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ABOVEGROUND BIOMASS AND CARBON STOCK ESTIMATION USING DOUBLE SAMPLING APPROACH AND REMOTELY-SENSED DATA

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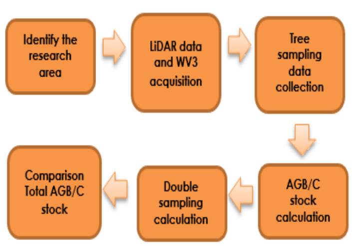
Nurul Ain Mohd Zaki[a], Zulkiflee Abd Latif[a*], Mohd Zainee Zainal[b]

[a]Applied Remote Sensing & Geospatial Research Group (ARSG), Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture ,Planning and Surveying, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[b]Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture ,Planning and Surveying, Universiti Teknologi MARA, 02600 Arau, Perlis , Malaysia

*Corresponding author
zulki721@salam.uitm.edu.my

Graphical abstract



Abstract

Tropical forest embraces a large stock of carbon and contributes to the enormous amount of aboveground biomass (AGB) in the global carbon cycle. In order to quantify the carbon inventory, field data is vital for accurately determining the forest parameter such as diameter at the breast height (DBH), height of the tree (h) ,crown diameter (CD) and tree species. The merging of the multi-sensory remote sensing which is LiDAR (Light Detection and Ranging) and very high resolution satellite imagery can reduce the labor intensive of field sampling for a large area of carbon inventory data. Double sampling approach which is combination of the field sampling plot measurement with ancillary remote sensing data used to improve the precision of AGB estimation compared by using field data alone. Hence, this study aims: (1) to describe the use of field data plots in a statistical way, and (2) to determine the potential of LiDAR data in a double sampling forest aboveground biomass and carbon stock inventories and (3) to compare the used of field data plot itself or combination with LiDAR data to quantify the aboveground biomass and carbon stock for upcoming inventories.

Keywords: Tropical Rain Forest, Double sampling approach, LiDAR, Aboveground Biomass, Carbon

1.0 INTRODUCTION

The most directly impacted by deforestation and degradation and the largest pool are the carbon that kept in the above-ground biomass of the living trees [1]. One third of the Earth's land surface consist of forest and continues serving in the carbon sequester and carbon sink for the living things on the earth surface. International organization that responsible to assess the climate change, Intergovernmental Panel on Climate Change (IPCC) conveyed the importance of determining the model for carbon stocks [2]. Hence, numerous studies had been done by researcher, to find the best way to quantify the aboveground biomass and carbon stocks from plot scale to regional scale up to global scale from all over the world [1]–[5].

Aboveground biomass (AGB)can be quantified by the use of allometric equation that had been develop from field inventory data [4],[6]. Undeniable, field based inventory is remain vital in the carbon stock estimation for forest structure[7]. However, this can be enhanced by the use of remote sensing technology where it could reduce the intensive field based sampling especially for larger forested area. Wide range of active and passive remote sensing technology that had been investigated by previous researchers [8]–[14] can provide many advantages for quantifying forest structure, monitoring and mapping of aboveground biomass.

1.1 Double Sampling Approach and Remote Sensing

Double sampling approach for aboveground biomass and carbon estimation had been applied by previous researcher [15] that investigate the relationship between ground based estimation with Light Detection and Ranging (LiDAR) data and found out that there is a strong relationship between carbon and LiDAR with the ground based data with the used of double sampling approach. Over the past few decades, the use of LiDAR had raised an interest among researchers in forestry and ecosystem studies [8], [16]–[18]. Given the strong relationships between carbon and LiDAR metrics, there is excellent scope for using LiDAR in conjunction with ground-based field measurements to provide improved inventory estimates of carbon using a double sampling approach.

