ESTIMATING ABOVEGROUND BIOMASS OF A TROPICAL FOREST IN NORTHERN BORNEO BASED ON INDIVIDUAL TREE CROWNS FROM IKONOS 2 DATA

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Abstract: Estimation of AGB and carbon of tropical forests has been a crucial factor to 'Reduction of carbon emissions from deforestation and forest degradation-*plus*', a monetary mechanism for combating global warming. We examined the use of IKONOS 2 data for estimating aboveground biomass of a tropical forest in Long Mio, Sabah, Malaysia. The IKONOS 2 data was corrected for path radiance and topographic effect before segmentation using the watershed method in ArcGIS. Correlation analyses between the segment variables and forest variables revealed that crown area extracted from the IKONOS 2 data (CA_s) had the strongest correlation with the field-measured diameter at breast height (DBH_f). Linear regression analysis produced a model to estimate DBH_f using CA_s with R^2 of 0.71. Cross-validation using the remaining half of the data set also showed very consistent result. The CA_s only represented upper canopy trees but estimated about 80% of the aboveground biomass.

INTRODUCTION

Tropical forest is important for carbon sink and source in global carbon cycling. Total 15 – 25 % of the global greenhouse emission per year comes from tropical forest (Houghton, 2005; Malhi and Grace, 2000). Estimation of aboveground biomass (AGB) of tropical forests has been an important input to 'Reduction of carbon emissions from deforestation and forest degradation-*plus*', a monetary mechanism for combating global warming. Accuracy of the estimation is important for reporting carbon stocks and carbon changes to the Kyoto Protocol (Muukkonen and Heiskanen, 2007). In fact, the AGB estimation methods must be verifiable, specific in time and space as well as covering large area at an acceptable cost.

Remote sensing with combination of ground inventory data is a reliable approach for AGB estimation. Many tropical forest AGB estimation studies were carried out using medium resolution satellite image such as Landsat (Phua and Saito, 2003), ALOS-PALSAR (Morel *et al.,* 2012) and Landsat ETM+ (Langner *et al*., 2012). Statistical models based on spectral band or vegetation index has been derived from medium resolution satellite image for AGB estimation. However, these models tend to underestimate tropical forest AGB due to dense canopy structure (Gibbs *et al*., 2007). Recently, tree crown detection using high resolution satellite images have been used to examine forest canopy structure (Pouliot and King, 2005, Wang *et al*., 2004 & Kubo and Muramoto, 2005). The high resolution remote sensing approach detects crown variables of upper canopy trees that comprise of most of the AGB. Significant relationships between ground measured AGB and crown variables derived from the high resolution satellite image have been found for temperate forests (Hirata *et al*., 2009; Wulder *et al*., 2002). This study examined the use of IKONOS 2 data for delineating individual tree crowns of tropical forest. We then explored the potential of the crown variable extracted from the IKONOS 2 data for constructing an AGB estimation model.

STUDY AREA

The study site is located at Sabah Forest Industries (SFI) in southern part of Sabah. It is located in the Sipitang district with the total areas of 288,138 ha. SFI was established in 1983 as wholly owned by government which produces pulp and paper. However, SFI had been privatized in 1993. A total of 288,623 ha of land are under SFI management. 183,346 ha are under Integrated Timber Complex (ITP) with 171,471 ha under license and 11,875 ha under titled land. Approximately 46,000 ha are planted with *Acacia mangium*and other *Acaccia*or *Eucalyptus* species and hybrids. The remaining 104,822 ha is managed using Reduced Impact Logging (RIL) methods which closely monitored by Sabah Forestry Department.

