EXPLORING FOREST DEGRADATION: TREE DENSITY AND ABOVEGROUND BIOMASS

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ABSTRACT: Assessing forest degradation is increasingly important to support a transparent and reliable reporting system for Reduced Emission from Deforestation and Forest Degradation-plus (REDD+) in combating the climate change. Exploration of forest degradation is still insufficient in the tropical region. In this paper, the logged-over Tangkulap and Deramakot Forest Reserves in Sabah, Malaysia-Borneo were thoroughly studied. Using the IKONOS-2 image, forest was segmented based on multi-resolution algorithm in eCognition and classified into forest degradation types. AGB was used to guide the classification into three levels of forest degradation i.e. very-degraded (VDF), degraded (DF) and intact forests (IF). The accuracy was assessed at 0.65 of Kappa coefficient (79% of overall accuracy). Under each forest degradation class, the distribution patterns of tree densities and AGBs at the respective strata of understory, canopy and emergent were examined. Statistical mean and standard deviation were used to describe the variation patterns. Tree density of understory strata is saturating at DF and IFs. Tree density of emergent strata at IF is about twice higher than at DF. AGB at IF is 3.6 and 1.8 times higher than at VDF and DF, respectively. Standard deviation of AGB tends to increase nonlinearly from VDF to IF. This study has examined the patterns of tree density and AGB in order to understand the recovery processes of the degraded forest.

1. INTRODUCTION

Forest degradation was addressed as a reduction of capacity of forest to provide goods and services caused by human-induced disturbances (FAO, 2011). Forest degradation may have many definitions across of many countries which require different standard assessment. Classifying a forest according to biomass is one of the criteria to define the forest degradation (FAO, 2011).Critically, nearly 80% of land surface in Sabah and Sarawak, the Malaysia-Borneo states, was impacted by previously undocumented, high-impact logging and clearing operations from 1990 to 2009 (Bryan *et al.*, 2013). In degraded forest, forest structure reflects upon the intensity and recovery processes after the logging events (Imai *et al.*, 2009).

About 64% of permanent forested land in Sabah, or 2.56 million hectares, is designated for timber commercial production which the implementation is towards a sustainable practice. Most of forests in Sabah have been logged more than once. Some of these logged forests were let to recover after being impacted by the anthropogenic disturbances particularly from logging activities. However, there is still few study conducted to review the characteristics of the recovering degraded rainforests. Monitoring forest degradation by using a remote sensing is more challenging than monitoring the land use conversion (Lambin & Pasteur, 1999).

In this study, rainforests was divided into four stratum by height, the forest floor (< 5 m), understory ($5 \leq h < 20$ meters), canopy ($20 \leq h < 40$ meters), and emergent (≥ 40 m). Population of structural stands at respective stratum are important to describe the recovery processes. Since extractions of forest information at object scale level is available using high resolution satellite image, we therefore classified the forest according to degradation level. Texture-based information improved land cover classification (Lu *et al.*, 2004). Trends of recovering forest growth were then examined focused on the forest structures, tree density and AGB, with respect to the forest degradation level.

2. STUDY SITE

Forest Management Unit 19 and 17A, or known as Deramakot and Tangkulap Forest Reserve (refer to as Tangkulap and Deramakot) (Figure 1), located inside the jurisdiction of Beluran and Tongod districts of Sabah, Malaysia-Borneo. Forests in the areas are dominated with mixed lowland dipterocarp species which was known for its high biomass content. Topography of the areas varies from flat to undulating with average elevation of 100m above sea level. Climate at this region is equatorial with two monsoon rain seasons: from May to September and November to March. Mean annual temperature is 28ºC while annual rainfall is 3,100mm.

Deramakot and Tangkulap are classified as commercial estate forest by Sabah Forest Department which falls under the permanent production forest. Historically, Deramakot was logged since 1956 until 1989 based on conventional logging, stop for a while and then resumed logged in 1995 using reduced impact logging technique. For Tangkulap, the forest was highly logged since 1970s until 2000. Due to sustainable concept of forest management in Deramakot, after 1995, the forest has been conferred a certification from the Forest Stewardship Council in 1997 until 2015, the longest certified rainforests in the world. The recovery progression occurred at different timing has left the forest with various degradation conditions.

