MANGROVE PLANTATION FOREST ASSESSMENT USING STRUCTURAL ATTRIBUTES DERIVED FROM LIGHT DETECTION AND RANGING (LiDAR) DATA

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Commission VIII, WG VIII/7

KEY WORDS: Mangroves, Rhizophoraceae, Plantation, Point Cloud, LiDAR

ABSTRACT:

Estimating the structural and functional attributes of forests is integral in performing management strategies and for understanding forest ecosystem functions. Field sampling methods through plot level is one of the known strategies in forest studies; however, these methods have its limitations and are prone to subjected biases. Remote Sensing data, particularly that of Light Detection and Ranging (LiDAR) can be utilized to alleviate the limitations of extracting forest structure parameters. The study aims to characterize a Rhizophoraceae-dominated mangrove forest plantation. Point cloud distribution within a 1-hectare plot was processed by utilizing thirty (30) samples of 5x5 meter plots, which were analysed for the characterization and forest structure assessment. Point densities were grouped at intervals of 10% of the plot's maximum height (*Height at Bincentile or* HB_n) to determine where the clustering of points occur per plot. The result shows that most of the points are clustered at HB_n with height values ranging from 2.98 to 4.15 meters for plots located at the middle part of the forest, with a standard deviation of 1.78 to 3.69, respectively. On the other hand, sample plots that are located at the periphery part of the forest shows that the point clustering occurs at different heights ranging from 1.71 meters to 4.43 meters, with standard deviation values ranging from 1.69 to 3.81.Plots that are located along the fringes of the forest reflect a stunted clustering of points, while plots that explicitly show mangrove trimmings and cuts reflect even distribution in terms of point density within each HB_n. Both species present in the area (*R. mucronata and R. apiculata*) exhibits similar clustering, which could represent detection of Rhizophoraceae mangroves.

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1. INTRODUCTION

Mangroves are intertidal tree species that provide vast benefits both on a natural and socio-economic aspect. Mangroves are considered as one of the most productive ecosystems on Earth having a mean production of 2.5g C m^{-2} (Jennerjahn & Ittekot, 2002). These nutrient-rich wetlands also generate ample goods and services to society (Kathiresan & Rajendran, 2006). Therefore, understanding its overall structure is integral to enhance existing knowledge on mangrove conservation and management.

The dawn of remote sensing technology and its application on mangrove forest studies have yielded timely and less biased results compared to the traditional in-situ data gathering process. Remote-sensing and GIS-based processing is an effective tool to provide a synoptic view that may be difficult through in-situ method alone. This type of processing generated very important results for the ecological knowledge of mangrove ecosystems (Santos & Bitencourt, 2016). Furthermore, the emergence of LiDAR technology as a remote sensing tool levelled the notch for it provided even better results at higher resolution.

This paper presents mangrove forest assessment, particularly that of a mangrove plantation forest using the point density distribution from LiDAR. Clustering of points are analysed to determine whether the forest dynamics are possible to detect and understand through utilization of LiDAR data.

2. DATA AND METHODS

2.1 Site Description

Located on the province of Zambales, this coastal mangrove forest is a two (2) hectare mangrove plantation in one of the barangays of the municipality of Masinloc. This is a fringe mangrove forest wherein Rhizophoraceae mangroves dominate, specifically *R. mucronata and R. apiculata.* For this study, only one (1) hectare will be used for the analysis.

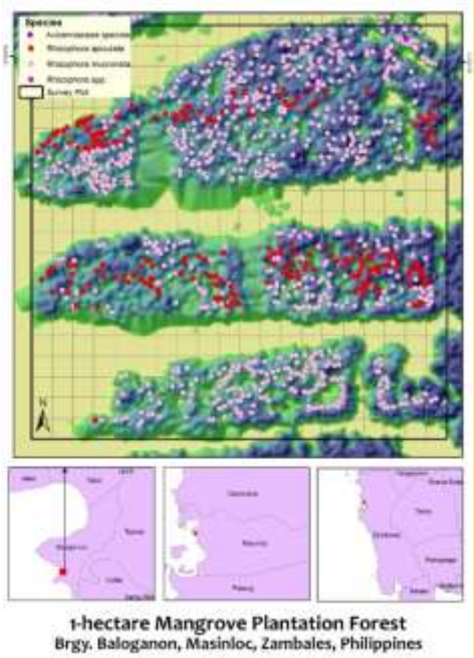

Figure 1. Location Map of the study site in Brgy. Baloganon, Masinloc, Zambales

The site was surveyed for field validation on November 2015. Collection of data such as individual tree geotagging and DBH measurement were made to validate the acquired LiDAR data. Measurement of sample Tree Heights, canopy cover using Digital Hemispheric Photography (DHP), and supplemental characterization using Terrestrial Laser Scanner (TLS) were also executed.

