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The Examination of The Satellite Image-Based Growth Curve Model Within Mangrove Forest

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Abstract

Developing growth curve for forest and environmental management is a crucial activity in forestry planning. This paper describes a proposed technique for developing a growth curve based on the SPOT 6 satellite imageries. The most critical step in developing a model is on pre-processing the images, particularly during performing the radiometric correction such as reducing the thin cloud. The pre-processing includes geometric correction, radiometric correction with image regression, and index calculation, while the processing technique include training area selection, growth curve development, and selection. The study found that the image regression offered good correction to the haze-distorted digital number. The corrected digital number was successfully implemented to evaluate the most accurate growth-curve for predicting mangrove. Of the four growth curve models, i.e., Standard classical, Richards, Gompertz, and Weibull models, it was found that the Richards is the most accurate model in predicting the mean annual increment and current annual increment. The study concluded that the growth curve model developed using high-resolution satellite image provides comparable accuracy compared to the terrestrial method. The model derived using remote sensing has about 9.16% standard of error, better than those from terrestrial data with 15.45% standard of error.

Keywords: Gompertz model, growth curve model, Richards model, standard classical model, Weibull model

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Introduction

The accurate estimate of the stand growth is crucial for establishing sustainable forest management. The stand growth information is required by the forestry planner for establishing yield regulation. Estimating the stand growth by conventional terrestrial method is costly, laborious, time consuming, and frequently too difficult to be applied. In tropical forest ecosystem, it is quite hard to establish a permanent plot and do a re-measurement consistently at a certain interval. The periodically re-measured sample plots may produce unbiased estimates of the growth for the forest during the period of the measurement. To obtain such information, up to now, only few researches that deliberately measure the mangrove growth, particularly in tropical region. In the tropics, the preparation of standing growth curves by terrestrial methods is less attractive work, since it is laborious, exhausting, and need a complicated preparation. Now, a development of the growth models has been an option, since it can provide an efficient way to prepare standing stock forecast (Vanclay 1994). With a growth model, forest manager can examine the likely outcomes with several alternatives of the silvicultural systems and management options. Previous studies (Cita, 2014; Karmali, 2015) carried out a terrestrial approach to measure the increment of natural mangrove stand in Kubu Raya, West Kalimantan. Evaluation of the terrestrial-based growth model for biological resource forecasting had been examined by many researches (Damgaard et al., 2002; Santoso, 2008).

With the development of information technology and remote sensing, especially the high-resolution images, the benefit of satellite imagery is increasingly recognized in the forestry sector, either to assess the stand quality or to predict the dimension of stands, such as stand stocks, stands growth, and forest monitoring. Recently, there is a high opportunity to take advantage of the existing imageries being procured commercially or for free. In a certain degree of accuracy, the reliability of satellite imagery utilization for forest inventory, standing stocks, biomass estimates, stand damage, forest degradation, forest cover changes, and the preparation of

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forest thematic maps have been proven by previous studies (Yin et al., 2003; Yusandi, 2015)). Remote sensing methods are very effective to be applied in a large areas although sometimes the accuracy are lower than the terrestrial methods. For that, the combination of terrestrial and remote sensing methods is a good approach for obtaining more accurate estimation with cheaper data and information, so that it can be used in predicting mangrove growth. Remote sensing technology is highly prospective considering its low cost, fast, multi-time, and multi-resolution, so it can be one of the alternative technologies in various forestry activities especially in estimating the value of stand growth.

During the establishment of the forest working plan, the accurate measurement result is required for predicting the final, as well as the intermediate yields. Therefore, a reliable, accurate, fast, and low cost measurement technique is required. This study emphasizes on the development of methods of standing growth of mangrove forest using remote sensing in West Kalimantan. As we knew that the conventional measurement of mangrove forest increment is still very limited due to the limitation of human resource, time consuming, and costly. Now, the estimation of natural mangrove forests might be done using high-resolution satellite remote sensing technology (Yusandi 2015). In addition, the use of the spectral band, i.e., green, red, and infrared band would be promising, since the spectral reflectance of each band is closely correlated with tree age, chlorophyll content, biomass, and moisture content in vegetation. This estimation was done with consideration of the availability of multi-time data (time series) within the last 25 years.

