LiDAR-Based Estimation of Canopy Fuel Parameters of Tree Plantation in Bukidnon, Philippines

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ABSTRACT

Forest wildfires in the Philippines are all human-caused. Resource managers are dependent on accurate estimates and spatially accurate forest structure information to govern this kind of phenomena. This study presents methods of using airborne laser scanning data to acquire forest and tree parameters that are critical in modelling forest fire behavior. The study aimed on assessing fuel models of a tree plantation through LiDAR (Light Detection and Ranging) point cloud data. The tree plantation under this study is located in the Municipality of Malitbog, Bukidnon that is managed by Bukidnon Forest Incorporated (BFI). Canopy fuel of Caribbean pine (*Pinus caribaea*) was determined through calculation of canopy bulk density (CBD), canopy base height (CBH), canopy fuel weight (CFW) and canopy height (CH), which are essential in mapping the spatial distribution and modelling fire behavior. The Canopy Fuel Estimator (CFE) software, developed by researchers from USDA Forest Service, was used in this study. The plantation's mean value of canopy fuel was extracted from available LiDAR data, which was also compared to the field data. Findings show that Caribbean pine plantation has high CBH (11.8 m), CH (31.5 m), and CBD (1.5 kg/m2). This indicates higher risk of forest fire in the area. Furthermore, field data for canopy fuel (CBH = 17.9 m, CH = 27.9 m, CFW = 2.9 kg/ha, CBD = 0.6 kg/m2) was observed to be close to LiDAR data (CBH = 11.8 m, CH = 31.5, CFW = 1.5 kg/ha, CBD = 1.5 kg/m2). Therefore, this study indicates the reliability of LiDAR data in modeling canopy fuel in a homogenous tree plantation through CFE. The maps produced can be used in fire behavior prediction, fuel reduction treatment prioritization and during active fire elimination.

Keywords: *Solar Radiation, Solar Variation, Solstice, Equinox*

INTRODUCTION

The use of remote sensing in acquiring accurate and spatially-explicit estimates for forest information structure can support many aspects on fire management and it has been increasingly used in estimating fuel properties (Morsdorf, Meier, Kötz, Itten, Dobbertin & Allgöwer, 2004). According to Roff, Goodwin, & Merton, (2005), airborne LiDAR system is a great tool to gain different source of fuel information and it has been used for estimating canopy height (CH), canopy base height (CBH), canopy bulk density (CBD) and canopy fuel weight (CFW) that would significantly improve the data creation in canopy fuel estimator (CFE) software developed by USDA Forest Service. The three dimensional distribution of forests can be obtained by using airborne LIDAR data (Andersen, McGaughey & Reutebuch, 2005). Also, LiDAR has the potential to compute and distinguish a range of fuel attributes, including understory fuel height and spatial technology (Means, 2000).

The landscape area of Bukidnon Forest Incorporated (BFI) have long been subjected to wildfires implying the need to provide more accurate fire behavior predictions for its management and the need to reflect on some factors, such as canopy height, dead and live fuel load, and percent of canopy cover, to determine available fuel types (Pyne, Andrews, & Laven, 1996). Thus, acquiring reliable and precise forest inventory information has been essential and critical for forest resources assessment and management. Also, the need to use complex fire behavior models to support environmental assessments was considered one of the keys to improve ecosystem health (Andrews and Queen, 1999).

This study was conducted to develop the use of LiDAR data in accurately and efficiently assessing fuel models in the Caribbean Pine Plantation of BFI. Specifically, this study aimed to develop several data fusion approaches to assess forest fuel models and map vegetation characteristics in order to generate spatially precise digital fuel maps.

METHODOLOGY

Figure 1 shows the study area which is located in Compartment 87, Siloo, Malitbog, Bukidnon, with a coordinates 8°29’23.43”N 124°59’27.54”E. According to Environmental Science for Social Change (ESSC, 2005), the forest cover type of the area is classified as pine forest. Two hectare plots were established in Compartment 87, and the current forest species was Caribbean Pine (Pinus caribaea).

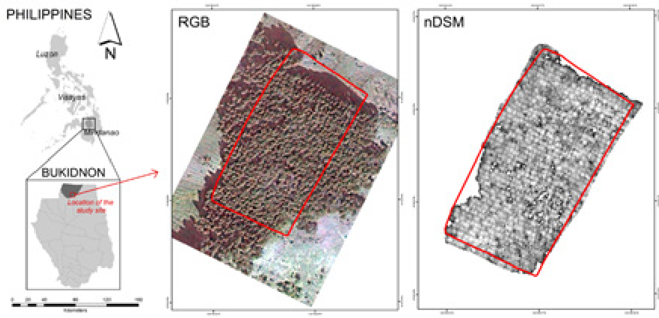

Figure 1. Location of Caribbean Pine Plantation in Comparment 87, Malitbog, Siloo, Bukidnon

LiDAR data of the study area was obtained last August 2013 using airborne LiDAR with an x position accuracy of +/- 20 cm and y position accuracy of +/-100 cm. The LiDAR data are considered low density since the average point is 2 points/m2 and average spatial resolution of 0.5 meters.