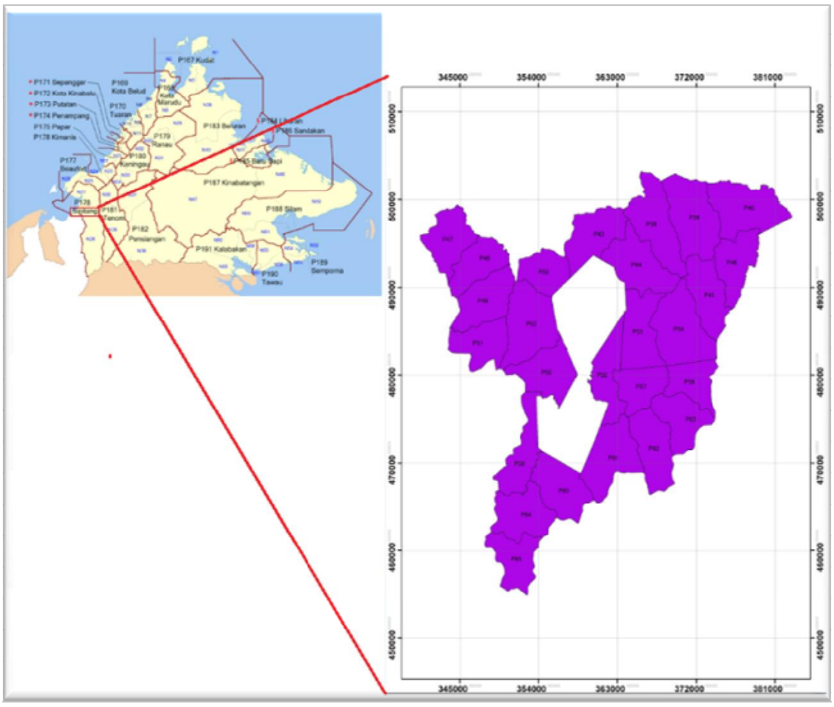

Figure 1: Location of the Sabah Forest Industry (SFI) in Southern Sabah, Malaysia

FIELD DATA

The first field trip was conducted from 26th November 2011 until 04th November 2011. We managed to survey 14 plots, which resulted in measurement of 908 trees. The second field trip was conducted between 7th and 13th February 2012. In total, 632 trees in 10 plots were measured in the second trip.

The plots were square with 30m horizontal distance for the sides. Each plot was facing north direction. Modification of plot size to 20m X 20m was done for degraded forest that consists of abundance small trees and less big trees. All trees with diameter at breast height (DBH) larger than or equal to 10 cm were counted. For degraded forest, trees with DBH smaller than or equal to 5 cm were measured. Firstly, tree numbering using chalk and tree positions were sketched. For tree positioning, the horizontal distance was measured from the Northwest corner of the plot. Tree parameters including DBH and tree height were measured. Differential GPS was used in to ensure minimal error for plot locations. The base unit was established at the local accommodation after correcting the errors with a GPS referential point at nearby Long Pasia area. The rover GPS was placed on the centre of the plot. All the plot coordinates were post-processed.

AGB of individual tree was calculated using the allometric equations of Kenzo et al. (2009). The equations differentiate species of early successional or highly degraded forest and primary forest.

SATELLITE IMAGE AND PROCESSING

An IKONOS 2 data acquired on 28th February 2010 was used. Ortho-rectification was conducted using the 30 meter resolution of Digital Elevation Model of the Shuttle Radar Topography Mission (DEM-SRTM). The IKONOS 2 data contains 4 multi-spectral bands of 4 meter resolution. Its panchromatic band has a spatial resolution of 1 meter. The multi-spectral and panchromatic bands were converted to spectral radiance followed Peterson (2001).

TOPOGRAPHIC EFFECT CORRECTION

Different sun illumination due to varying terrain's slope angle and position results in different brightness values of the same land cover types. Topographic normalization was conducted on the IKONOS 2 data in order to reduce the topography effect. For forest area, non-Lambertian method with Minnaert constant is preferred to the Lambertiam method (Smith *et al*., 1980). We used the 30 meter DEM-SRTM to derived slope and aspect images. The non-lambertian model is as follows;

$$L_H = L_\lambda \, cos\, e / (\cos e \cos i) k \tag{2}$$

where,

$L_H =$ = normalized radiance on flat surface with incident angle of zero
L_λ = radiance on terrain surface
e = slope
i = solar incident angle
k = Minnaert coefficient

The Minnaert coefficient, k describes the surface's bi-directional reflectance distribution function, where the scattering depends on surface roughness (Smith, 1980). The k can be obtained using linear regression analysis. The k varies between 0 and 1 where 1 representing perfectly diffuse reflector while small value means anisotropic scattering specific to the scene. As the research object of this study was forest, pixels of closed forest were selected to derive the *k*. A backward radiance correction model can then be developed based on the non-Lambertian assumption and Minnaert relationship (Smith *et al*., 1980).