Double sampling methods relating to carbon stocks assume that the population mean and total of auxiliary variables are known [19]. This approach need auxiliary variables , xi (LiDAR metrics)in phase 1,while y(carbon stock in ground plot) observe in Phase 2 [15].

$$\hat{T} = r\hat{T}_x\text{..........(1)}$$

$$r = \sum_{i=1}^{n} yi / \sum_{i=1}^{n} xi\text{.........(2)}$$

$$\hat{T}x = \frac{N}{n'}\sum_{i=1}^{n'} xi\text{........(3)}$$

Where;
y_i = carbon stocks for i plot
xi= means of *j*th LiDAR metric(auxiliary variable)
xj'= means of *j*th LiDAR metric(n sub sample)
n'=number of units in first sample(which include second sample)
n=no of units in second sample

1.2 Allometric Equation Calculation

There are a lot of equation that available that had been develop by previous researcher for tropical rainforest carbon estimation. Based on Table 1, summarize the allometric equation for aboveground biomass and carbon stocks estimation for the tropical rain forest where some of the equation used height, DBH as a predictor [4], [20], diameter only [6], [21], wood density specific [4], [6] and the most recent, using bioclimatic data for each place denotes as E [4]. By means of the value AGB that had been calculated from equation, the carbon stock of single tree were calculated by equation (2) using conversion factor 0.47 as suggested by IPCC, which represent 47% of dry of all biomass of the tree by default value [22].

Total Carbon Stock (MgCha^{-1}) = Total AGB x 0.47…...(4)

Table 1 Allometric Equation used for AGB/C calculation

Type of forest	Equation	Reference
MF	$AGB_{est} = \exp(-2.977 + In\,(\rho DBH^2\,H))$	[20]
MS	$\text{AGB} = \exp\,((\,2.59\ln\,(DBH)) - 2.75)$	[23]
TLDF	$AGB_{est} = 0.0829\ \times DBH^{2.43}$	[21]
TLDF	$In(AGB) = 2.196 \times In(DBH) - 1.201$	[6]
TRF	$AGB_{est} = \exp[-1.803 - 0.976E + 0.976In(\rho) + 2.673In(DBH) - 0.0299[In(D)]^2\,]$	[4]
TLDF	$1/M\_(I\ ) = 1/(0.124\,M\_S\text{^}0.794\ ) + 1/125$ $M_s = 0.0313 \times (DBH^2H)^{0.9733}$ $M_b = 0.136 \times M_S^{1.070}$ AGB_{est}: Ms + Mb + MI	[24]

(MF = Moist forest, MS = Mixed species, TLDF=Tropical lowland Dipterocarp Forest, TRF =Tropical rainforest, DBH =Diameter at breast height, H=height, AGB_{est} =Aboveground biomass estimation).

Nevertheless, according to [25] tropical rainforest hold the most extensive forest in the world with the vast diversity of tree diversity with layered canopies structure. This would give a challenging to estimate the aboveground biomass and carbon stock. With the advancement of remote sensing and geospatial technology, estimation of aboveground biomass can provide spatial, radiometric, temporal, and also quantitative measurement [26]–[28]. However, the appropriate method should be refined, to estimate the above ground biomass using a remote sensing integration with the field measurement.

This paper will present the performance of double sampling approach which is combination of field-plot inventory data and LiDAR data estimation for tropical lowland *Dipterocarp* forest of Ayer Hitam Forest Reserve, Selangor, Malaysia. The main aim of this investigation is to obtain the relationship between biophysical parameter field plots inventories data .In order to achieve this goal, hereby the objectives that will be fulfill:

(a) To calculate the field data plots in a statistical way using allometric equations,
(b) To determine the potential of LiDAR data in double sampling forest aboveground biomass and carbon stock inventories by linear regression technique,
(c) To compare the use of field data plot and combination with LiDAR data to quantify the aboveground biomass and carbon stock.

2.0 EXPERIMENTAL DESIGN

Based on Figure 1 below, the research methodology begins with identification of potential study area for data collection. Then, LiDAR and WorldView3 data was acquired at the study area. Next, tree sampling acquisition had done for the study area. After that, calculation of aboveground biomass and carbon stocks and double sampling regression will be done and output the comparison between both method.

