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Estimating mean tree crown diameter of mangrove stands using aerial photo

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Abstract

Geostatistics was applied to estimate mean tree crown diameter using high spatial resolution aerial photo of three different mangrove forest structure in the Mahakam Delta, East Kalimantan, Indonesia. The variogram analysis of the aerial photo was succeeded to estimate mean tree crown diameter of mangrove forest of Mahakam Delta. The Range of variogram was used to predict mean tree crown diameter and came to result with the error about 6.19% or less than 0.5 m. Based on this study, green band looks promising but still need more exploration and further test especially for complex canopy structure such as lowland Dipterocarp forest which completely distinct to Mangrove forest. Despite of its successness, variogram was not succeed to estimate mean crown diameter of high density mangrove forest plantation sites. Close-spacing plantation suppressed tree crown growth and development. In the aerial photo, it produced smooth texture feature of tree crown with less edge of shadow. Consequently, tree crown became indistinguishable.

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Keywords: geostatistics; variogram,; crown diameter; mangrove forest; Mahakam delta

1. Introduction

Forest canopy is defined as the proportion of the forest floor covered by the vertical projection of the tree crowns [1] and recently become an important part of forest inventories [2]. It becomes a key aspect for many studies in

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forestry to improve understanding on stand and landscape structure and dynamics, and to develop suitable methods for the inventory and mapping of old-growth forests [3]. Forest canopy can also be used to predict stand volume, because tree crown that configure the canopy structure [4] has close correlation with stem diameter and the density of trees in a stand [5].

Unlike stem dbh (diameter at breast height) that can be easily measured from the ground-based standing position, tree crown measurement is considerably challenging and difficult. In lowland tropical forest, the highest tree can exceed up to 60-80 m, albeit average forest canopy height ranges between 25-45 meter [6]. Emergent trees normally occupy the upper storey of forest canopy and gain maximum of sunlight. Ground measurement of tree crown requires clear sight on the crown edges which is essentially difficult to gain in tropical forest due to overlap with other canopy stratum.

On the other hand, recent remote sensing product offers high spatial resolution imagery such as IKONOS, QuickBird, WorldView or digital aerial imagery, which brought opportunities to study forest canopy from different angle, opposite to the ground measurement. Using remote sensing image, various methods to measure stand canopy or tree crown size were developed. Pouliot et al. [7] and Brown et al. [8] utilized manual delineation and automatic detection to estimate crown size. However, in complex tropical forest, manual crown delineation using high spatial resolution image may produce user bias [9]. It missed many small crowns. It also probably merged groups of smaller crowns and interpreted it as single larger crowns [10]. Meanwhile, automated crown delineation algorithms, such as local maxima and local minima detection, do not always success for identifying the crown apex or differentiate individual trees. Both algorithms depend on the brightest pixel (local maxima) and dark pixels (local minima) on the image which adequate in coniferous or even-aged forest but often misleading in tropical forest canopy.

Another method uses variogram as part of geostatistical approach to estimate tree crown size or diameter [11]. In theory, variogram can be used to understand the relationship between scene structure and the characteristics of the variogram based on the assumption that each pixel in digital remote sensing data is realization of regionalized variable at the pixel location. Moreover, Woodcock et al. [12] and Zawadzki et al. [13] explained when variogram constructs over a particular image with infinite size then the range - a mathematical model parameter of variogram - contains information of the object size in the corresponding image. The aim of this research is to examine variogram (geostatistical method) for estimating mean tree crown diameter of mangrove forest in the Mahakam Delta using high spatial resolution data. The estimation is validated using actual field measurement data collected from ground sample plots.

2. Methods

2.1. Study area

Mangrove forest in East Kalimantan is mostly located at the estuary of major river system. There are several major rivers in this province and Mahakam is the largest and the longest one. Mahakam delta is indeed the estuary of this 700 km long of Mahakam River. In this area, mangrove covers nearly 1,500 km2. Wide and vast area of mangrove forest had attracted people to settle not only for traditional fishery-related activities but also to open aquaculture ponds. As demand on shrimp or fish product increased, the expansion of new ponds resulted in conversion of more than 50% of mangrove forest especially in the outer ring of the delta at the sea front. Hence, the establishments of sample plot on the ground for measuring crown diameter of mangrove tree were selectively laid out to capture three following mangrove forest condition that is undisturbed mangrove stands (Plot 2), young mangrove stands at the abandoned pond (Plot 1) and 12 years old mangrove plantation site (Plot 3A and 3B).

2.2. Materials

Aerial survey was conducted in February 2012 by PT. Total E&P Indonesia and produces orthorectified digital photo in RGB format, two tiles of photo covering a small patch of remaining mangrove forest (approximately 8 km^2) in the Mahakam delta, is used. Geographically, the photo was captured an area between 117.54º - 117.56º East and 0.52º - 0.56º South. This natural color aerial photo has fine spatial resolution 0.15 m and 8 bit data stored in Geo-TIFF format. In this study, only green band is used for variogram analysis due to its visual pleasantness. Tree crowns structure are more likely identified using green band compare to red and blue band. Green band reflects more energy from the sun as the source of passive sensor (e.g. digital camera) while red and blue band absorb most of them.