ATMOSPHERIC CORRECTION

Different atmospheric conditions caused by meteorological and sun angle variations affect spectral reflectance on the ground. Atmospheric correction aims at removing the scattering, absorption and atmospheric distortion (Siegal *et al*., 1980; Vermote *et al*., 1997). The scattering effect is mainly constituted of path radiance, which can be corrected using the dark object subtraction (Chavez, 1988). The dark object value for each band was determined using the histogram method. The left part of the histogram of each band was examined to determine the haze influence. The haze influence is indicated by the sharp increase in the number of pixels at nonzero radiance (Chavez, 1988).

TREE CROWN DELINEATION

The processed multi-spectral bands were pan-sharpened with the panchromatic band. The pan-sharpened multi-spectral images were used for segmentation with the watershed method. Prior to segmentation, reversal images of the pan-sharpened IKONOS 2 images were generated. All non-tree areas were masked out for delineating the tree crowns in ArcGIS 9.3.

The segmentation's result was compared with the field data to identify the individual trees. Since lower canopy trees cannot be observed by the satellite sensor, it can be assumed that the tree crowns obtained from a high resolution satellite data correspond to the trees on the ground according to the largest tree to smaller tree (Hirata *et al*., 2009). The percentage of AGB that can be detected was calculated for each plot. Regression analysis the crown variables from the IKONOS image and field measured variables was carried out.

ABOVEGROUND BIOMASS ESTIMATION

Since tree height or DBH cannot be directly extracted from the IKONOS image, we examined the relationship between crown variables (crown perimeter, crown diameter and crown area) from the IKONOS image and field measured DBH. The crown variable that had the strongest correlation with the field measured DBH will be analysed with linear regression. The resulted model was used to estimate AGB of the plots. The estimated AGB was compared with the actual AGB from the field measurement to examine the usefulness of the AGB estimation model.

RESULTS AND DISCUSSION

In total, 1531 trees were measured in the 24 plots. Of the total number of trees, 31% had DBH larger than 20cm. However, segmentation of the IKONOS 2 data detected 574 tree crowns. The segments represented 38% of the total trees. This means most of the segments were upper canopy trees. 76% of trees in plot 24 were successfully detected on the IKONOS 2 data (Figure 2). In contrast, plot 5 had lowest percentage of tree crown detection with 15% (Figure 3). Plots with low percentage of detected tree crowns were in highly degraded forests. Therefore, percentage for the detected tree crown in degraded forest is lower than intact forest. Clump of small trees in the highly degraded forests tend to be segmented into a big segment (Hirata, 2008).

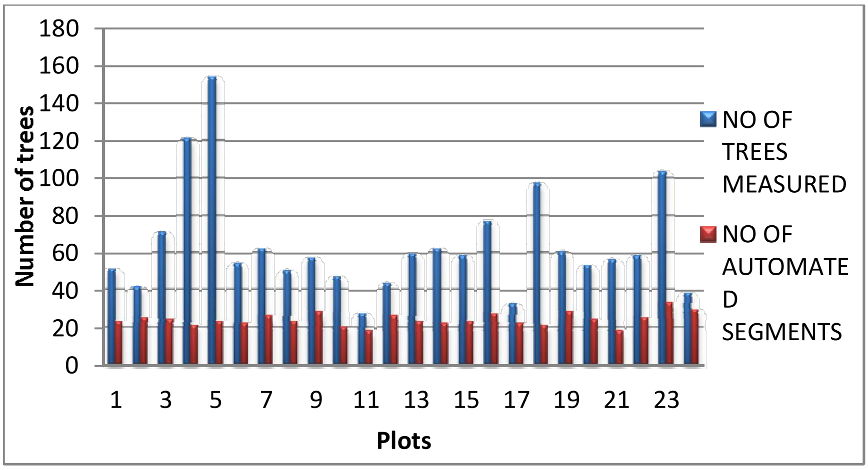

Figure 2: Number of trees measured and number of automated segments for each plot