In this study, the estimation of stand age was derived from time series satellite imageries. The spatial information of the stand age was then used to determine the location of field measurement plots representing each age class with a cross-sectional approach. Field measurement plots were chosen in such a way that assuming the site quality and the disturbance obtained of the stand are similar (Cita 2014; Karmali 2015). Furthermore, the field measured data is correlated with SPOT 6 image. The main objective of this study is to establish and obtain the best model of mangrove growth curve using the SPOT 6 digital image. The specific objective is to assess the mean annual increment (MAI) and current annual increment (CAI) of mangrove stand during a rotation period.

Methods

Study site The study area includes mangrove forest ecosystem and swamp forest. Both are located in Kubu Raya District, West Kalimantan Province. The dominant species are *Rhizophora apiculata*, *Bruguiera gymnorrhiza*, and *Xylocarpus granatum* (Cita, 2014; Karmali, 2015). Data collection had been done since 2013, followed by data processing from February to November 2017 at Forest Resource Inventory Laboratory, Department of Forest Management, Faculty of Forestry, IPB University.

Data, hardware, and software Other data used are high-resolution SPOT 6 images that include blue, green, red, and infrared bands acquired in 2015 and field measured data on 50 × 50 m sample plots representing stand age (post logging). Field data include tree diameter, tree height, pole, sapling, tillers, litter, and necro mass (dead wood and debris). Measurements were made in 2013, 2015, and 2016. Supporting data include map of forest area function, forest land cover map, and location of settlement. Processing and data analysis was carried using the desktop computer with ERDAS Imagine and Microsoft Excel for statistical analysis.

Study procedure The steps of the study include: (1) data collection, both main and supporting data from relevant agencies, (2) image pre-processing including data format conversion, geometric correction and selection of research area (AOI), and radiometric correction using image regression approach. The correction of atmospheric disturbances by regressing this digital value can justify the digital value of the Landsat TM image pixels recorded at different date (Devaranavadgi et al., 2013). Haze and noise reduction as well as image enhancement were also performed in this study (Ali et al., 2016; Dimyati et al., 2018).

Image processing

A review of the age of logged-over stands and plot locations A review of the map was conducted to update the land cover present in the image. Determination of plot cluster location for the measurement of increment which is a continuation of previous research (Cita, 2014; Karmali, 2015), on logged-over forests of 1989, 1998, 2002, 2006, 2008, and 2009. Stand age used in this research is age of logged-over secondary forest. Each representative stand age was then measured by three to four clusters. Cluster is a collection, group, set, or combination of certain plots that have similar characteristics. Each cluster is split back into a plot measuring 50 × 50 m in which it is divided into 25 × 25 m.

Image-based vegetation index and volume estimation model development The vegetation index is widely used to sharpen or enhance the contrast of the different grades of vegetation cover density resulting in a more representative and significant new image. The transformation of the vegetation index is performed to obtain the vegetation index value of each pixel to be used as the independent variable for regression with the terrestrial measurement volume data. The vegetation index used in this study is NRGI. Prior to develop volume estimation model, the data were evaluated with a normality test. Normality test results show that the normal distributed free variable is found in Ln transition (Natural logarithm of normalized difference vegetation index, Ln NDVI; Natural logarithm of green normalized difference vegetation index, Ln GNDVI; Natural logarithm of red-green index, Ln RGI; and Natural logarithm of transformed vegetation index, Ln TVI)). Furthermore, the data were used to develop standing stock estimation model.