Fine spatial resolution of aerial photo distinguishes clearly between intact mangrove forests and mangrove plantation sites from the apparent of its canopy structure. Other land use and distinct objects such as housing, ponds dike, school, canal, rivers, walk paths and wooden bridges are also identifiable and helped a lot to plan the strategy for plot survey (Figure 1).

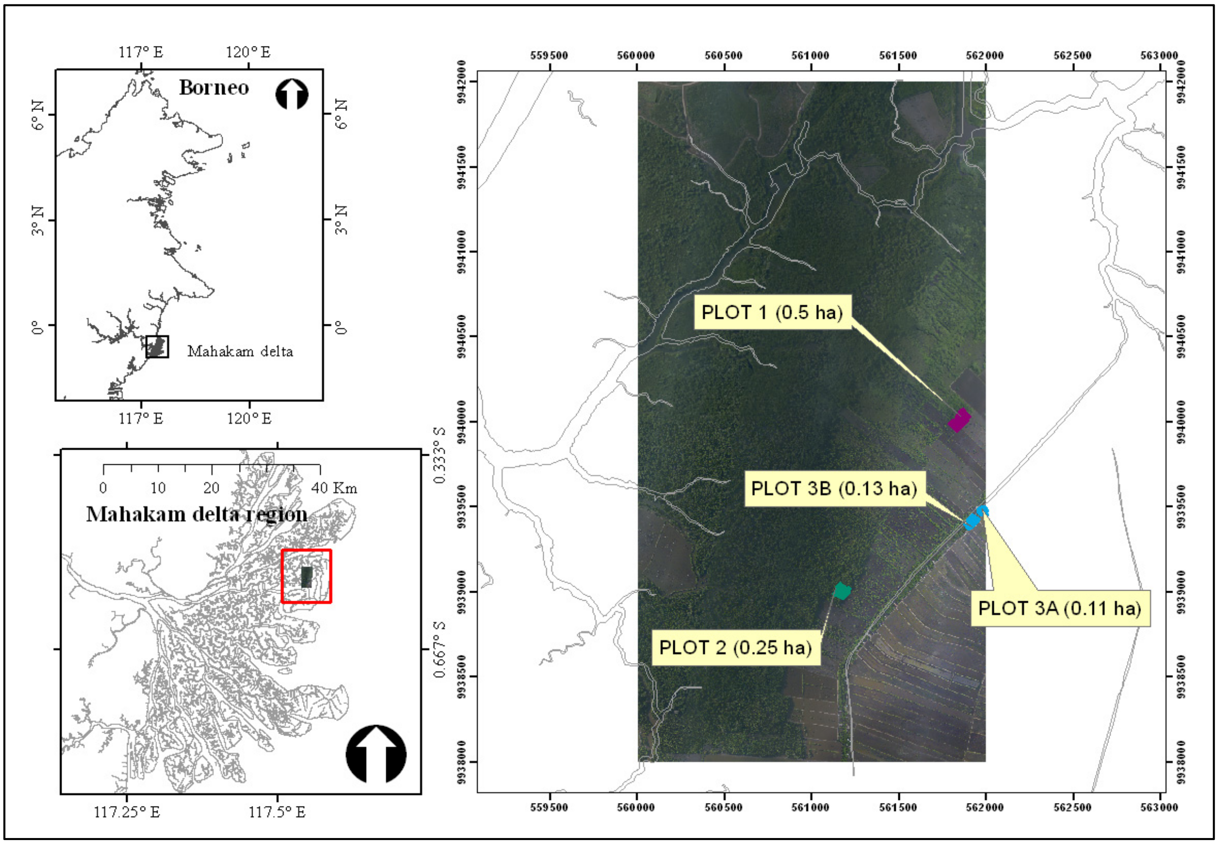

Fig. 1. Study site at Mahakam delta region and distribution of plots over an area 8 km^2 of aerial photo.

2.3. Plot establishment

Four plots were established in Mahakam delta area in August 2013. The locations of plots were represented three different mangrove conditions. Rectangular plots of 50×100 m (Plot 1) and 50×50 m (Plot 2) were set up to represent natural mangrove regeneration and intact mangrove forest, respectively. Meanwhile, two blocks of mangrove plantation forest (Plot 3A and 3B) were selected for representing artificial mangrove forest. There is no clear information when pond in plot 1 is abandoned. However, local people informed that the pond has not been actively managed in the last five years. For intact mangrove forest in plot 2, local people confirmed that this area have no experienced of major impact activities such as massive tree cutting, planting, etc.

In order to locate plot positions on the aerial photo easily, plot 1 and plot 2 used dike and pond corner as ground control point. Complete plots boundary on the photo simply drawn using plot actual size. Similar approach applied for plot 3A and 3B. However, instead of using dike as ground reference, plantation block that clearly distinguishable in the photo were used. Since man-made objects in this area are plentiful, identifying plot location in the aerial photo becomes easier.