2.2 LiDAR Data

The LiDAR data used for this study is an airborne LiDAR data obtained from flight 939P of Pegasus (Optech Inc) on 13 January 2014. The flight has a flying height of 1323 meters above ground and that covers ground at 2 pulses per square meter.

2.3 LiDAR Processing

The raw LiDAR data was initially pre-processed to normalize the points in relation to the elevation values. From the adjusted points, vegetation points are filtered and will serve as the input to compute the necessary LiDAR derivatives such as the Canopy Height Model (CHM), the Height at bincentile (HB_n) and the non-cumulative bincentile (NCB_n) values. These derivatives will then be used for the structure assessment of the Rhizophoraceae mangroves in this fringe plantation forest.

The HB_n are the height values at intervals of 10% of the plot's maximum height.The NCB_n on the hand, are the number of points or point density per HB_n. Each 5x5 meter plot samples were processes to extract its corresponding HB_n and NCB_n values.

The other LiDAR derivatives are also extracted as supplemental data for the structure assessment. Table 1 shows the summary of the LiDAR derivatives.

LiDAR Parameter	Description
NCB_{10}	Number of points at the 10% interval of max height
NCB_{20}	Number of points at the 20% interval of max height
NCB_{30}	Number of points at the 30% interval of max height
NCB_{40}	Number of points at the 40% interval of max height
NCB_{50}	Number of points at the 50% interval of max height
NCB_{60}	Number of points at the 60% interval of max height
NCB_{70}	Number of points at the 70% interval of max height
NCB_{80}	Number of points at the 80% interval of max height
NCB_{90}	Number of points at the 90% interval of max height

This contribution has been peer-reviewed.
doi:10.5194/isprsarchives-XLI-B8-617-2016

NCB_{99}	Number of points at the 99% interval of max height
AVG	Average height
COV	Canopy Cover
DNS	Density
KUR	Kurtosis
MAX	Maximum Height
MIN	Minimum Height
P01	First percentile
P05	Fifth percentile
P10	Tenth percentile
P25	Twenty fifth percentile
P50	Fiftieth percentile
P75	Seventy fifth percentile
P90	Ninetieth percentile
P95	Ninety fifth percentile
P99	Ninety ninth percentile
QAV	Quadratic average
SKE	Skewness
STD	Standard deviation

Table 1. Summary of the LiDAR derivatives

2.4 Plot Location

The sample plots were initially categorized depending on its location in the riverine mangrove forest. The location of the plots may either be on the middle part of the forest or at the periphery. This distinction is established in order to determine whether there is an eminent difference in terms of shape structure and point density distribution on the two types of locations. Fifteen (15) sample plots of pure Rhizophoraceae located at the middle part of the forest was selected, along with another fifteen (15) pure Rhizophoraceae plots located at the periphery part of the mangrove forest. A total of thirty (30) plots was used in for this study.

2.5 Structure Typology

Structure typology or the set of criteria for the mangrove structure assessment was established in this study to come up with a methodology to assess this mangrove plantation forest.

The initial structure typology has three major components: Height, Shape, and Canopy Cover. These are the LiDAR derivatives that will be primarily used for the structure characterization of the prominent Rhizophoraceae mangroves in the site.

For the height, the maximum height of each 5x5 meter sample plot were identified and a set of sub-criteria is created, wherein each plot will be categorized accordingly.

Height	Max Height value
Stunted	3-4 meters
Average	5-9 meters
High	above 9 meters

Table 2. The established sub-criteria for the height factor

The shape factor categorize each plot based on its measure of central tendency by computing the weighted mean and the corresponding standard deviation values for each sample plot. This is used to quantify the clustering shape of each plots' point density distribution. The mean of the weighted mean for each plot will be analysed. The weighted mean is computed using the formula:

$$x = \frac{\sum_{i=1}^{n}(x_i * w_i)}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where:
$\sum$= summation
$\bar{x}$ = weighted mean
w_i= weight given to the point density at certain HB_n
X_i= summation of HB_n

In addition, the canopy cover values derived from LiDAR will serve as the third factor in the structure characteristics. The canopy cover is computed as:

$$CC_{LiDAR} = \frac{\text{\# of 1}^{st}\text{ returns above the cover cut-off (1.37m)}}{\text{All first returns}} \quad (2)$$

Further analysis of the canopy cover was done in order to enhance the characterization process. The relationship between the number of trees and its corresponding field DBH to the LiDAR canopy cover values was investigated as well.

