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STUDY ON THE USE OF SMALL FORMAT NON-METRIC AERIAL PHOTOS FOR ESTABLISHING AERIAL TEAK STAND VOLUME TABLE (*A case study in Randublatung Forest Management Unit, PT. Perhutani Unit I, Central Java*)

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ABSTRAK

*Penelitian ini mengkaji tentang pemanfaatan foto udara non-metrik format kecil (SFNAP) guna menyusun tabel volume udara tegakan jati (*aerial stand volume table of teak wood) *di KPH Randublatung, Perum Perhutani Unit I, Jawa Tengah. Sebagai perbandingan, pengkajian terhadap penggunaan potret udara metrik konvensional (CAP) juga dilakukan. Hasil penelitian menunjukkan bahwa secara teknis SFNAP layak digunakan untuk mengestimasi potensi tegakan sebagaimana ditunjukkan oleh hasil tes statistik. Model terbaik untuk estimasi volume tegakan jati menggunakan SFNAP di lokasi penelitian adalah V = 52,4 – 0,469 C (r^2 = 76,2%), sedangkan model terbaik menggunakan CAP adalah V = 32,4 – 0,246 C (r^2 = 69,1%).*

INTRODUCTION

During the last three decades, forest as a natural resource given a significant contribution to the Indonesia's economic growth. To keep its existence and sustainability, it should be well managed. This forest resource can only be well managed when supported by accurate and reliable data that could be detected through forest inventory. Due to the vastness of the forest area, the terrestrial inventory method is usually cost consuming. Alternatively, the application of remote sensing technique through the application of aerial photographs and satellite imagery followed by adequate ground checking are more preferable. In Java, teak wood (*Tectona grandis L.f*) has been long time as a main forest product that consumed by most of population either for their life or for industrial intake. Randublatung forest management unit (Kesatuan Pemangkuan Hutan/KPH), is one of the concession areas of PT. Perhutani that recently sufferred from illegal cutting. To monitor and inventory the remaining forest stand in accurate and speedy manner, there is a need to use remote sensing technique, particularly using large scale of aerial photos.

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Now, availability of non-metric cameras, which technically become more and more sophisticated, provided an opportunity that aerial photos with a small format could be able to substitute conventional aerial photos (CAP) usually taken with metric cameras.

To support the government programs in natural resources inventory (NRI), especially for production forest, now, PT. Perhutani had established forest mapping and inventory programs using SFNAP. The work presented in this research was a part of the work initiated by the cooperation between PT. Waindo SpecTerra and the Geodetic Engineering Department, Gadjah Mada University on Forest Mapping Project using small format aerial photos. It is expected that the result of SFNAP would be applicable in forest inventory, such as estimating stand or tree volumes.

The small format non-metric aerial photos (SFNAP) used in this study is aerial photos taken from small/light aircraft using 35 mm or 70 mm type camera and has standard picture format of 2.4 x 3.6 cm or 5.5 x 5.5 cm. Warner *et al* (1996) noted that small format aerial photography provides a low-cost source of aerial photo with simple technology. It could be applied when aerial photos are needed immediately at a low cost, e.g. disaster mitigation (flooding, earthquakes). Jaya and Cahyono (2001) found that the SFNAPs are feasible to be used for forest interpretation. In particular, planners, managers and decision-makers need an up-to-date data to monitor and control the developments in fast changing areas (e.g. urban and sub-urban areas). The small format image quality depend on: (1) *the subject*, which will have certain qualities, such as terrain contrast, lighting and atmospheric haze; (2) *the camera lens quality*; (3) *the type of film used, granularity and tonal quality*; (4) *the exposure and film processing*; (5) *the degree of apparent image motion* and (6) *the print quality*.

Objectives

The main objective of this study is to evaluate the technical applicability of Small Format Non-metric Aerial Photograph in establishing aerial stand volume table of teak forest in comparison with the CAP.

METHODS

Study area and data

Major of the study area is part located in Banjarrejo, Kradenan and Randublatung, Jati Districts, Regency of Blora, while the rest is located in Gabus District, Regency of Grobogan, Forest Management Unit (KPH) Randublatung Central Java. The areas extend from 111°20’ to 111°28’ East longitude (Perum Perhutani, 1993), and from 7°10’ to 7°15’ South latitude. This research was conducted from February to August 2001.

The photos examined in this study were small format non-metric aerial photos acquired in 2001 and conventional (metric) aerial photos acquired in 1992. Data processing was done in several places namely PT. Waindo SpecTerra, BTIC building - SEAMEO – BIOTROP, Laboratory of Aerial Photo Interpretation, Faculty of Forestry, Bogor Agriculture University and SPH Salatiga. Field observations were done within

Randublatung Forest Management Unit (Kesatuan Pemangkuan Hutan/KPH), Bekutuk and Ngliron Forest Division (Bagian Hutan / BH).

Tools and equipment used were light aircraft (KitFox™ series 5 voyager) with 3 passengers, camera Canon EOS 1000, stereoscope, parallax bar, micrometer wedge, crown density scale, measuring tape, compass, hagameter and GPS Garmin 38.