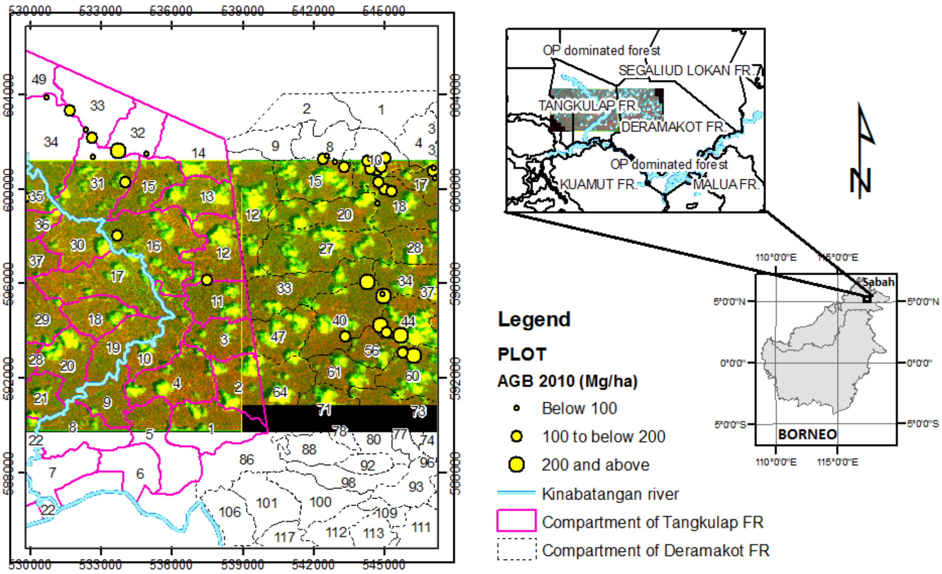

Figure 1. Map of Deramakot and Tangkulap Forest Reserves; picture at the right side is Borneo Island (map projected using WGS84 datum), picture at the middle (above) is the study area overlaid with IKONOS-2 image (display in mode R:red, G:green, B:blue), and picture at left is the enlarged study areas (map projected using Universal Transverse Mercator (UTM 50N) datum and image display in mode R:near infrared, G:red, B:blue). Plots are indicated by yellow dots, size of dot reflects the AGB level.

3. HIGH-RESOLUTION SATELLITE IMAGE ANDPREPROCESSING

The IKONOS-2 image, captured on July 2010, covers 350km^2 with coverage about 22% of Deramakot and 60% of Tangkulap. It is difficult to get an image that is totally cloud free in the tropics region. Image atmospheric correction was done based on Dark Object Subtraction technique. For image georeferencing, 53 ground control points (GCP) were used which are the significant mark on the land, such as junction or sharp curve of the roads. Georectification Root Mean Square Error (RMSE) was less than 2 meters.

4. DATA COLLECTION AND AGB CALCULATION

Ground data was collected between October 2010 and February 2013, covering three forest conditions; very-degraded, degraded and intact forests (Figure 2). Shape of ground plot is circle with radii of 15 to 20 meters.

Accessibilities by roads determined the distribution of plots. Height and diameter at breast height (DBH) were measured for trees that having a DBH ≥ 10 cm. Secondary data from Forest Research Centre of Sabah Forest Department were also used in the analysis. Allometric equation using DBH was used to calculate the AGB of tree (Kenzo *et al.*, 2009). For plots that were collected earlier or later than 2010, correction of AGB was done based on Clark *et al.* (2001). After a thorough checking, there are 63 usable plots were used in the analysis.

(a) Very-degraded forest

(b) Degraded forest

(c) Intact forest

Figure 2: View in forest plots, pictures taken between 1000 to 1500 hours. Condition in the forests was humid and moderately hot at sunny day.

5. FOREST DEGRADATION CLASSIFICATION

Using a commercial software eCognition (developed by Definiens Imaging Company), the forest was classified into three levels of forest degradation classes; the very-degraded, degraded and intact forests. A strategic approach in segmentation, similar to Korom *et al.*, (2014), was implemented and quite useful in finding the best parameter setting. The summary of input bands and parameter settings of multi-resolution algorithm are as in Table 1.AGB was used to guide the forest degradation classification. Spectral, textural and geometrical properties were used in the classification. Accuracy assessment for the classification was carried out based on plot using Kappa coefficient analysis.