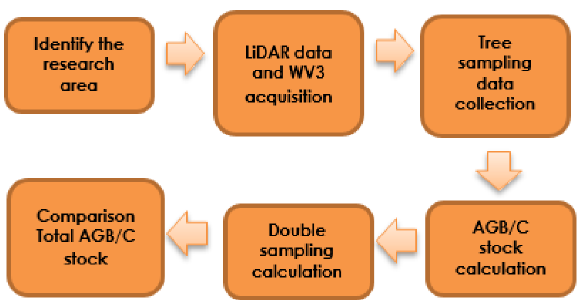


Figure 1 Block diagram of the processes of the system

2.1 Study Area

The study area is located at Latitude 3°00'24.19"N, Longitude 101°38'25.24"E in the Ayer Hitam Forest Reserve, Selangor State, Malaysia. This secondary forest comprises of various species that dominant by family tree from *Dipterocarpacaea*. Some of the species available in this study area are listed as Critically Endangered (CR) species, for an example, *Hopea Sulcata* (Merawan meranti) [29].

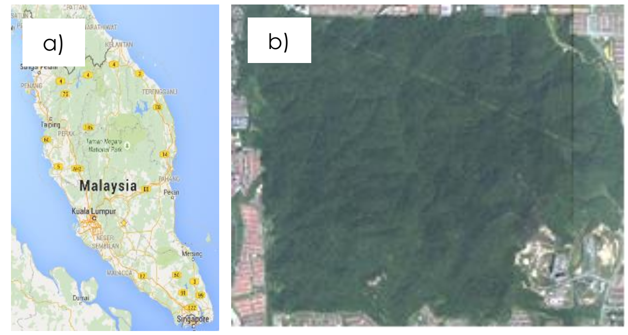


Figure 2 A map of the location of the study area. a) Shows the location of Selangor District, at Peninsular Malaysia, b) shows a location of Ayer Hitam Forest Reserve Lowland Dipterocarp forest covered by the WorldView-3 satellite image data

2.2 Remotely-sensed Data

WorldView-3 imagery (0.3m. spatial resolution) used as a base map of the study area was acquired on 9th December 2014. Figure 2b shows the whole Ayer Hitam Forest Reserve covering by WorldView-3, eight bands multispectral imagery.

The LiDAR data was acquired using a Eurocopter 120 on August 2013. The LiteMapper-Q560 that consists of RIEGL LMS-Q560 laser scanner for LiDAR scanner was mounted in the aircraft, along with the Hassleblad digital camera.

2.3 Tree Sampling Data Collection

The sampling design that had been adopted was using stratified random sampling. Rectangular plot of 2ha consist of 50 subplots (20 m x 20 m) had been collected on May 2015. The dendrometric data collection which is total height, bole height, crown diameter, diameter at breast height (DBH) 1.3 m height and species had been made. The height are measured using DISTO D5 laser ranger while the DBH (1.3 m above ground height) was measured using a DBH tape. During field data collection, a base station of GPS (Global positioning system) observation was established at the open space to get enough satellite to provide the good differential to the study area. Then, from the base station, supplementary point were establish to the subplot area by traversing using total station. Each of the GPS observation was observed about 4 hours to reach mm. accuracy.

3.0 RESULTS AND DISCUSSION

3.1 Aboveground Biomass and Carbon Estimation Based on Field Data

Appropriate equation to estimate the AGB needs to be chosen properly according to the site suitability and characteristic. Undeniably, the most accurate method to estimate the AGB is by using destructive sampling[6]. Nevertheless, applying the allometric equations is the typical methods to estimate the AGB since it allow massive estimation of AGB without destruct the forest.

According to [30], using the generic model shown that higher performance compared to local allometric model. Based on the output calculation shown by Figure 3 using six different type of equation, [21] show the highest coefficient of determination, R^2 which is 0.9981 followed by [6] = 0.9997, [24] = 0.9766, [23] = 0.9958, [20] = 0.924 and finally [4] = 0.924. Previous research by [4], using allometric equations stratified by bioclimatic zones improve the precision of AGB estimation subsequently be likely to be establish on broader series of DBH and height. [4], [20].