In total, sampled plots took an area of nearly 1 ha (Fig. 2). All tree stems with dbh larger than 5 cm and their vertical crown projection to the ground were measured. Their species name was also recorded. All plots are dominated by *Rhizophora* sp. with only two other species found in the sampled plots, i.e., *Avicennia* sp. and *Xylocarpus* sp. *Avicennia* species sparsely grows in plot 1 while *Xylocarpus* species were found near to the dike in plot 2. Mangrove plantation site represented by two plots 3A and 3B are typical monoculture plantation project using *Rhizophora* species. *Avicennia* species that are found very few in this plots existed for about 12 year ago prior to the plantation project.

During fieldwork, walking in thick muddy soil and measuring tree stem diameter with high collar root position such encountered in *Rhizophora* trees were among the most challenging parts. Stem diameter was measured approximately 30 cm above the most upper collar root [14]. For young juvenile trees with no collar root, dbh was measured at normal position. A significant number of *Rhizophora* trees with more than one stem grew from the same base were another interesting ecological finding. For these unique trees, all stems were measured as individual tree as long as they meet the minimum dbh size requirement (larger than 5 cm).

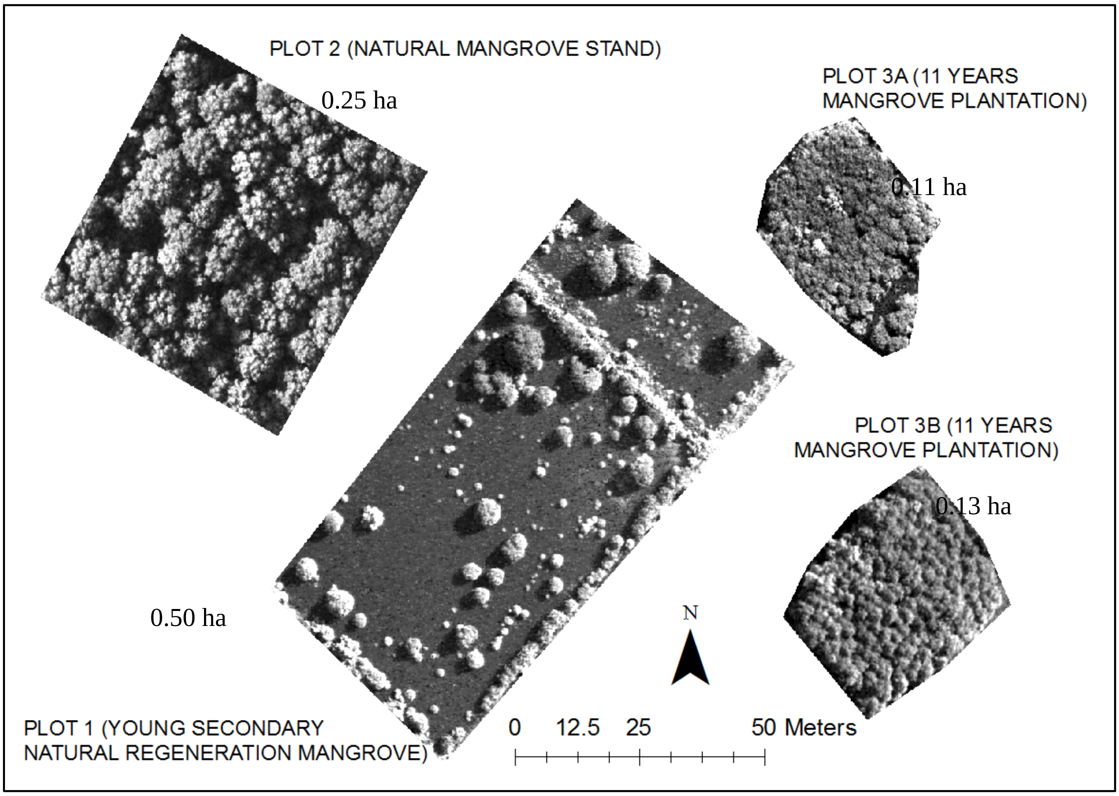

Fig. 2. Clipped aerial photo corresponds to plot position and shape (full plot field of view). Variogram analysis applied to these cropping images to estimate crown diameter of mangrove stands.

2.4. Data preparation

The geometric distortion of aerial photo is corrected using available ground control points (GCP's) and distinct features which can be identified both on the image and field such as pond dike junction. The next process will involve a geostatiscal method to estimate mean tree crown diameter of the plots.

2.5. Geostatistical method

Geostatistics works with the concept of autocorrelation of spatial data. The concept of geostatistics relies on a regionalized variable; a variable intended to recognize any phenomenon spreads in space and exhibits a certain spatial structure [15]. In term of digital aerial photo, pixel value is the only variable that can be used to detect any structure of dominant object on the image. And the structure of pixel values of green band reflects crown as an object on the image better than blue and red band because crown contains chlorophyl.

Geostatistics manifests through gammavariance function which measure the degree of spatial continuity. The variogram is two-dimensional graph of gammavariance value as a function of distance. The experimental gammavariance is derived by calculating one-half of the average squared difference in data values for every pair of data locations separated by distance (h)[13] using equation (1).