Table 1. Segmentation and classification of IKONOS-2 image using eCognition

Band input	**Scale; colour; compact**	Feature Space Optimization settings: Separation distance	Feature Space Optimization settings: Dimension	**Class**	**Level**
B **R** **NIR**	230; 0.3; 0.8	2.691	Spectral: Blue (standard deviation) Near infrared (mean)	Forest** Bare land Cloud Shadows	Land cover

			Textural: Near infrared (GLCM correlation) Near infrared (GLCM entropy) Geometrical: Compactness Asymmetry	Water Building No-data area	
	230; 0.3; 0.8	0.365	56 various dimensions	Very-degraded forest Degraded forest Intact forest	Forest degradation classes

Note: Forest class (indicated by **) was further re-classified into forest degradation classes.

6. TREE DENSITY AND ABOVEGROUND BIOMASS STATISTICAL EXPLORATIONS

Based on the overlaid of classified forest degradation map and plot distributions layer, plots that fall within a specific class were identified. Trees in the same specific forest degradation class were gathered and its composition of tree density and AGB for every respective stratum (understory, canopy and emergent) was analysed. Two statistical aspects, mean and standard deviation, were used to explain the variation of forest degradations.

7. RESULTS AND DISCUSSION

Based on the IKONOS-2 image, forest degradation classes were presented in Figure 3. This result was based on parametric settings in Table 1. Separation between classes resulted in poor Euclidean distance (0.365) and large dimensions (56 parameters) which demonstrate the instability of the process. This setting was determined by using the function of Feature Space Optimization which sets the best parameter settings based on the independent variables.

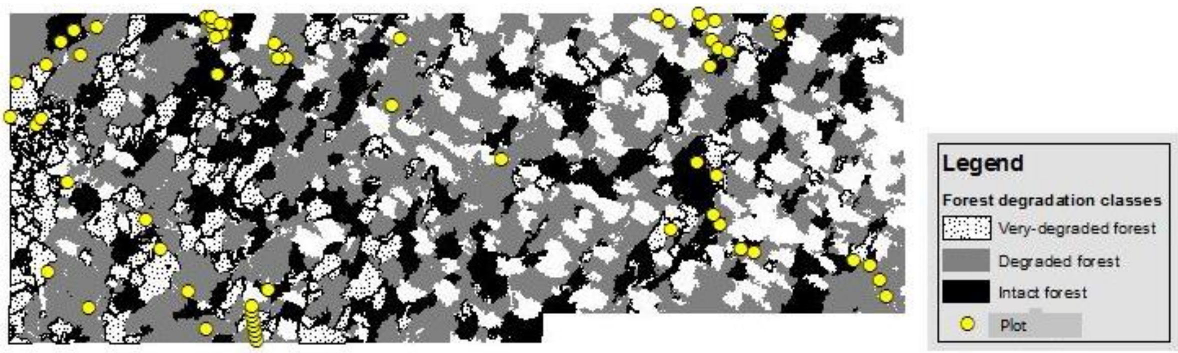

Figure 3: Representation by forest degradation classes with some missing information due to clouds and shadow coverage

Plots were used as comparison with the classified forest degradation. Classification of the forest degradation had resulted in 79% accuracies (Kappa coefficient 0.65) (Table 2). User's accuracies are 65%, 91% and 73% for VDF, DF and IF respectively, which reflect on the error of commission (inclusion). Producer's accuracies are 93%, 78% and 67% respectively, which reflect on the error of omission (exclusion). Out of the 63 plots, 20 plots were used to explore very-degraded forest class, 32 plots for degraded forest class and 11 plots for intact forest class.