Terrestrial-based and image-based growth curve model of mangrove Based on the results of regression analysis, the best model obtained $V = 0.066752e^{22.839611*NRGI}$ with the coefficient of determination has a value R^2 of 93.92%, R^2adj of 92.80%, and SR of 12.7%. Field observation results and estimation results were then used for establishing the growth curve. In general, the growth curve will make the "S" form which is often called the S-shaped curve (sigmoid curve). If the growth curve form is sigmoid, the value of "y" will range from 0 to 1. To get the value of the volume growth curve, then

Table 1 The growth model forms evaluated in this study

Growth model's name	Growth model form	Remarks
Standard logistic model	$y = y_{min} + (y_{max} - y_{min})/(1 + e^{[-a\,(x-c)]})$	e = the natural logarithm base (also known as Euler number), c = the x-value of the sigmoid's midpoint, a = the steepness or slope of the curve, and y = standing stock volume ($m^3\ ha^{-1}$) at the age x.
Richards model	$y = y_{min} + (y_{max} - y_{min})/[(1 + v\, e^{-a\,(x-c)}]^{1/v}$	
Gompertz model	$y = y_{max}{}^{e^{-e^{-a(x-c)}}}$	
Weibull model	$y = y_{max}(1 - e^{-ax^{b}})$	

the equation should be enhanced with the curve's minimum value (y_{min}) and the maximum value (y_{max}) of the yield or standing stock volume in ($m^3 ha^{-1}$). This original shape curve is then called as the standard logistic function. In this study, beside the standard logistic model, the authors also evaluated the modified growth function established by Richards, Gompertz, and Weibull as tabulated in Table 1. Many researchers have tested the reliability of the growth curve applied to the field of biology (Sanchez-gonzalez et al., 2005; Sedmak & Scheer, 2012) to calculate growth.

In Richards function constant v is inserted, if v = 1 then the equation will be the same as the classical equation. The Richards function had been several times examined in estimating the biological forest growth either in tree diameter or height of some species (Sanchez-Gonzalez et al., 2005; Sedmak & Scheer, 2012). In the Gompertz function, the maximum rate of growth is reached at the inflection of the curve. The Weibull function is excellent for empirical curve fitting and it ensures that size or density is zero at time zero, which is useful in many applications (Birch, 1999).

Accuracy of the model The standard error of the estimate (SE-y) is a measure of the accuracy of predictions. The examination of the mangrove growth curve model was done using standard error value (SE-y) between the estimated result (V_{fit}) and the observed value (V_{act}), which is expressed by the common formula as follows Equation *[1]*:

$$SE = \sqrt{\frac{t_{\alpha/2(df)}\left[\Sigma(V_{act}-V_{fit})^2\right] / df}{V_{act}}} \times 100\% \qquad [1]$$

note: SE = standard error; df = degrees of freedom (n-1); t (α/2, df) = t value of confidence level (α) 5%; V_{act} = actual data value of standing growth ($m^3\ ha^{-1}$); V_{fit} = estimated value of standing growth ($m^3\ ha^{-1}$). In the determination of the growth function using satellite imagery, the recommended model is a function that has a small SE, consistently giving in predicting growth rate variables such as MAI and CAI.

Calculating volume increment The forest increment was divided into the CAI, Periodic Increment (PI), and MAI (Prodan, 1968). This study was conducted by using volume parameters with two different approaches, i.e., MAI and CAI which are calculated by the following Equation *[2]*:

$$MAI = \frac{V_t}{t}\ ; \text{and } CAI = \frac{V_t - V_{t-1}}{dt} \qquad [2]$$

note: V_t = volume at age i ($m^3\ ha^{-1}$), V_{t-1} = previous volume ($m^3\ ha^{-1}$), t = age (years), dt = time interval measurement (year).

Results and Discussion

Identification of the growth model Of the four forms of logistical model studied using terrestrial data, i.e., standard logistic, Richards, Gompertz, and Weibull models, it was found that the Richards model provides the smallest SE-y of 14.29% (Table 2). However, the difference of the SE-y values among those models are very small. The Gompertz model is the second best model after the Richards, having the SE-y values of 14.34%.

As presented earlier, to facilitate the assessment of the standing stock, the development of the growth curve model is carried out by utilizing the digital remote sensing data, as summarized in Table 2. It is shown that the Richards model gives the most accurate results compared to others, with the smallest Se-y value among the Standard logistic, Weibull, and Gompertz models. In comparison with the terrestrial-based model, the study also shows that the image-based growth models give better accuracy of yield prediction of only 5% than the terrestrial methods ,i.e., about 14.6%. These results indicate that the model of the growth provided an accurate assessment with a tolerable error. This is in line with the Prodan (1968) that the allowable error is about 25% for models of regression equation with single variable, or 20% for regression model with two variables. Thus, it could be recognized that both the terrestrial-based and the image-based models provide a relatively accurate estimate of mangrove growth.