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \{z(x_i) - z(x_i + h)\}^2 \qquad (1)$$

In this study, gammavariance of all possible pairs of pixels from clipped aerial photo were computed to construct variogram graph. Principally, the gammavariance computation is limited to the size of the clipping image. The size of this clipped image will affect the variogram graph and the model. The extent or the dimension of these clipping images is so-called field of view (FOV) and it is essential in gammavariance analysis.

Technically, it is possible to put all gammavariance values and their corresponding distance at one variogram graph. However too many gammavariance values make variogram less meaningful and more likely to be unintelligible [16]. Therefore, simplification or binningis necessary by grouping gammavariance into several distance (h) classes, so-called number of lags. The span or interval of distance (h) class will determine the lag size. All gammavariance values within a distance class will be averaged. By displaying these averaged gammavariance values, variogram graph will look simpler.

Once simple variogram from binning process is obtained, a mathematical model can be fittedto figure out the underlying relationship of gammavariance and distance. This variogram model have at least three parametersthat is nugget, range and sill. Range is the distance where gammavariance reaches the highest value as product of mathematical modeling. In many studies such as Feng et al. [17], this range has been successfully estimated tree crown size especially for coniferous trees. However, in tropical forest, a different result might be obtained as canopy shape and structure are completely different to coniferous. Since range is essential for this study, it is necessary to know the sensitivity of this value in the binning process.

2.6. Range (R_v) sensitivity to different number of lags

In binning process, two parameters i.e. lag size and number of lags need to be determined. Combination of lag size and number of lags will affect the variogram model, which means it also affects the range (R_v) values. For raster format data, pixel size is a good indicator to determine the lag size [18]. In this study, the lag size was set to0.15 m for aerial photo. Number of lags determines the degree of the simplification. For example, number of lags 100 is simply means that there are 100 bins or distance classes so that gammavariance values can be classified into those bins and averaged. As a rule of thumb, the multiplication of lag size and number of lags should be about half of the largest distance among pixel pairs of clipped images [18].

In this process, different numbers of lags representing various distance classes in between one-fifth to one-third of the possible longest distance were tested. Additionally, three different mathematical models i.e. spherical, exponential and gaussian were used to derive the range value (R_v). Testing different variogram models are intended to find which model is suitable and fitted with a specific forest condition as suggested by Köhl et al. [19]. To check the sensitivity, R_v from different number of lags and different mathematical models will be put together in the chart. When R_v from different number of lags shows less variation among them, it may suggest that variogram had succeeded to estimate object size.

2.7. Mean tree crown diameter from plot ($\overline{C}d$) and mean of range ($\overline{R}_v$)

Mahakam delta comprises numerous and complex distributary channels. In the bank of this distributary channel, *Rhizophora* sp. commonly grows. According to Kitaya et al. [20], *Rhizophora* sp. has high survival rate because they are tolerance to the long tide inundation period. Hence, in Mahakam delta, this species are encountered in many abandon ponds. This species also used frequently for the afforestation projects.

In four established plots in this area, *Rhizophora* species is dominant. *Rhizophora* species often grow to be a multi-stem tree. The multi-stem tree is unique character as response to the extreme environment. It is normally found only at specific areas such as swamp forest or peat forest but not common in lowland Dipterocarp forest. Consider to this unique stem condition, mean tree crown diameter ($\overline{C}d$) of trees in the mangrove plots were summarized separately for single-stem and multi-stem tree.

With careful observation, the measurement of crown diameter projection of trees in the mangrove plots were accomplished. The mean tree crown diameter ($\overline{C}d$) from plot was then compared to the mean of range value of variogram model ($\overline{R}_v$) from different number of lags. Mean tree crown diameter ($\overline{C}d$) is calculated using the following formula:

$$\overline{C}_d = \frac{1}{n}\sum C_d \qquad (2)$$

where C_d is crown diameter of individual tree, and *n* is the number of sample trees. Meanwhile, mean of the range of variogram ($\overline{R}_v$) is calculated using the formula:

$$\overline{R}_v = \frac{1}{n}\sum R_v \qquad (3)$$

where R_v is the range value of variogram derived from specific number of lags, and *n* is the number of tested "number of lags". Error of estimation was measured as the percentage of deviation of $\overline{R}_v$ value as predictor from the observed $\overline{C}_d$ value as the reference.

3. Results and discussion

3.1. Stand structure of plot data

The result showed that *Rhizophora* sp. is dominated up to 85% of all stems in all four plots in Mahakam delta. Other species such as *Avicennia* sp. were found only 14% in plot 1, 3% in plot 3A and 6% in plot 3B. Mature *Avicennia* sp. tree was found in the plantation plots, which indicated this species, existed prior to the plantation program. On the other hand, 5% of *Xylocarpus* sp. were found in symbiosis with *Rhizophora* sp. in plot 2.

In average, multi-stem trees consists of approximately 4-5 stems in plot 1 and plot 2 but lower to 2-3 stems in two plantation site plots (3A and 3B). Tree density of plot 3A and 3B is 2,336 trees ha-1 and 3,592 trees ha-1, respectively. Meanwhile plot 1 and plot 2 has only 652 trees ha-1 and 1,584 trees ha-1, respectively (table 1).Dense vegetation in the plantation plots appeared to suppress tree growth in horizontal direction. It yielded a slim tree, with small crown and similar height.