Table 2: Accuracy assessment of forest degradation classification

	# Plots	Manually-classified VDF	DF	IF	Totals	User's accuracy	Producer's accuracy	Total accuracy	Kappa coefficient
Algorithm-classified	VDF	13	5	2	20	65%	93%	79%	0.65
	DF	1	29	2	32	91%	78%		
	IF	0	3	8	11	73%	67%		
	Totals	14	37	12	63				

Note: VDF Very-degraded forest, DF Degraded forest, IF Intact forest

Discussions on recovery trends of forest growth of tree density and AGB will be based on Figure 4. Basically, mean of tree density is low for understory, followed by the canopy and emergent in all forest types. It was estimated that the percentage of mean tree density for emergent are 0.7% at VDF, 2.5% at DF, and 4.6% at IF. Although mean of tree density for emergent is the lowest but its AGB contributes up to one-third of total forest biomass. Mean tree density for understory strata seemed to saturate at DF and IF, only 3% increment, which explains the population in this strata is stabilizing. Mean tree density for canopy seemed to increase linearly but for emergent, it emerged at double rate (106%). Standard deviation for tree density at DF is lowers than at VDF and IF for both understory and canopy stratum. But for emergent strata, standard deviation of tree density is lowest at VDF and highest at IF.

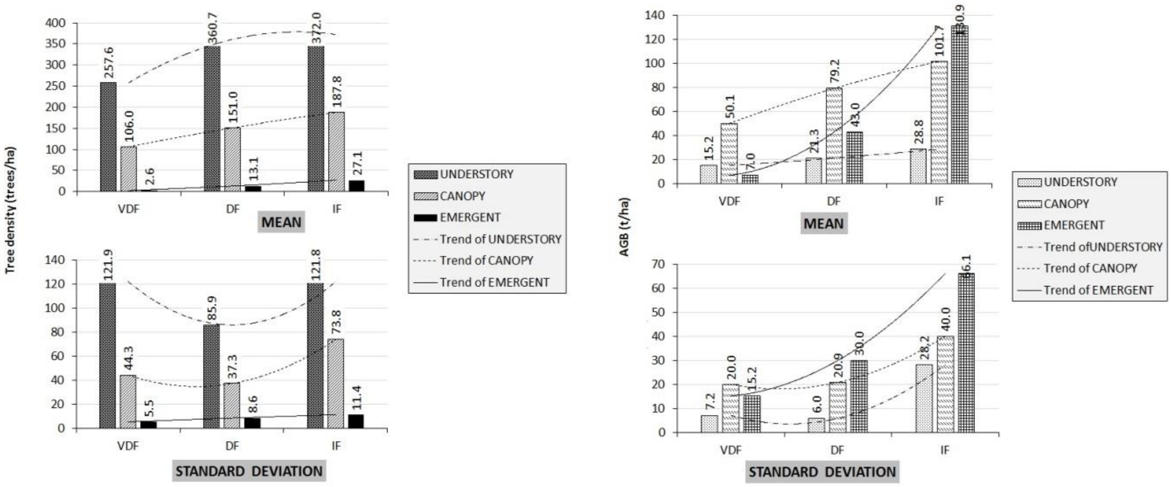

Figure 4: Distribution trends of tree density (left side) and AGB (right side) for respective forest degradation prior to understory, canopy and emergent strata

Basically, IF stores higher AGB than VDF and DF. Mean AGB of the understory strata is always low, ranging from 15.2 t/ha for VDF to 28.8 t/ha for IF. The mean AGB of the understory and canopy increased linearly while mean AGB of emergent increased exponentially. For VDF and DF, mean AGB for canopy strata is higher than the emergent, which indicates the removal of AGB during logging. Total of mean AGB at IF (261.4 t/ha) is higher than DF (143.5 t/ha), which indicates the restoration of AGB. Standard deviation of AGB tends to increase nonlinearly for all stratum layers. Comparison between standard deviation of AGB showed that standard deviation at IF is higher than DF for understory, canopy and emergent stratum. Surprisingly, standard deviation of AGB for canopy strata is comparable at VDF and DF but increasing at IF.

8. CONCLUSION

In this paper, a recovery trend of forest growth was examined through the distribution patterns of tree density and AGB at three forest degradation types; very-degraded, degraded and intact forests. Trend has shown that the population of understories grows fast, reaching its sustainable population during at degraded forest phase. Canopies and emergent are linearly expanding its population when let to recover over time. AGB of emergent is high for intact forest. This study contributes towards an understanding of growth recovery for the degraded forest.

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