However, the allometric equation develop by [21] shown the most highest result, supported by the finding by [31] shown that this equation most affect the dependent variable compared to other equations.

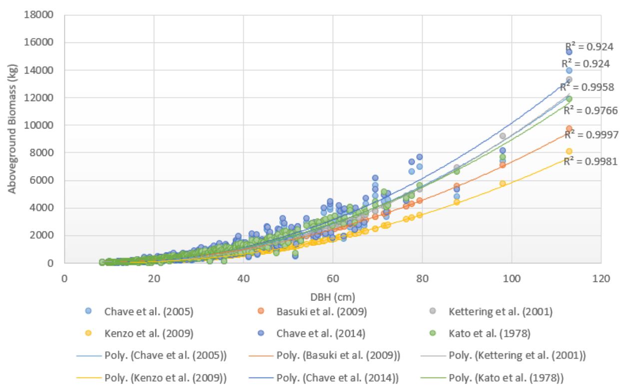


Figure 3 Aboveground biomass using six different equations

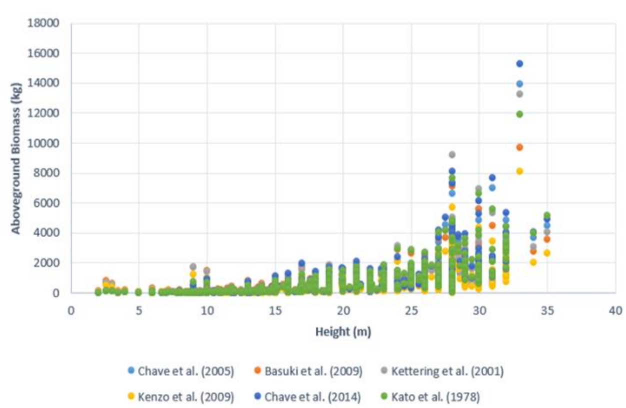


Figure 4 Aboveground biomass against height from the field

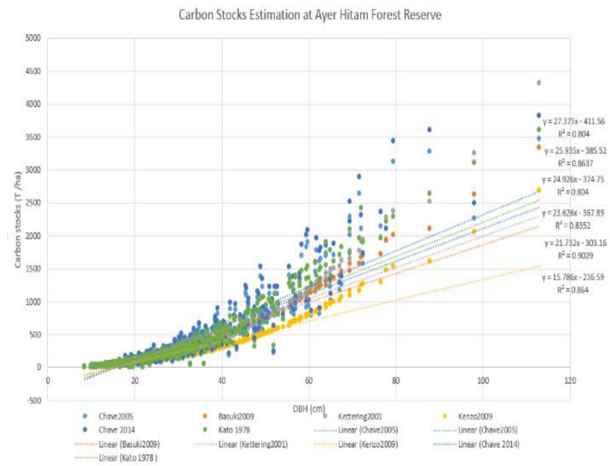


Figure 5 Carbon stocks regression equation based on field sampling

Figure 4 shows the dependent variable of height against AGB showing that the taller the height of the tree, the higher AGB estimation. Based on the Figure 5, the carbon stocks estimation were calculate using equation [4], [6], [20], [21], [23], [24] and was converted to carbon stocks estimation using conversion factor equation (4).

3.2 Aboveground Biomass Estimation Based on Double Sampling Ratio Estimation

Ground based estimates and ratio estimate of carbon stocks using equation (1)-(3) are shown in Table 2 while the ratio estimation of AGB/C stock is shown in Table 3.