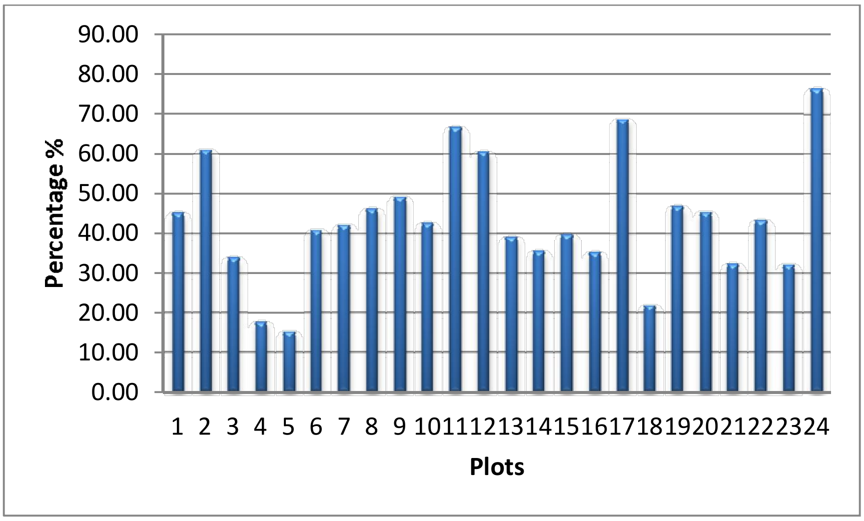

Figure 3: Percentage of tree crown detected for each plot

Crown variables included crown diameter, crown perimeter and crown area were extracted from the detected tree crowns for regression analysis with ground measure variables. Of the total number of detected crowns, 287 trees were used for model building while the remaining half was used for model validation. Among the pair of dependant and independent variables tested, linear regression between crown area (CA_s) from the IKONOS 2 data and DBH produced the best model with a R^2 of 0.711 (Figure 4). The models as well as the variables in the model were significant at 1% level.

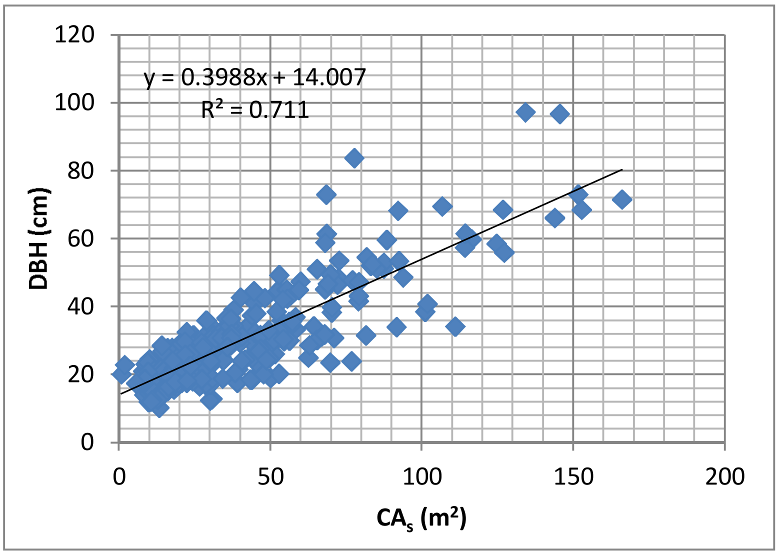

Figure 4: Linear regression between crown area from IKONOS 2 data (CA_s) and field measured DBH