Based on the four models, it is possible to estimate the volume of mangrove stands at any given age, which is then applicable for calculating the MAI and CAI values of each model, either using terrestrial-based or image-based approach (Table 3). From the age estimate differences between the terrestrial-based and image-based approaches, it is known that the model having similar estimation with small estimate differences between terrestrial and image estimates are standard logistic and Richards model. In terms of the consistency of the age estimation in recognizing the maximum MAI and CAI, the Richards model is more consistent than the standard model, since both the CAI and the MAI have only one-year difference. With the Richards model, the maximum value of image-based CAI was achieved at 18 years old, while maximum value of terrestrial-

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Table 2 The terrestrial-based and image-based growth models developed using Standard, Richards, Gompertz, and Weibull equations

Symbol	Model types	Model parameters		a	C	v	SE-y%
		Min vol	Max vol				
Terrestrial-based model							
TS	Standard log	0.00	367.59	0.30452	18.61856	0.00000	14.63
TR	Richards	0.00	3.86	0.16111	18.82441	0.22111	14.29
TG	Gompertz	0.00	449.25	0.15945	7.28809	0.00000	14.34
TW	Weibull	0.00	681.73	0.00009	2.75269	0.00000	14.91
Image-based model							
MS	Standard log	0.00	300.87	0.30086	17.02067	0.00000	6.34
MR	Richards	-4.23	6.72	0.11832	8.49417	0.14117	5.86
MG	Gompertz	0.00	359.30	0.16471	6.01518	0.00000	6.62
MW	Weibull	0.00	326.36	0.00009	3.08510	0.00000	6.18

Table 3 The maximum CAI, MAI, and their corresponding age using terrestrial-based and image-based model

Parameter	Standard		Richards		Gompertz		Weibull	
The maximum value of CAI & MAI (m^3 $ha^{-1}year^{-1}$)								
	CAI	MAI	CAI	MAI	CAI	MAI	CAI	MAI
Ter.Incr	27.9	12.9	24.1	12.9	24.1	12.9	24.9	15.3
Img.Incr	22.5	11.2	18.6	11.3	19.9	11.2	19.5	11.2
Age at the maximum value of CAI and MAI (year)								
Ter.Incr	19	25	19	28	19	28	26	35
Img.Incr	18	23	18	27	17	25	18	25
Age.Dif	1	2	1	1	2	3	8	10

Ter.Incr = terrestrial-based increment; Img.Incr = Image-based increment; Ter.Age= the stand age at the maximum terrestrial-based increment; Img.Age= the stand age at the maximum image-based increment; Age.Dif = difference between ages estimated by terrestrial and image-based models.

based CAI was found at 19 years old. Similarly, the estimated maximum value of MAI with Richards model was achieved at 28 years old, while the terrestrial approach, found the maximum MAI at 27 years old, with only one year difference. The prediction with the image-based model resulted to the maximum CAI and MAI age values, one year faster than those from the terrestrial-based model. This study shows that the image-based growth curve obtain the maximum estimates of CAI and MAI that are not significantly different from the actual data, especially those produced by Richards model. The model that produced a considerable difference was the Weibull model with an 8 year difference for CAI and 10 years for MAI. With this Weibull model, there is a high gap between the terrestrial-based model and image-based model.

With the image-based Richards model, the maximum MAI value at age 27 is 11.26 m^3 ha^{-1} $year^{-1}$, while with the terrestrial data, the MAI value at the same age is 12.87 m^3 ha^{-1} $year^{-1}$. At this 27-year old stand, there is about 13.36% (1.63 m^3 ha^{-1} $year^{-1}$) deviation, where the image-based have lower estimate than the terrestrial model. In terms of stand yields, the image-based model estimates the standing stock of mangrove at 27-year old is about 304.1 m^3ha^{-1}, lower than the terrestrial-based model providing at about 347.6 m^3 ha^{-1}. From a management perspective the terrestrial-based approach seem provide over-estimated standing stock, but with the image-based estimate allows more sustainable forest management.