Table 2 Calculation of mean and standard deviation

Variable	n	Mean	s.e	Sum
x'_i	911	21.216	6.876	19348.94
x_i	245	20.695	5.149	5070.38
y	245	20.210	5.167	15418.9

(s.e = Standard error, n = number of sample)

Table 3 Ratio estimation of AGB/C stock

Item	Ground Based estimate		Regression estimate		Ratio of regression to ground based estimate
	Mean	s.e	Mean	s.e	
AGB	20.210	5.166	20.695	5.149	0.976

(s.e = Standard error, AGB = Aboveground biomass)

3.2 Tree Height

A total of 245 tree heights were measured during field data collection and also height corresponding from

LiDAR dataset. Based on the Figure 6, R^2 showed the high value, which is 0.988 where about 98% predicted compared to the actual value. Based on T-test, there was no significance difference between heights measured from field compared to estimate from LiDAR dataset. T-test of tree height from field and LiDAR is shown in Table 4

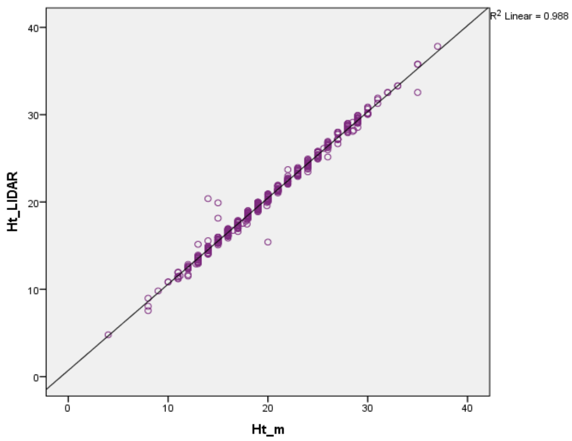


Figure 6 LiDAR tree height (Ht_LIDAR) against field tree height (Ht_m)

Table 4 T-test of tree height from field and LiDAR

Test	df	Test stat	P Value	Correlation
T-Test	488	-1.041	0.918	0.991

There is no significantly different (p>0.05) between height measured from field and height derived from LiDAR. However, there is a strong correlation between height measured from field and derived from LiDAR.

4.0 CONCLUSION

Based on the findings, there is a potential of using airborne LiDAR to improve the aboveground biomass and carbon stocks estimation for the lowland Dipterocarp forest. However, measuring height by using airborne LiDAR is very difficult especially for dense area of tropical forest. The obstacle lies in capturing intermingle tree shadowed by lower canopy layers. In order to improve the estimation of the aboveground biomass and carbon stocks using double phase sampling method, the regression of mean height of the LiDAR would be the further research as it would provide a low cost stratification estimation using LiDAR data for a larger area of forest.

A good relationship between LiDAR metrics and field sampling data would become an excellent scope for using LiDAR in conjunction with ground sampling to improve the inventory estimates of carbon using double sampling approach.

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References

[1] Clark, M. L., Roberts, D. a., Ewel, J. J., and Clark, D. B. Estimation Of Tropical Rain Forest Aboveground Biomass With Small-Footprint Lidar And Hyperspectral Sensors. *Remote Sens. Environ.* 115(11): 2931-2942.

[2] Asner, G. P. and Mascaro, J. 2014. Mapping Tropical Forest Carbon: Calibrating Plot Estimates To A Simple Lidar Metric. *Remote Sens. Environ.* 140: 614-624.

[3] Fayolle, A., Doucet, J.-L., Gillet, J.-F., Bourland, N. and Lejeune, P. 2013. Tree allometry in Central Africa: Testing The Validity Of Pantropical Multi-Species Allometric Equations For Estimating Biomass And Carbon Stocks. *For. Ecol. Manage.* 305: 29-37.

[4] Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. Duque, A., Eid,T., Fearnside, P., Goodman, M. R. C., Henry, M., Martínez-Yrízar, A., Mugasha, W. a, Muller-Landau, H. C., Mencuccini, M., Nelson, B. W., Ngomanda, A., Nogueira, E. M., Ortiz-Malavassi, E., Pélissier, R., Ploton, P., Ryan,C. M., Saldarriaga, J. G., and Vieilledent, G. 2014. Improved Allometric Models To Estimate The Aboveground Biomass Of Tropical Trees. *Glob. Chang. Biol.*

[5] Baccini, A. and Asner, G. P. 2013. Improving Pantropical Forest Carbon Maps With Airborne Lidar Sampling. *Carbon Manag.* 4(6): 591-600.