The highest mean of dbh is measured in plot 2, the plot consists of intact mangrove trees. The maximum dbh in this plot is recorded at 28.33 cm slightly larger than maximum dbh in plot 3B. However in plot 3B, the maximum dbh was measured from *Avicennia* tree which exist prior to the plantation program.

Table 1 shows *Rhizophora* species in the plantation plots grew at rate 0.83 cm year-1 in average, meanwhile some other trees astonishingly were grew even faster exceeding 2 cm year-1. Study by Sukardjo and Yamada [21] revealed the mean increment of *Rhizophora* mucronata stand in Central Java, Indonesia was reaching up 0.89 cm year-1. *Rhizophora* sp. is one of the easily planted species and highly adapted even to the land which formerly occupied by other dominant species such as *Nypa fruticans* [22]. Besides having high survival rate [20], *Rhizophora* sp. seed is abundant in quite large quantity, easy to collect and temporarily piled. Therefore, in many mangrove plantation or afforestation project, this species is often recommended especially in Mahakam delta region.

Table 1. The summary of forest parameters (dbh and number stem per hectare) of four plots

Plot	Number stems ha^{-1}	Mean of dbh (cm)	Standard deviation (cm)	Minimum dbh (cm)	Maximum dbh (cm)
1	652	7.85	2.40	5.09	23.24
2	1584	11.41	3.88	5.09	28.33
3A	2336	9.99	2.23	5.41	16.87
3B	3592	9.98	3.11	5.09	28.01

3.2. Crown size estimation of mangrove plot

Crown size was measured through its vertical projection to the ground. But it is not a simple method, nor easy or straightforward technique as people may think. To get accurate crown size, one should have clear observation of the crown edges which in reality it is difficult to define. A good thing about crown measurement in this area is that mangrove forest has only a few canopy layers and almost symmetric, which eased the observation to determine crown edges.

Table 2. The summary of mean tree crown diameter ($\bar{C}d$) of single-stem and multi-stem trees in the plots

Plot	Tree category	Number of trees	$\bar{C}_d$(m)	Standard error
1	Single-stem trees	96	2.21	0.12
	Multi-stem trees	51	4.13	0.27
2	Single-stem trees	70	4.22	0.19
	Multi-stem trees	73	6.75	0.21
3A	Single-stem trees	40	2.79	0.09
	Multi-stem trees	82	3.34	0.11
3B	Single-stem trees	99	2.92	0.10
	Multi-stem trees	127	3.28	0.09

Table 2 shows that mean tree crown diameter ($\bar{C}d$) of the plantation plots are almost identical. The difference of $\bar{C}d$ in plot 3A and 3B is only 6 and 13 cm for multi-stem trees and single-stem trees, respectively. The intact mangrove (plot 2) exhibited the largest crown diameter which might indicated the maximum growth of crown development at this site in contrast with plot 3A and 3B where $\bar{C}d$ of multi-stem trees are among the smallest one. In fact, it is even smaller than $\bar{C}d$ of single-stem trees in plot 2. This finding suggested that close spacing plantation has suppressed crown development especially when thinning (a selective removal tree method in forestry, which intended to boost tree growth by liberating spaces) was not implemented.

3.3. Variogram with various number of lags of mangrove plots

As mentioned in earlier section, range of variogram (R_v) is used as a predictor of object size in the photo or imagery limited to certain of FOV size. In this study, the targeted object is crown diameter. As shown in figure 3, when number of lags is small (e.g. 10 or 20), variogram model responded by giving small R_v. In plot 1 and plot 2, R_v rapidly increased as the number of lags enlarged to 40 but then started to constant. When R_v starts to constant, it may suggest that object with finite size has been recognized by variogram. The most likely reason for this assumption is that object in remote sensing constructs mainly by homogenous or nearly homogenous pixel values. If equation (1) computes these homogenous pixel values to an object, it may produce almost similar gammavariance values. When R_v from different number of lags starts to constant (variation of R_v value from different number of lags is small), it means that gammavariance values are also constant or similar because the pixel value already saturated. Start from number of lags 50 to 100, variogram had recognized the same object and therefore, it gave the same R_v value. Surprisingly, in Fig. 3, all of the mathematical models i.e. spherical, exponential and Gaussian, demonstrated a similar result.

Nevertheless, slightly different result was exhibited by plot 3A and 3B where R_v values had no trend to flatten when the number of lags increased (figure 4). Opposite to plot 1 and 2, this situation might suggest that variogram was unable to recognize and estimate object through R_v values in plot 3A and 3B. These two different graphs may also give an indication that variogram succeeded to detect different crown or canopy structure of mangroves. Crown of individual tree in natural mangrove forms distinct objects as combination of crown shape, crown size and sun angle. Sun angle plays pivotal role to shape shadow in between the trees, which may segregate objects from their background. Shadows from the sun radiance helps to construct a clear crown objects. In contrast, this situation did not clearly reflect on the mangrove plantation site. Crown grew relatively homogenous in shape and size and the tree height is almost similar. In this case, when the sun radiance hit the crown of the trees, it does not produce clear crown objects. Shadows are limited and therefore, canopy surface of mangrove plantation becomes smoother and therefore, individual crown will not be segregated.