3. RESULTS AND DISCUSSION

All the factors were taken into account during the structure characterization and analysis. All 30 5x5 meter sample plot were processed and thoroughly examined to come up with a set of descriptors for this mangrove plantation forest.

3.1 LiDAR point cloud

The normalized point cloud data is shown in Figure 2, wherein the vegetation points are filtered. Figure 2 and 3 illustrated the NCB_n layers and the derived CHM.

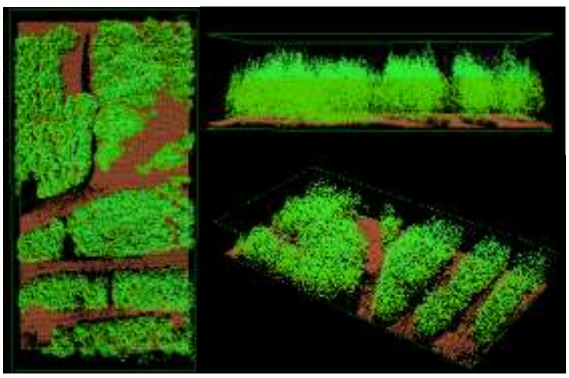

Figure 2. Point cloud data are classified as ground and vegetation

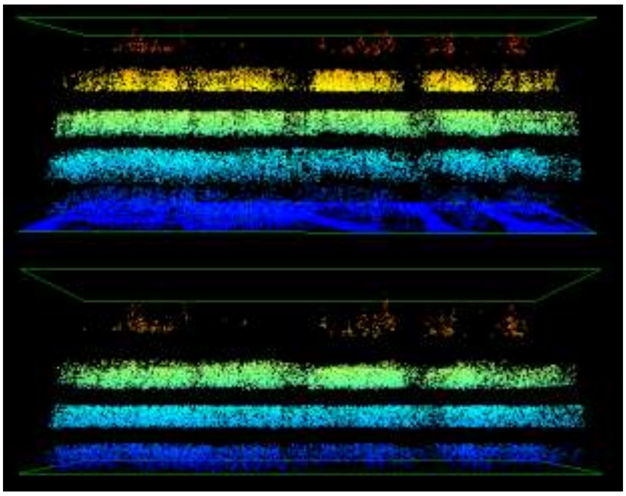

Figure 3. The clustering of points at 10% of maximum height or NCB_n

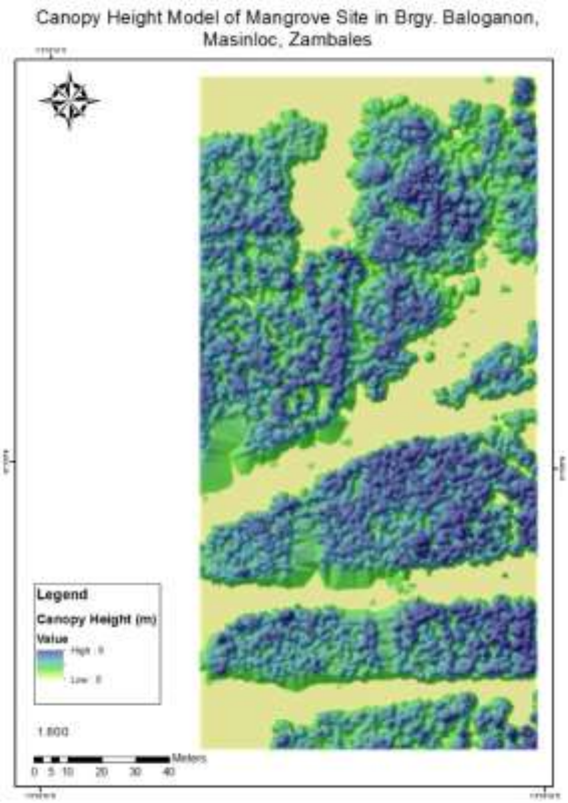

Figure 4. The derived Canopy Height Model (CHM) for the site in Brgy. Baloganon, Masinloc, Zambales, Philippines

3.2 Height Characteristics

The maximum height of each sample plot were identified and categorized accordingly. The results showed that 100% of the sample plots located at the middle part of the forest have average canopy height values ranging from 5-9 meters only. On the other hand, 6.67% and 93.33% of the sample plots located at the periphery part of the forest stunted growth and average growth respectively.