[6] Basuki, T. M., van Laake, P. E., Skidmore, A. K. and Hussin, Y. a., 2009. Allometric Equations For Estimating The Above-Ground Biomass In Tropical Lowland Dipterocarp Forests. *For. Ecol. Manage.* 2578: 1684-1694.

[7] Malhi, Y., Aragão, L. E. O. C., Metcalfe, D. B., Paiva, R. Quesada, C. a., Almeida, S., Anderson, L., Brando, P., Chambers, J. Q., da COSTA A. C. L., Hutyra,L. R., Oliveira, P., Patiño, S., Pyle, E., Robertson, H. A. L. and Teixeira, L. M. 2009. Comprehensive Assessment Of Carbon Productivity, Allocation And Storage In Three Amazonian Forests. *Glob. Chang. Biol.* 15(5): 1255-1274.

[8] Gonzalez, P., Asner, G. P., Battles, J. J., Lefsky, M. a., Waring, K. M. and Palace, M. 2010. Forest Carbon Densities And Uncertainties From Lidar, Quickbird, And Field Measurements In California. *Remote Sens. Environ.* 114(7): 1561-1575.

[9] Carreiras, J. M. B., Vasconcelos, M. J. and Lucas, R. M. 2012. Understanding The Relationship Between Aboveground Biomass And ALOS PALSAR Data In The Forests Of Guinea-Bissau (West Africa). *Remote Sens. Environ.* 121: 426-442.

[10] Alves, L. F., Vieira, S. a., Scaranello, M. a., Camargo, P. B., Santos, F. a M., Joly, C. a. and Martinelli, L. a. 2010. Forest Structure And Live Aboveground Biomass Variation Along An Elevational Gradient Of Tropical Atlantic Moist Forest (Brazil). *For. Ecol. Manage.* 260(5): 679-691.

[11] Mohd Zaki, N. A., Abdul Latif, Z., Zainal, M. Z. and Zainuddin, K. 2015. Individual Tree Crown (ITC) Delineation Using Watershed Transformation Algorithm For Tropical Lowland Dipterocarp, *Proc. IEEE 2015*. 2: 237-242.

[12] Abd Latif, Z., Aman, S. N. A. and Ghazali, R. Delineation Of Tree Crown And Canopy Height Using Airborne Lidar And

Aerial Photo. *2011 IEEE 7th Int. Colloq. Signal Process. its Appl.* 2: 354-358.

[13] Latif, Z. A., Zamri, I. and Omar, H. 2012. Determination Of Tree Species Using Worldview-2 Data. *2012 IEEE 8th Int. Colloq. Signal Process. its Appl.* 383-387.

[14] Blackburn, G. A., Abd Latif, Z. and Boyd, D. S. 2014. Forest Disturbance And Regeneration: A Mosaic Of Discrete Gap Dynamics And Open Matrix Regimes? *J. Veg. Sci.* 25(6): 1341-1354.

[15] Stephens, P. R., Kimberley, M. O., Beets, P. N., Paul, T. S., Searles, H. N., Bell, A., Brack, C. and Broadley, J. 2012. Airborne scanning Lidar In A Double Sampling Forest Carbon Inventory. *Remote Sens. Environ.* 117: 348-357.

[16] Mascaro, J., Detto, M., Asner, G. P., and Muller-Landau, H. C. 2011. 2011. Evaluating Uncertainty In Mapping Forest Carbon With Airborne LiDAR. *Remote Sens. Environ.* 115(12): 3770-3774.