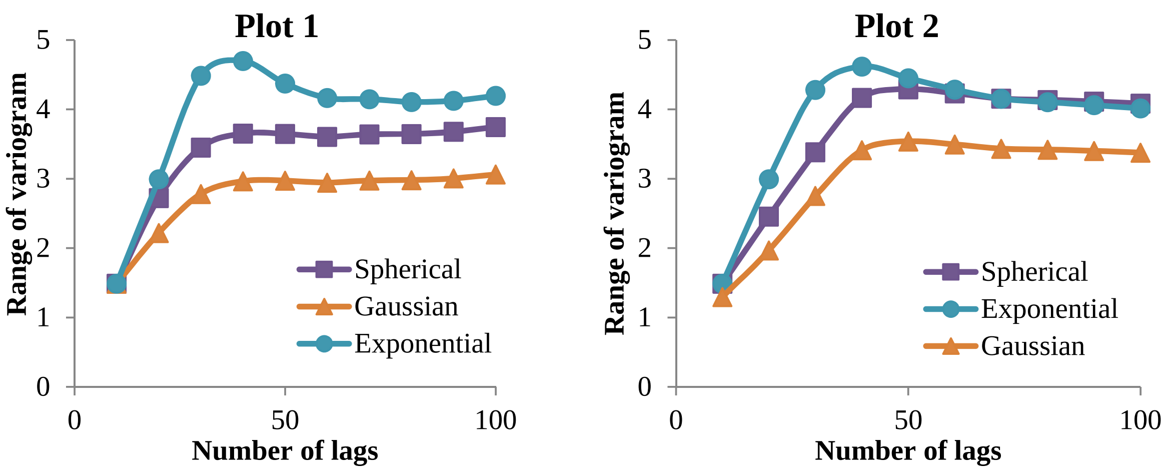

Fig. 3. Range of variogram value (Rv) analysis in response to different number of lags of plot 1 and plot 2 using green band of aerial photo.

Among three mathematical models, exponential consistently yields the highest R_v values followed by spherical and Gaussian model. To check which model has produced the lowest error as final evaluation, mean tree crown diameter ($\overline{C}d$) and mean of R_v values ($\overline{R}_v$) from different number of lags were compared. The error was calculated as the percentage of deviation of $\overline{R}_v$ from $\overline{C}d$ (Table 3 to Table 5).

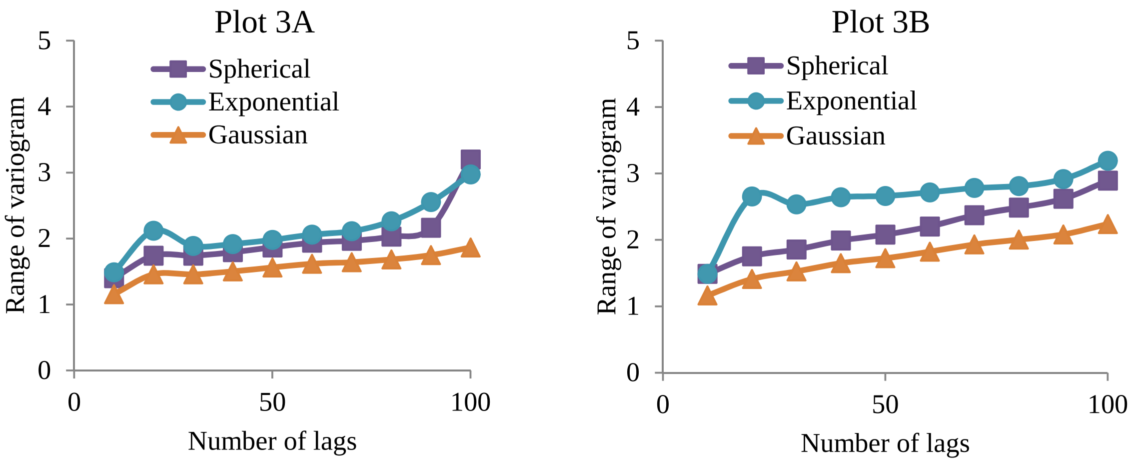

Fig. 4. Range of variogram value (Rv) in response to different number of lags of plot 3A and plot 3B using green band of aerial photo.

There is no clear explanation to this phenomenon except that multi-stem trees in plot 1 are detected in the photo as dispersed solitaire big stem trees. Meanwhile, single-stem trees are mostly small size trees, which probably less detected by variogram. In addition, for this particular situation, variogram captured larger objects better than smaller objects. In contrast, multi-stem trees of plot 2 showed larger error compared to the single-stem trees, because aerial photo captured the crown of multi-stem tree not as a group but as an individual crown. Natural growing mangrove contributed to provide enough space for crown of each stem to grow.