3.3 Shape Characteristics

To understand the overall structure of the Rhizophoraceae mangrove in a fringe mangrove forest, the shape characteristics was also taken into account through computing the weighted mean values of the point density clustering per plot.

Majority of the sample plots that are located at the middle part of the forest have majority of its point density occur at around 2.98 to 4.15 meters, with a standard deviation of 1.78 to 3.69, respectively. On the other hand, sample plots that are located at the periphery part of the forest shows that the point clustering occurs at different heights ranging from 1.71 meters to 4.43 meters, with standard deviation values ranging from 1.69 to 3.81 as shown in Table 3.

The result also shows that most of the plots that are located along the middle or the inner part of the forest are more intact and the point density clustering is consistent. On the contrary, inconsistent point density clustering is evident in the sample plots located at the periphery part of the forest, which could be due to its exposure to several environmental stressors such as tidal fluctuation and exposure to wind action. Figure 5 and 6 shows the visual representation of the height and point density distribution using column blobs.

Middle Plots			**Periphery Plots**		
Sample Plot	Mean	Std Dev	Sample Plot	Mean	Std Dev
Plot 0	3.49	1.78	Plot 0	1.97	2.66
Plot 1	2.98	2.39	Plot 1	1.71	1.69
Plot 2	3.07	1.90	Plot 2	3.44	2.88
Plot 3	3.54	1.55	Plot 3	3.39	3.28
Plot 4	3.61	2.06	Plot 4	3.54	3.71
Plot 5	3.51	2.96	Plot 5	2.93	2.93
Plot 6	3.89	3.69	Plot 6	3.48	2.78
Plot 7	2.92	3.51	Plot 7	3.90	4.36
Plot 8	3.18	3.08	Plot 8	2.67	2.78
Plot 9	3.34	3.73	Plot 9	3.10	2.82
Plot 10	3.42	3.52	Plot 10	3.76	3.34
Plot 11	3.37	3.27	Plot 11	3.78	3.23
Plot 12	3.74	3.47	Plot 12	3.14	2.61
Plot 13	3.92	3.69	Plot 13	4.43	3.81
Plot 14	4.15	2.72	Plot 14	3.16	2.92

Table 3. Measure of central tendency of the point density clustering per sample plot.

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doi:10.5194/isprsarchives-XLI-B8-617-2016

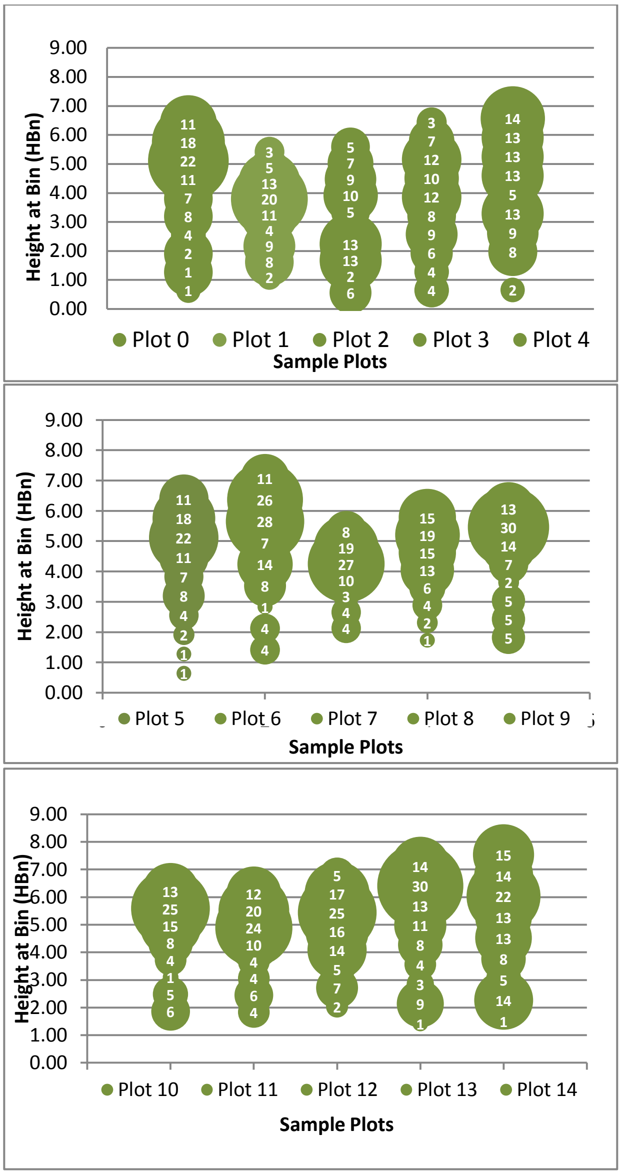
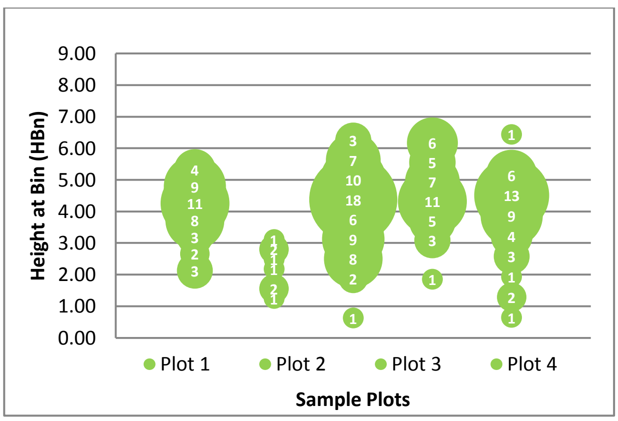