[17] Mitchard, E. T. a, Feldpausch, T. R., Brienen, R. J. W., Lopez-Gonzalez, G., Monteagudo, A., Baker, T. R. 2014. Markedly Divergent Estimates Of Amazon Forest Carbon Density From Ground Plots And Satellites. *Glob. Ecol. Biogeogr.* 23(8): 935-946.

[18] Saeidi, V., Pradhan, B., Idrees, M. O. and Abd Latif, Z. 2014. Fusion of Airborne LiDAR With Multispectral SPOT 5 Image for Enhancement of Feature Extraction Using Dempster-Shafer Theory, *Geosci. Remote Sensing, IEEE Trans.* 99:1-9.

[19] Fernow, B. E. 1906. *Forest Mensuration*. 24(624).

[20] Chave, J., Andalo, C., Brown, S., Cairns, M. a, Chambers, J., Eamus, Q. D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B. W., Ogawa, H., Puig, H., Riéra, B. and Yamakura, T. 2005. Tree Allometry And Improved Estimation Of Carbon Stocks And Balance In Tropical Forests. *Oecologia*. 145(1): 87-99.

[21] Kenzo, T., Furutani, R., and Hattori, D. 2009. Allometric Equations For Accurate Estimation Of Above-Ground Biomass In Logged-Over Tropical Rainforests In Sarawak, Malaysia. *J Res.* 14365-372: 365-372.

[22] IPCC. 2006. Guielines for National Greenhouse Gas Inventories Volume 4 Agriculture,Forestry and other Land Use. 4.

[23] Ketterings, Q. M., Coe, R., van Noordwijk, M., Ambagau, Y. and Palm, C. a. 2001. Reducing Uncertainty In The Use Of Allometric Biomass Equations For Predicting Above-Ground Tree Biomass In Mixed Secondary Forests. *For. Ecol. Manage.* 146(1-3): 199-209.

[24] Kato, R., Tadaki, Y., and Ogawa, H. 1978. Plant Biomass And Growth Increment Studies In Pasoh Forest. *Malayan Nature Journal*. 30(2): 211-224.

[25] Gitelson, A. a., Peng, Y., Arkebauer, T. J., and Schepers, J. 2014. Relationships Between Gross Primary Production, Green LAI, And Canopy Chlorophyll Content In Maize: Implications For Remote Sensing Of Primary Production. *Remote Sens. Environ.* 144: 65-72.

[26] Asner, G. P. and Mascaro, J. 2014. Remote Sensing of Environment Mapping tropical forest carbon : Calibrating plot estimates to a simple LiDAR metric. *Remote Sens. Environ.* 140: 614-624.

[27] Claverie, M., Demarez, V., Duchemin, B., Hagolle, O., Ducrot, D., Marais-Sicre, C., Dejoux, J.-F., Huc, M., Keravec P., Béziat, P., Fieuzal, R., Ceschia, E., and Dedieu, G. 2012. Maize And Sunflower Biomass Estimation In Southwest France Using High Spatial And Temporal Resolution Remote Sensing Data. *Remote Sens. Environ.* 124: 844-857.

[28] T. Ahamed, Tian, L., Zhang, Y. and Ting, K. C. 2011. A Review Of Remote Sensing Methods For Biomass Feedstock Production. *Biomass and Bioenergy*. 35(7): 2455-2469.

[29] IUCN. 2014. The IUCN Red List of Threatened Species., *Version 2014.2.*, 2014. [Online]. Available: <http://www.iucnredlist.org>.

[30] Rutishauser, E., Noor'an, F., Laumonier, Y., Halperin, J., Hergoualc'h, K. and Verchot, L. 2013. Generic Allometric Models Including Height Best Estimate Forest Biomass And Carbon Stocks In Indonesia. *For. Ecol. Manage.* 307: 219-225.

[31] Omar, H., Ismail, M. H., Hamzah,K. A. and Mohd Shafri, H. Z. 2014. Factors Affecting L-Band Alos Palsar Backscatter on Tropical Forest Biomass, *Glob. J. Sci. Front. Res.* 14(3).