Forest inventory of biophysical parameters for individual Caribbean pine (Pinus caribaea) trees was conducted last November 2014. The included parameters were tree height, tree position and diameter at breast height (DBH). Individual tree stands along with the corner points of the 2 ha plot were acquired using Total Station (TS) instrument, whereas DBH of trees was acquired using tree caliper.

The idea to make a scheme and amend some formula in Microsoft Excel software to automatically compute the canopy fuel weight, canopy bulk density, canopy base height, and stand height to further evaluate LiDAR result was obtained using the method developed by Cruz and Wakimoto (2003) called Canopy Fuel Stratum LiDAR characteristics Calculator.

LiDAR-based fuel estimates were generated using the software developed by Andersen et al. (2005), the Canopy Fuel Estimator (CFE). The Estimator calculates LiDAR-derived variables for the maximum, mean, and coefficient of variation for the LiDAR canopy heights. It also has several quantile-based metrics that describes LiDAR canopy height distribution, as well as canopy density metric. The software contains simulations that uses LiDAR-derived variables to foresee canopy fuel weight, crown bulk density, canopy base height, and canopy height in the study area. A simple data comparison of average, minimum, and maximum results from the fieldwork and LiDAR was done. R2 was also computed to test relationship between the two datasets.

RESULTS AND DISCUSSION

Canopy Fuel Calculation

Tree height of Pine at the study area ranges from 18.5 m to 32.9 m based on field measurements. In contrast, a range of 19.17 m to 31.8 m tree height was derived from the LiDAR data. Figure 2 shows a relationship of individual tree height from field and LiDAR data that was computed. The R2 between field and LiDAR data was 0.60, implying moderate relationship. This is obvious, since the laser data used in the study site has a low dense point cloud data.

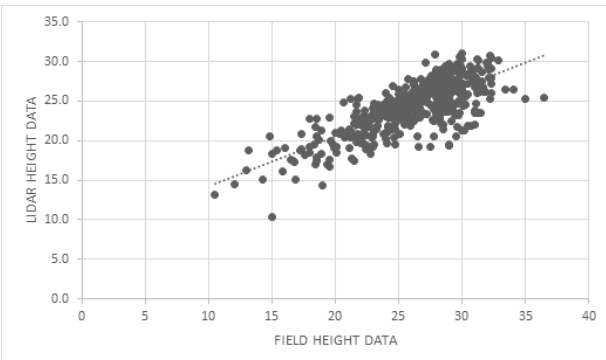

Figure 2. Field versus LiDAR measurement (R^2 = 0.60)

Table 1 shows the comparison of canopy fuel parameters. LiDAR measurement had higher Canopy Bulk Height (CBH) of 11.93m, Canopy height (CH) of 19.76m, Canopy Bulk Density (CBD) of 1.56kg/ha, and Canopy Fuel Weight (CFW) of 1.49kg/m2. This indicates that there is a significant relationship between LiDAR vs field data, and that LiDAR data can be used in estimating canopy fuels. Its ability to estimate canopy fuels is not limited only to Caribbean pine plantation as well but also to other forest plantation present in the area.

Table 1.
Comparison of Generated Results from Field and LiDAR Result

Parameter	Average		Min		Max	
	Field	LiDAR	Field	LiDAR	Field	LiDAR
CBH (m)	9.67	11.93	13.38	21.22	1.78	-4.29
CH (m)	16.57	19.76	23.12	26.34	2.72	11.27
CBD (kg/ha)	0.27	1.56	0.96	0.54	0.016	3.50
CFW (kg/m2)	1.20	1.49	28.60	1.71	0.000052	0.061

