build-Up Index and WVVI=WorldView Improved Vegetation Index

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

Model	Predictor Variable for $\sqrt{V}$	p	I^2	RMSE
1	rb1, rb3	2	0.74	0.18
2	rb3, rb5	2	0.74	0.18
3	Rb1, rb3, rb4	3	0.71	0.18
4	rb3, RDVI, WVVI	3	0.75	0.18
5	rb3, rb8, lnDVI, SAVI	4	0.76	0.18
6	rb1, rb3, rb6, pWVBI	4	0.75	0.18

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

IV. CONCLUSION

The best predictive model for estimating stand volume of Eucalyptus plantation is model 6, as follows;

$$\hat{v} = [-3.77 + 1435.76(rb1) + 355.98\,(rb3) - 484.26\,(rb6) - 6.64(pWVBI)]^2 \quad (p \leq 0.05,\ R^2=0.86) \qquad (2)$$

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. 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.

V. ACKNOWLEDGEMENT

The authors would like to express their deepest gratitude to Ministry of Education, Malaysia for providing research grants through the Fundamental Research Grant Scheme (FRGS) (600-RMI/FRGS 5/3 (38/2014)), Universiti Teknologi MARA (UiTM) and Sabah Forest Industries (SFI) for providing logistic related services and field data collection.

VI. REFERENCES

Ahern, J, Erdle, T, Maclean, DA & Kneppeck, ID 1991, 'A quantitative relationship between forest growth rates and Thematic Mapper reflectance measurements', International Journal of Remote Sensing, vol. 13, no. 2, pp. 387 – 400.

Ardö, J 1992, 'Volume quantification of coniferous forest compartments using spectral radiance recorded by Landsat Thematic Mapper', International Journal of Remote Sensing, vol. 13, no. 9, pp. 779–786.

Ching, OT 2018, Malaysia's 2017 timber exports to surpass RM23b, New Straits Time, viewed 25 September 2018, <https://www.nst.com.my/business/2018/01/327221/ malaysias-2017-timber-exports-surpass-rm23b>.

Edekunle, VAJ, Nair, KN, Srivastana, AK & Singh, NK 2013, 'Models and form factors for stand volume estimation in natural forest ecosystems: a case study of Katarniaghat Wildife Sanctuary (KGWS), Bahraich District, India', Journal of Forestry Research, vol. 24, no. 2, pp. 217–226.

Gemmell, FM 1995, 'Effects of forest cover, terrain and scale on timber volume estimation with Thematic Mapper data in a rocky mountain site', Remote Sensing of Environment, vol. 51, pp. 291–305.

Hall, RJ, Shakun, RS, Arsenault, EJ & Case, BS 2006, 'Modelling forest stand structure attributes using Landsat 7 ETM+ data: application to mapping of aboveground biomass and stand volume', Forest Ecology and Management, vol. 225, pp. 378 – 390.

Hexagon Geospatial Inc. 2018, Erdas Imagine 2018 USA.

Higgins, JPT & Thompson, SG 2002, 'Quantifying heterogeneity in a meta-analysis', Statistics in Medicine, vol. 21, pp. 1539-1558.

Higgins, JPT, Thompson, SG, Deeks, JJ & Altman, DG 2003, 'Measuring inconsistency in meta-analyses', British Medical Journal, vol. 327, pp. 557-560.

Latifah, S, Teodoro, RV, Myrna, GC, Nathaniel, CB & Leonardo MF 2018, 'Predicted stand volume for Eucalyptus plantations by spatial analysis', in IOP Conf. Ser.: Earth Environ. Sci. 126 012117. doi: 10.1088/1755-1315/126/1/012117.

Mäkelä, HA & Pekkarinen, A 2004, 'Estimation of forest stand volumes by Landsat TM imagery and stand-level field-inventory data', Forest Ecology and Management, pp. 245 – 255.

Malaysian Timber Council (MTC) (2012) Malaysia: Forestry & Environment (Facts & Figures), Report from Malaysian Timber Council, September, pp. 28.

Meskimen, G & Franklin, EC 1978, 'Spacing Eucalyptus grandis in southern Florida a question of merchantable versus total volume', Southern J. of Applied Forestry, vol. 2, no. 1, pp. 3-5.

Mohammadi, J, Shataee S & Babanezhad, M 2011, 'Estimation of forest stand volume, tree density and biodiversity using Landsat ETM+ data, comparison of linear and regression tree analyses', Procedia Environmental Sciences, pp. 299 – 304.

Ripple, WJ, Wand, S, Isaacson, DL & Paine DP 1991, 'A preliminary comparison of Landsat TM and SPOT-1 HRV multispectral data for estimating coniferous forest volume', International Journal of Remote Sensing, vol. 12, no. 9, pp. 1971 – 1977.

SAS Institute Inc. (2018), SAS 9.4. Cary, NC, USA.

Shapiro, S & Wilk, MB 1965, 'An analysis of variance test for normality (complete sample)', Biometrika, vol. 52, no. 591–611.

Suratman, MN, Bull, GQ, Leckie, DG, Lemay, VM, Marshall, PL & Mispan, MR 2004, 'Prediction models for estimating the area, volume, and age of rubber (Hevea brasiliensis) plantations in Malaysia using Landsat TM data', International Foresty Review, vol. 6, no. 1, pp. 1–12.

Whittinghill, LJ, Rowe, DB & Cregg, BM 2013, 'Evaluation of vegetable production on extensive green roofs', Agroecology and Sustainable Food Systems, vol. 37, no. 4, pp. 465-484. doi: 10.1080/21683565.2012.756847.