As it can be predicted from the previous $\bar{R}_v$, plot 3A was the only plot where the estimation of $\bar{C}d$ of single-stem and multi-stem trees were looked not so promising as the error reached 23.44% and 36.05%, respectively (Table 3 to 5). By visual interpretation, the aerial photo showed smoother canopy surface of plot 3A compared to plot 3B although the plantation on both locations took at the same year and the same species. From plot inventory dataset, some information might be interesting to explain this interesting discrepancy. Plot 3B has number of single-stem trees greater than plot 3A that is 43.8% and 32.8%, respectively. And surprisingly, the average of dbh of single-stem trees is always higher than multi-stem trees in both plots. Average dbh of single-stem trees and multi-stem trees in plot 3A is 10.8 cm and 9.9 cm, respectively. Meanwhile in plot 3B, the average dbh is 12.0 cm for single-stem trees and 9.5 cm for multi-stem trees. Hence, it appears that larger portion of single-stem tree crown in plot 3B contributed to the canopy structure more than those in plot 3A. Plot 3B has quite significant number of single-stem tree with large dbh in general.

Table 3. The percentage error of estimation of $\bar{C}d$ from $\bar{R}_v$ derived using spherical model for each of plots and tree category

Plot	Tree category	$\bar{C}_d$(m)	$\bar{R}_v$ (m)	Error	Model
1	Single-stem trees	2.211	3.328	50.52%	Spherical
	Multi-stem trees	4.134	3.328	-19.50%	Spherical
2	Single-stem trees	4.224	3.651	-13.57%	Spherical
	Multi-stem trees	6.748	3.651	-45.90%	Spherical
3A	Single-stem trees	2.789	1.983	-28.90%	Spherical
	Multi-stem trees	3.339	1.983	-40.61%	Spherical
3B	Single-stem trees	2.918	2.173	-25.53%	Spherical
	Multi-stem trees	3.279	2.173	-33.73%	Spherical

Since gammavariance calculation is limited to the field of view (FOV), it is necessary to check the consistency of variogram estimation for different FOV size. In this study, field of view is defined as the extent of satellite image or aerial photo used for gammavariance computation (e.g. satellite image cropped to the plot size). Plots 3A and 3B are too small in term of size; therefore, Plots 1 and plot 2 were used to test for the new smaller FOV. FOV was designed to include the center of the plot and follow a circle shape (C shape) and two perpendicular transects (transect A and B) as shown in figure5. Exponential mathematical model was used for generating range values (R_v) for each FOV because it produced the lowest error of estimation in average compared to spherical and gaussian (Table 3 to 5).

Table 4. The percentage error of estimation of $\overline{C}d$ from $\overline{R}_v$ derived using exponential model for each of plots and tree category

Plot	Tree category	$\overline{C}_d$(m)	$\overline{R}_v$(m)	Error	Model
1	Single-stem trees	2.211	3.878	75.40%	Exponential
	Multi-stem trees	4.134	3.878	-6.19%*	Exponential
2	Single-stem trees	4.224	3.846	-8.96%*	Exponential
	Multi-stem trees	6.748	3.846	-43.01%	Exponential
3A	Single-stem trees	2.789	2.135	-23.44%	Exponential
	Multi-stem trees	3.339	2.135	-36.05%	Exponential
3B	Single-stem trees	2.918	2.639	-9.55%*	Exponential
	Multi-stem trees	3.279	2.639	-19.50%	Exponential

* deviation below 10% is less than 0.5 meter different

In general, $\overline{R}_v$ from exponential model produced better mean tree crown diameter ($\overline{C}d$) estimation. Gaussian model yielded $\overline{R}_v$ close to $\overline{C}d$ for single-stem tree in plot 1 with 23.19% of error. Meanwhile, multi-stem trees at the same plot had smaller error of 6.19% obtained from exponential model. Plot 2 which is similar to plot 1 as natural growing mangrove, showed different result where $\overline{C}d$ of single-stem trees had successfully estimated using exponential model with error only 8.96% but less accurate for multi-stem trees where error reached 43.01%.

Table 5. The percentage error of estimation of $\overline{C}d$ from $\overline{R}_v$ derived using gaussian model for each of plots and tree category

Plot	Tree category	$\overline{C}_d$(m)	$\overline{R}_v$ (m)	Error	Model
1	Single-stem trees	2.211	2.740	23.93%	Gaussian
	Multi-stem trees	4.134	2.740	-33.72%	Gaussian
2	Single-stem trees	4.224	3.010	-28.74%	Gaussian
	Multi-stem trees	6.748	3.010	-55.39%	Gaussian
3A	Single-stem trees	2.789	1.569	-43.74%	Gaussian
	Multi-stem trees	3.339	1.569	-53.01%	Gaussian
3B	Single-stem trees	2.918	1.755	-39.86%	Gaussian
	Multi-stem trees	3.279	1.755	-46.48%	Gaussian

During field measurement, GPS recorded the position of trees inside plot 1 and plot 2 but not for plot 3A and plot 3B. This is also the reason FOV was only tested for plot 1 and plot 2. In order to get fair comparison, only trees falls inside the FOV were used to calculate mean tree crown diameter of each FOV. The results are presented in Table 6 and 7.