Figure 5. Visualization of the point density distribution clustering for sample plots located at the middle part of the forest



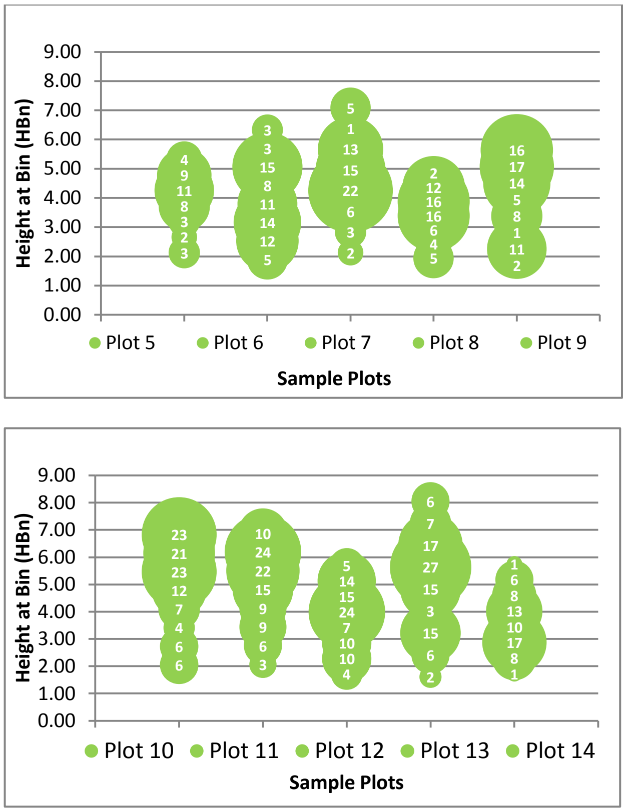


Figure 6. Visualization of the point density distribution clustering for sample plots located at the periphery of the forest

3.4 Canopy Cover Characteristics

The canopy cover derived from LiDAR was also examined to further enhance the characterization study. The number of trees per plot, as well as the average Diameter at Breast Height (DBH) that was collected in-situ were correlated to the Canopy Cover values. The overall canopy cover of the sample plots located at the middle parts of the forest have Medium (80-94.99) to High (95-100) canopy cover, while plots that are located along the peripheries have values ranging from Low (below 80) to High (95-100) as shown in Table 4.

The correlation between LiDAR canopy cover and Field DBH suggest that there is a direct relationship between the two as shown in Figure 7 and 8, respectively. However, it was also observed that the individual tree species situated in each sample plot greatly influence the correlation. The different cases and the corresponding correlation is shown in Table 5.