Mapping Canopy Fuel

Regression results for tree height between field and LiDAR data shows moderate relationship. Models have been developed to establish functional relationship between the LiDAR data and the canopy fuel measures. These equations created by Andersen et al. (2005) can be used to generate maps of canopy fuel LiDAR characteristics over the entire extent of the LiDAR data coverage. Figures 3–6 show maps of stand height, canopy fuel weight, canopy bulk density, and canopy base height over the Bukidnon Forest Incorporated study area, with measurements provided at a 5 × 5-meter grid cell resolution. The minimum conditions necessary to initiate and propagate crown fires are assumed to be strongly influenced by the stand structural variables of CBD and CBH. Figure 3 reveals that Caribbean pine plantation has an average height of 40–50 meters. The same range was observed in the study site during the actual field data gathering. Whereas in Figure 5, CBD ranges from 0.083–0.187 kg/ha. This implies that the area is vulnerable to fire due to the estimated range result. Moreover, Figure 6 shows the result in CBH with a range of 15–25 meters. It is noteworthy that the higher the CBH is, the more vulnerable the forest is to fire because of the ladder fuels such as shrubs and understory trees present in the area. Figure 4 presents that the result of the CFW ranges between 0.98–2.94 kg/m2. The result implies that the greater the weight of CFW (live and dead foliage, live and dead branches, and lichen of trees and tall shrubs that lie above the surface fuels) the more the Caribbean pine plantation is vulnerable to fire.

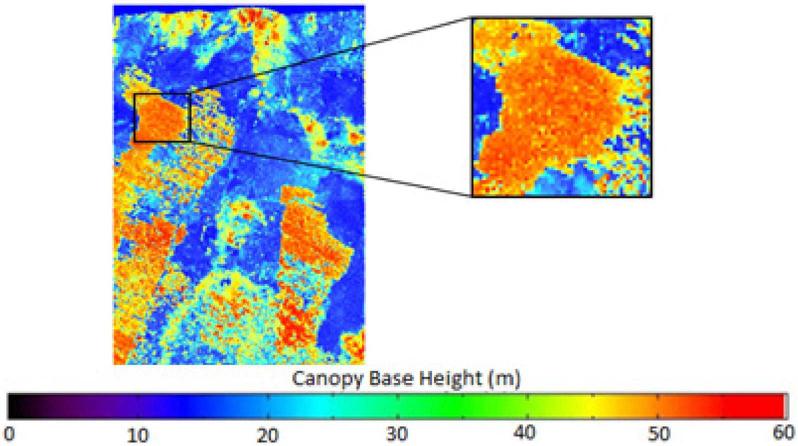

Figure 3. Stand Height Map (5-meter resolution), Bukidnon Forest Incorporated

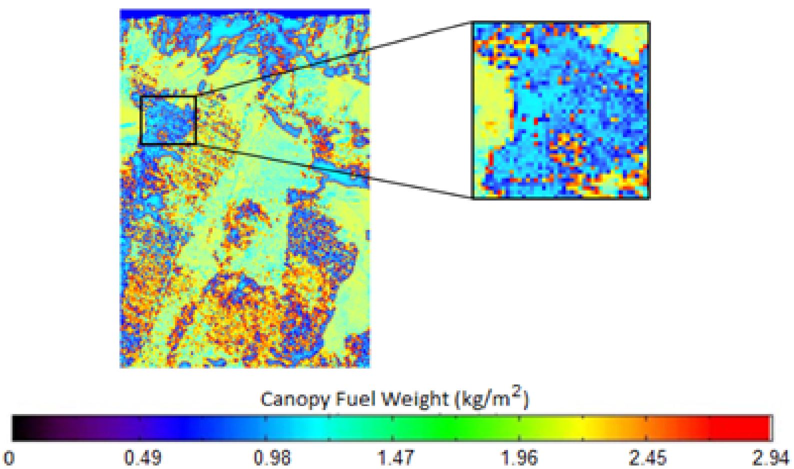

Figure 4. Canopy Fuel Weight Map (5-meter resolution), Bukidnon Forest Incorporated

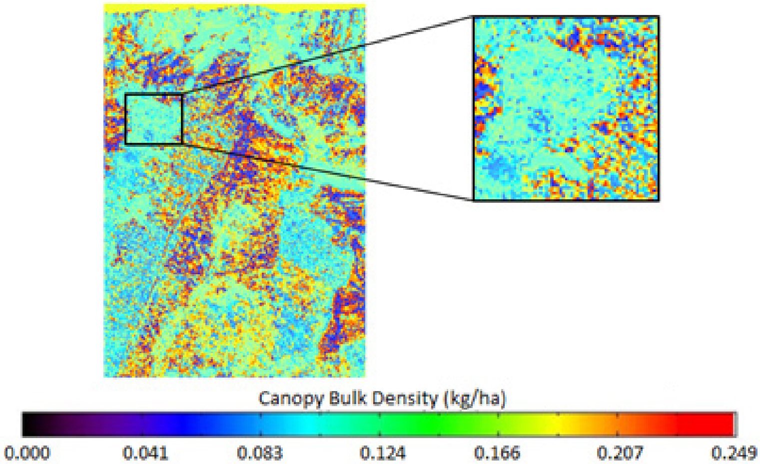

Figure 5. Canopy Bulk Density Map (5-meter resolution), Bukidnon Forest Incorporated