Table 6. The percentage error of estimation of $\overline{R}_v$ from $\overline{C}d$ of each FOV in plot 1. Exponential model was used to derive range values

Tree category	$\overline{C}_d$(m)			$\overline{R}_v$ (m)			Error		
	Shape A	Shape B	Shape C	Shape A	Shape B	Shape C	Shape A	Shape B	Shape C
Single-stem trees	2.50	Ø	1.88	3.84	2.21	3.07	53.60%	Ø	63.73%
Multi-stem trees	3.69	1.37	3.18	3.84	2.21	3.07	4.07%*	61.31%	-3.31%*

* deviation below 10% is less than 0.5 meter different
Ø = no single-stem tree exists inside the shape Btransect

Table 7. The percentage error of estimation of $\bar{R}_v$ from $\bar{C}d$ of each FOV in plot 2. Exponential model was used to derive range values

Tree category	$\bar{C}_d$(m)			$\bar{R}_v$ (m)			Error		
	Shape A	Shape B	Shape C	Shape A	Shape B	Shape C	Shape A	Shape B	Shape C
Single-stem trees	3.99	4.04	4.19	4.64	3.32	4.11	16.29%	-17.74%	-1.98%*
Multi-stem trees	6.68	6.42	6.69	4.64	3.32	4.11	-30.53%	-48.25%	-38.60%

* deviation below 10% is less than 0.5 meter different

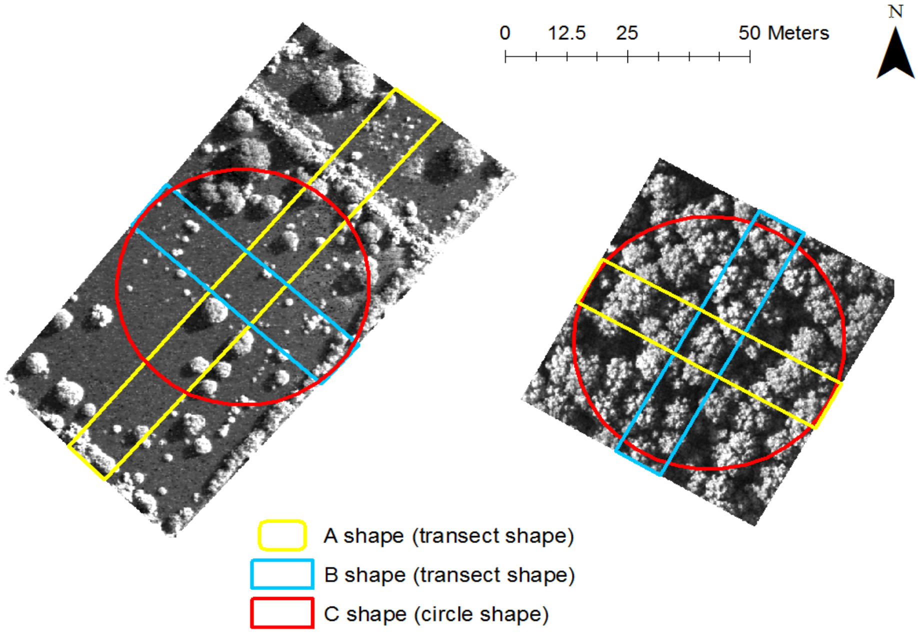

Fig. 5. Different tested of field of view (FOV) of plot 1 and 2 in mangrove forest.

In general, variogram analyses of different FOV in mangrove forest have slightly similar results to the previous analysis using full plotsize of FOV. Multi-stem trees are estimated better than single-stem trees in plot 1 (Table 6) simply because multi-stem trees are dominant growing in these FOV's (Fig. 5). However, among three FOV's, transect B exhibited the highest error of estimation (61.31%). The most likely reason addresses this error is because the variogram had estimated the object that is actually a line of planted mangrove trees, which was planted on the edge of the pond. This line planted trees can be visually seen in the FOV of plot 1 which is located at the lower part of transect B.

Meanwhile, single-stem trees in plot 2 were estimated better than multi-stem trees (Table 7). Field observation may give the answer to this issue. From field observation of multi-stem trees in plot 2, it was found that only one or two stems of the tree clump that may reach to the top of the canopy. Other stems are not tall enough to occupy the canopy because they are younger, just recently growth. In mangrove forest, stems of multi-stem tree may grow one by one and obviously not at the same time. Therefore, it makes sense if only one stem emerge to reach the top of canopy layer. This fact may answer why crown of single-stem trees are well estimated compared to multi-stem trees.

In addition, FOV of C shape produced the lowest error of estimation, in contrast with FOV of transect A and B. From Fig. 5, it appears that FOA of transect A coincidentally captured bigger crown and FOV of transect B captured small crown objects. Meanwhile, the FOV of C shape occupied bigger areas compare to transect A and B and hence, FOV of C shape captured more objects and making the estimation of mean tree crown diameter better.

4. Conclusion

Geostatistics proved to be a promising method to estimate one of the most difficult parameter of tree in the forest that is crown size. Range of variogram (R_v) estimates mean tree crown diameter in relatively low error as it compared to the plot data. Green spectral band of aerial photo (0.15 m spatial resolution) is suggested in this study and show a good result but not limited to other spectral bands to test in the future study.Variogram shows better estimation in the natural forest sites rather than plantation sites because their canopy structure reflects different signature in the aerial photo.

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