The terrestrial measurement (Cita, 2014) shows that MAI value over 24 years is about 9.280 m^3 ha^{-1}, slightly lower than the image-based model obtained in this study (11.06 m^3ha^{-1}); while the CAI calculated by (Cita, 2014) found 12.31 m^3ha^{-1}, lower than those obtained by image-based in this study, i.e., 14.81 m^3ha^{-1}. In comparison with the terrestrial-based estimates, the image-based estimates are closer to the terrestrial measurement (Cita, 2014). The image-based approach results are also close to the results obtained other research Karmali (2015), providing MAI prediction about

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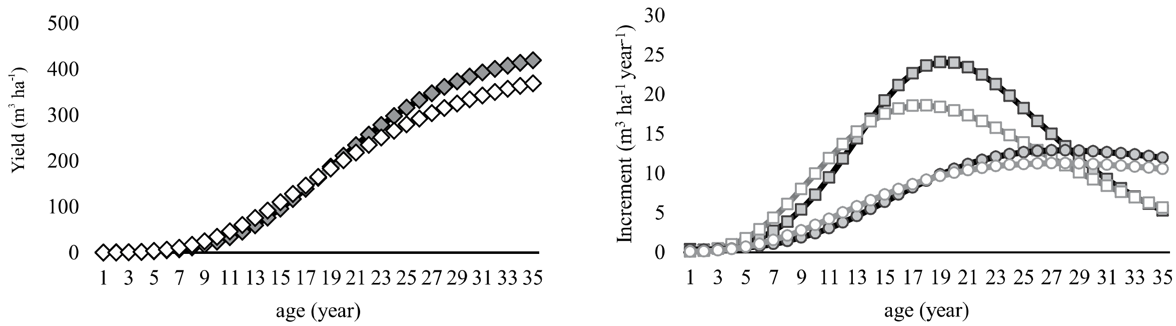

Vfit TR = standing stock estimate using terrestrial approach; Vfit_CR = standing stock estimate using image approach; CAI CR = image-based CAI; MAI CR = MAI-based image, terrestrial CAI TR = terrestrial-based CAI; MAI TR = terrestrial-based MAI; Vfit_TR (—◆—); Vfit_TR (—◇—); CAI TR (—■—), CAI CR (—□—), MAI TR (—●—), MCAI CR (—○—).

Figure 1 The terrestrial-based and image-based Richards growth models of mangrove stand (a) , CAI and MAI derived from the terrestrial-based and image-base Richards model (b).

11.0 m^3ha^{-1} at 26 years old, while the image-based is about 11.24 m^3ha^{-1}.

In general, standing stocks tend to increase as the stand age increase, as depicted in Figure 1a. The curve of the mangrove standing stock with the image-based model approach has a gentle slope than the terrestrial-based model. Up to the middle age, 18 years, the image approach yielded greater estimates than the terrestrial approach. Conversely, after the age stand is older than 18 years then terrestrial-based approaches are more likely have higher estimate values. The difference in the yield values continue to increase as the increase of the stand age.

In the growth curve of mangrove with SPOT 6 image approach, very rapid growth achieved at age 18 years (Figure 1b), then gradually slowed down. The growth continues to occur with age 35 years. Age 18 years on the sigmoid curve, CAI is the maximum, this age as a half-value because when 18 years of age occurs maximum annual running increments. However, this study shows that the average annual increment declines since the age of 27 years. With Richards growth function, mangrove stands have not reached asymptotically until age 35 years.

After the initial growth phase, the plant will experience rapid growth acceleration close to the turning point and after the inflection point, the growth continue to increase before entering the asymptotic phase to experience slow growth (tend to stagnate) (Prodan, 1968). The initial growth phase of a terrestrial-based growth curve begins at 6 to 10 years, from 9 to 27 years of age with an adult growth stage, and after 24 years of age ends with a declining MAI value. With a terrestrial-based model, the results of the calculation of the increment tend to be higher than the image-based approach. An image-based volume growth curve produces an underestimate volume of terrestrial-based volume growth over the age range of 17 years. The calculation of this stand growth model produces excellent value for image-based and terrestrial-based approaches, besides that this model is reliable because the growth of the stand follows the growth rule of sigmoid-shaped growth.