Functional Type	Plot Location	Sample Plots	No of trees	Canopy Cover	Ave Field DBH
Fringe (ZBS Plot)	Middle	Plot 0	3	76.8	5.15
		Plot 1	6	95.4	6.50
		Plot 2	5	79.7	5.38
		Plot 3	7	90.5	5.30
		Plot 4	5	97	6.78
		Plot 5	7	100	6.28
		Plot 6	6	100	7.88

		Plot 7	15	100	4.81
		Plot 8	10	98.6	5.70
		Plot 9	7	100	6.95
		Plot 10	7	100	6.13
		Plot 11	9	100	7.26
		Plot 12	7	89.4	7.64
		Plot 13	5	100	7.80
		Plot 14	8	100	5.61
	Periphery	Plot 0	0	61.1	0.00
		Plot 1	2	12.1	6.33
		Plot 2	1	96.7	8.28
		Plot 3	2	61.3	6.68
		Plot 4	2	60.3	7.88
		Plot 5	2	47.5	7.40
		Plot 6	9	97.2	6.70
		Plot 7	6	90	7.96
		Plot 8	4	96.8	7.04
		Plot 9	15	98.4	5.96
		Plot 10	7	95.7	7.59
		Plot 11	10	90	8.64
		Plot 12	6	100	6.01
		Plot 13	8	93.9	9.31
		Plot 14	6	95.3	8.90

Table 4. Canopy Cover values per plot along with their corresponding field dataset.

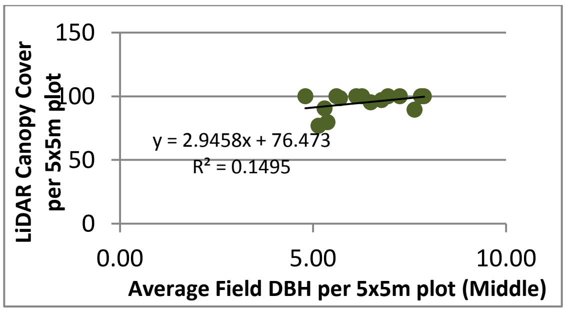


Figure 7. Linear Regression equation of the CC and DBH correlation for the sample plots located at the middle part of the forest.

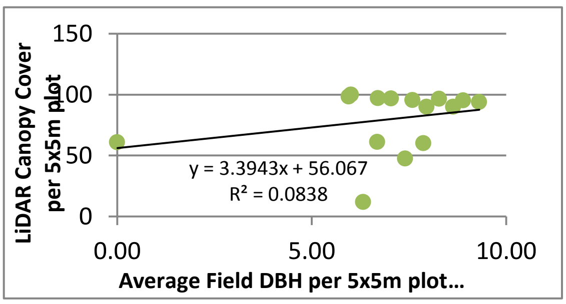


Figure 8. Linear Regression equation of the CC and DBH correlation for the sample plots located at the periphery part of the forest

CASES	CANOPY COVER (LiDAR)	AVERAGE DBH (DBH)	REMARKS
Case 1	High	High	Direct relationship between CC and DBH
Case 2	High	Low	Number of trees included in the computation Tree spacing competition for sunlight
Case 3	Low	High	damaged mangroves (anthropogenic or naturally induced)
Case 4	Low	Low	mangrove regenerants or young mangroves
Case 5	with CC data	no field DBH	trees may be existing at the time of acquisition, but are already non -existing at the time of field validation

Table 5. Different cases of correlation between LiDAR canopy cover values and Field DBH

4. CONCLUSION

LiDAR can serve as an important tool to accurately characterize the mangrove forest using LiDAR derivatives such as the Canopy Height, Point density distribution, and canopy cover values. Upon examining each LiDAR derivatives, particularly that of canopy height and point density distribution values, it was found out that the Rhizophoraceae mangroves that are planted in this forest mostly have stunted growth, having height values ranging from 5 to 9 meters. The study proved that the growth of Rhizophoraceae shows consistent pattern in terms of point density distribution if located at the middle part of the forest. Consequently, Rhizophoraceae that are located at the periphery part of this plantation forest have inconsistent point density clustering due to immediate exposure to certain environmental stressors. The canopy cover could also serve as an integral tool to characterize Rhizophoraceae in this type of mangrove forest. LiDAR-derived canopy cover could also be used as an initial data to understand gap dynamics and provide insights to understand the mangrove forest stand. Therefore, immediate assessment of the overall Rhizophoraceae plantation can be done by utilizing the above-mentioned LiDAR derivatives.

ACKNOWLEDGEMENTS

This research is funded by the Department of Science and Technology (DOST) under the Nationwide Detailed Resource Assessment Using LiDAR (Phil-LiDAR 2), Project 3: Forest Resource Extraction from LiDAR Surveys (FRExLS). Utmost acknowledgement is given to the Disaster Risk and Exposure Assessment for Mitigation (UP DREAM) and Phil-LiDAR 1 for the LiDAR data of the study site. Due recognition is also given to the municipality of Zambales for its assistance during the field validation survey.

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