Subsequently, AGB for the detected tree crowns were calculated using the allometric equations of Kenzo el al. (2009) that differentiate tree species and forest types. The actual AGB was plotted against the AGB estimated from the detected tree crowns (Figure 5). A regression line was well-fitted through the origin with a slope of 0.785 that indicated some under-estimation. Nevertheless, the model and the estimates have surpassed what was achieved with medium resolution satellite data. The differences between the actual AGB and the estimated AGB in terms of mean and total were remarkably small (Table 1). As the approach is based on crown variable, the model that estimates DBH was not affected by the problem of spectral value saturation, which is known to affect estimation of index-based model in medium resolution satellite data (e.g. Phua & Saito, 2003; Langner et al., 2011).

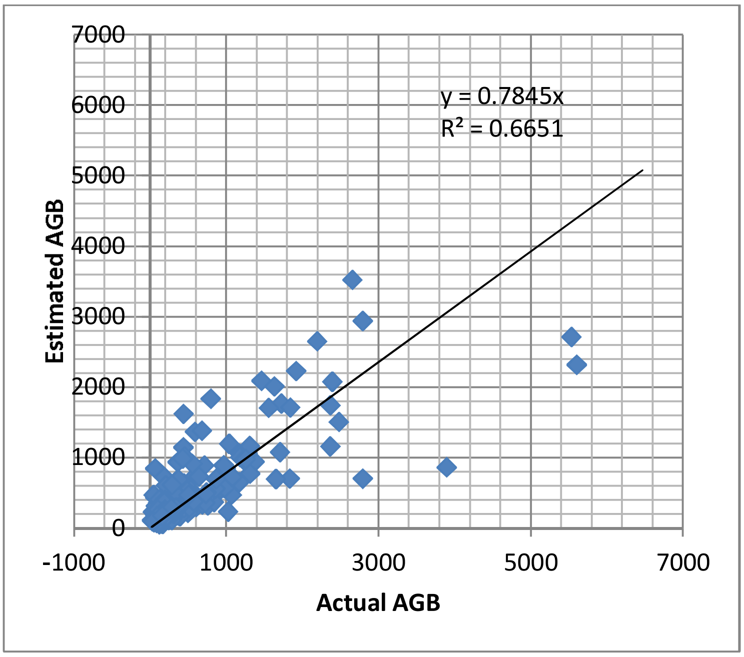

Figure 5: Comparison between actual AGB and estimated AGB using the model

Table 1: Cross-validation of AGB estimation.

	Mean Actual AGB (kg/tree)	Mean Estimated AGB (kg/tree)	Total AGB of Cross validation set (kg)
Model building	504.4	469.5	195,255.4
Validation	515.7	515.1	209,059.6

Tree crown delineation using high-resolution satellite data is affected by the canopy condition. Commission error and omission error affected the accuracy of the AGB estimates (Hirata, 2009). Only upper canopy tree crown can be extracted using the IKONOS 2 data. Errors of tree crown extraction from high resolution satellite data are affected by overlapping crowns in a tropical forest (Wulder *et al*., 2002). In our study, small trees that are located under the canopy layers or known as supressed trees could not be detected using the IKONOS 2 data. In addition, highly degraded forest with young stands, uniform tree height and flat canopy surface led to the underestimation of AGB. Cluster of trees are often segmented into one big crown area (Hirata 2008).

CONCLUSION

This study investigated the potential use of IKONOS 2 for estimating AGB of tropical forest. Segmentation using the watershed method on the IKONOS 2 data only detected upper canopy tree crowns. The estimation model of DBH using CA_s with a R^2 of 0.711 was the best approach for estimating AGB of the tropical forest. The mean and total estimated AGB values were very close to the values of actual AGB, as shown by the cross-validation analysis.

High-resolution satellite image that can capture upper canopy trees can generate crown variables for building allometric model that leads to AGB. On the other hand, airborne LiDAR has been known for its ability in accurate estimation of tree height. Combining high-resolution satellite image and airborne LiDAR for improving AGB estimation in tropical forest will be an important research topic to address.

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