The growth of the standing stock is influenced by stand density and silviculture treatments and stewardship management (Hardjana, 2010) the species competition to obtain growing space may also inhibit the increment (Istomo et al., 1999). Management of forest stands is a way of managing forests to obtain high yields in harvesting while maintaining forest sustainability. The point of intersection between the MAI and CAI curves is the age indicating the stand already reaches the maximum increments. The intersection between MAI and CAI curves can be used to determine the harvest time (Gunawansyah, 2006). When the curve of MAI and CAI is intersected then at that age the stand could be harvested to obtain optimal results. The MAI and CAI curves will intersect at the maximum MAI value. The image-based MAI and CAI curves intersected at the age of 27 years with MAI value of 11.26 m^3 $ha^{-1}year^{-1}$ and yielding standing stock of 304.07 m^3ha^{-1}, whereas in terrestrial-based MAI and CAI curves intersected at 28 years old with a MAI value of 12.89 $m^3ha^{-1}year^{-1}$ and a standing stock of 315.06 m^3ha^{-1}.

The study also shows that the calculation of the value of the image-based standing stock shows a smaller value with the cutting life time faster than terrestrial-based volume. With this information, it is known that the estimation of an image-based volume yields a slightly lower value than a terrestrial-based volume. Based on these results it is known that the maximum cutting cycle (mature cutting age) of mangrove would occur at the age of 27–28 years. In this study site, logging activities and yield arrangement are done with a 20 year cutting cycle. From this study, it can be concluded that the logging activities should be carried out with a cutting cycle of at least 27 years to obtain optimal results in forest management.

The MAI values of mangrove volumes tend to fluctuate starting from 3 year old stand age (Cita, 2014). The MAI values are ranging from 0.97 m^3 ha^{-1} $year^{-1}$ at 3 years-old up to 9.28 m^3 ha^{-1} $year^{-1}$ at the 24 years-old. This study found that the MAI and CAI curves have not been intersected until the age of 24 years. The standing volume of the stands in this study is almost similar to Cita (2014) but shows the age of harvesting is faster than those from terrestrial-based prediction. Similarly, when compared with Karmali's study (Karmali, 2014), the standing stock provided in this study showed a faster cycle, i.e., at 26 years old, the curve of MAI and CAI is not crossed yet. That is, the growth estimation generated in this study, both from terrestrial-based and image-based estimates provide a similar estimation. The best model in estimating the growth came from the Richards' model.

Conclusion

The study concludes that a high resolution remote sensing image could be used to develop a yield curve of mangrove with an accurate estimate having only 5% of standard error value, better than a terrestrial-based growth model that has a 14.6% standard error. The image-based growth curve is y = 4.63 + 275.599/(1+*exp*[-0.35(*x*16.51)]) while the terrestrial-based growth curve is y = 4.23 + 328.728/(1+*exp*[-0.37(*x*17.86)]). This concludes that the image based growth model could be used to estimate increment (CAI and MAI) as well as to determine the optimal harvesting age. The terrestrial-based growth curve concluded that the highest CAI occurred at the age of 19 years with a growth rate of 24.06 $m^3ha^{-1}year^{-1}$, while on the image-based growth model, the maximum CAI was achieved at 18 years at a rate of 18.57 $m^3ha^{-1}year^{-1}$. With the image approach, standing volume at 18 years was 164.66 m^3ha^{-1}, while with terrestrial approach, the standing volume at 19 years was 186.95 m^3ha^{-1}. With the image approach, maximum MAI value of mangrove forest was reached at age 27 years with 11.26 $m^3ha^{-1}year^{-1}$ increment, while terrestrial approach was achieved at 28 years old with 12.89 ha^{-1} $year^{-1}$ increment.

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