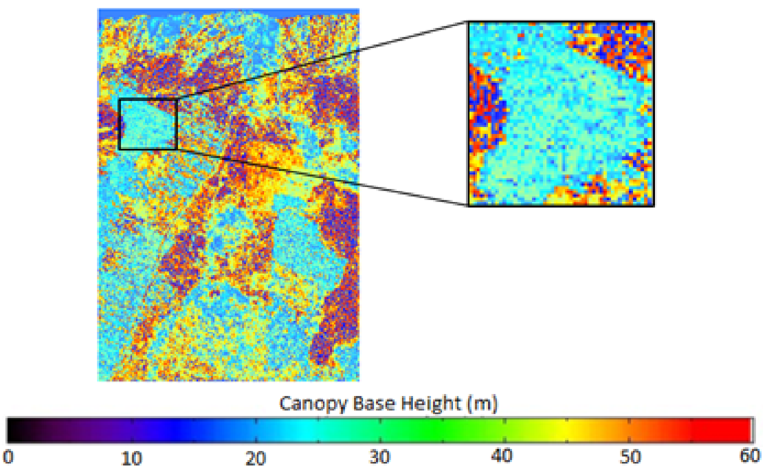

Figure 6. Canopy Base Height Map (5-meter resolution), Bukidnon Forest Incorporated

The outcome demonstrates that LiDAR can be utilized to deliver exact evaluation on basic canopy fuel measurements, such as, canopy fuel weight, bulk density, canopy base height, and stand height. It appears that the utilized spellbinding components were catching crucial data related to quantitative canopy fuel attributes.

There are various possible hotspots for error between the LiDAR-based metric inside a plot zone and the model-based assessment produced from field data measurements. First, crown base height in the field was not measured but was calculated using standard formula and canopy stand height parameter instead. This presents an important source of variability into the field-based assessments. Second, LiDAR characterization canopy base height and stand height as an edge estimation of crown mass density makes this metric very delicate to displaying presumptions identified with how fuels are vertically conveyed. Hence, even little deviations from the accepted uniform dispersion of fuels along the length of the crown for few trees in the plot could largely affect the assessment of canopy base height and stand height. Edge impacts could likewise prompt critical contrasts between the LiDAR and field-based assessments. The listed tree in the field does not represent the spatial position of tree crowns inside the plot, since crown fuel assessments are figured for the whole crown connected with each stem falling inside the plot even if the larger portion of the crown is located outside of the plot. Conversely, the LiDAR information extracted for a given plot incorporates just estimations of canopy materials that were situated inside the plot. While actualizing the regression based way to deal with displaying crown fuel variables, it is basic to get field information over the full scope of stand sorts present in the zone to be mapped.

Looking at the assessed fuel parameters in various forest and structure in the area with field inventory are unreliable. In this case, BFI has 4 forest types present in Siloo, Malitbog Bukidnon but only Caribbean Pine was considered for inventory in this study. This can be the reason why it is more sensible inside the gathered field estimation contrasted with the other forest stand. It could have been better if every forest type present in the area were measured in order to have accurate fire prediction. Therefore, models developed in this study are meant to determine the potential of this methodology for crown fuel estimation in Caribbean Pine plantation in the Philippines, and do not essentially reflect vital structural relationships for natural stands. Even though a full model validation was outside the scope of this study, in an operational circumstance, the predictive regression models should be validated to assess the results over the full range of stand structures present in the area of interest.

CONCLUSION

This study shows that LiDAR can be utilized to estimate canopy fuel measurements productively and precisely over extensive ranges. Canopy fuel measurements based upon the LiDAR height information can be utilized to create maps that provides spatial delineation of canopy fuel distribution over the site. These maps (or GIS inclusions) can serve as an immediate contribution to a forest fire model, for example, FARSITE, conceivably empowering a more reasonable and exact prediction of fire spread and intensity.

The result between field and LiDAR data shows a moderate relationship (R2=60%). The majority of the forest parameter in LiDAR data (CBH=11.8 m, CH=31.5, CFW=1.5 kg/ha, CBD=1.5 kg/m2) acquired the highest result compared to the field data (CBH=17.9 m, CH=27.9 m, CFW=2.9 kg/ha, CBD=0.6 kg/m2. The result shows a good indication that LiDAR data has the ability to estimate forest parameters even it is low dense LiDAR. Therefore, the study can be more advantageous if the acquired LiDAR data is high dense point cloud.

RECOMMENDATION

In order to improve the accuracy of the results a high dense point cloud acquisition and adding of imagery with better image characteristics (higher spatial and spectral resolution) is recommended. The developed approach in fire and fuel management is recommended among all forest types to further investigate the characteristic of each forest parameters in the Philippines.

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