Data processing were used are Arc View for processing SDH-PDE, ERMapper 6,0, MapInfo 5, Ozy Explorer, AutoCAD 2000, Transform (Geodetic Department, UGM) for UTM - Polyeder transformation, Minitab 11 for statistic calculation, Excel and Microsoft Word 2000 for reporting.

General Procedures

SFNAP data acquisition

The procedure of data acquisition was adopted from the work of PT. Waindo SpecTerra in collaboration with the Geodetic Engineering Department, the University Gadjah Mada on Forest Mapping Project using small format aerial photos. According to Haryuatmanto (1995), the procedure of data collection using small format non-metric aerial photography technique, includes (1) data recording using 35 mm camera, (2) making ground control using GPS-Video and (3) photo acquisition. The specifications of SFNAP are as follows:

Photograph	:	small format non-metric aerial photo
Camera focal length	:	35 mm
Flying height average	:	1500 m
Photo Scale	:	1: 8000
Film size	:	2.4 cm x 3.6 cm
Photo Size	:	15.2 cm x 10.1 cm
Photo Type	:	Color
Run	:	20
Photo ID	:	18024-18025
Date of photo acquisition	:	February, 2001
Courtesy	:	PT. Waindo Specterra

Photo interpretation

The steps of image interpretation implemented in this study consisted of (1) selection of sampling plot, (2) choosing aerial photo both CAP and SFNAP and (3) interpretation of stand variables such as crown cover (C), tree height (*H*), crown diameter (*D*) and number of tree (*N*). Technical procedure for measuring *C, H, D* and *N* follows the standard method as described in Paine (1981). Number of plots that were interpreted on the SFNAP and CAP are 25 and 26 plots, respectively. These sampling plots were selected in such manner so they can represent available stand age, bonita (site index) in each forest division. Tables 1 and 2 describe the bonita (site index), stand age and forest division represented by sample plots in the both SFNAP and the CAP, respectively.

Table 1. CAP plot sampling

Cutting/planting plot	Year of planting	Bonita (site index)	Stand age	Forest Division
86	1979	3.5	12	Ngliron
87a	1971	4-4.5	20	Ngliron
88ab	1958	4	33	Ngliron
127	1934	3.5	57	Bekutuk
128	1933	4-4.5	58	Bekutuk

Table 2. SFNAP plot sampling

Cutting/planting plot	Year of planting	Bonita (site index)	Stand age	Forest Division
86	1979	3	22	Ngliron
87a	1971	3	30	Ngliron
88ab	1958	4	43	Ngliron
127	1934	3.5 - 4	67	Bekutuk
128	1933	4.5	68	Bekutuk
74	1957	3	44	Ngliron
76b	1946	3.5	55	Ngliron
76d	1952	3.5	49	Ngliron
77c	1963	3	38	Ngliron

Ground measurement

To establish the regression model expressing the relationship between stand variables and stand volume, the plots interpreted in the SFNAP were also checked in the fields. The field measurements were done between April and June 2001. For 26 sample plots measured on the CAP, the field data were derived from the tally sheet collected by PT. Perhutani in 1991. It should be noted that the CAPs were taken 1992. The ground activities covered in this research are measurement of tree height, tree diameter, and counting of tree number per plot. The tree height from the base until top of the tree crown was measured using hagameter. The diameter of tree was measured at the breast height. These variables are used to predict the total tree volume based on Local Volume Table.

The sampling plots were selected using systematic sampling with random start. The 0.1-ha ground sample plots were laid out across the stand, in which the distance between plot was 200 m x 200 m. The coordinate of plot location was mapped using GPS.

Data analysis

Analysis of the data included (1) data processing and (2) establishment of the regression model for both the CAP and SFNAP.

(1) Data processing

Prior to establish the regression model, the field data were processed into stand volume per plot (m^3/plot). Furthermore, the ground stand volume was treated as dependent variable (*V*), while the stand variables measured on the photos such as crown cover (*C*), stand height (*H*), crown diameter (*D*) and number of tree (*N*) were treated as independent variables.

(2) Establishment of the best regression model

The regression models examined in this study are simple and multiple regressions. To build the model of stand volume from aerial photo, it is necessary to select the most appropriate variables and model. Various researches found that the relationship between the stand volume and the stand variable were in the form of linear, logarithmic and or exponential model. In this study, selection of the model was based upon practical and statistical considerations. The best regression model is the model that explains the close relationship between predictor (dependent variable), *y*, and independent variable, *x*. During selection of the model, the best model should consider the fewer number of independent variables in the equation and the easiness level on measuring those independent variables in the photos.

Statistically, determination of the best model was based on statistic of *F* and coefficient correlation (*r*) test. F-test was used for examining the significance of regression. If the calculated F exceeds the critical F-value in the table (95% confidence level), then it means that at least one coefficient of regression is significant (reject the hypothesis Ho: $\beta_1=0$ running a risk of less than 5% of being wrong). In the particular case of fitting a straight line, this F-test for "regression" is equivalent to the t-test, when testing individual coefficient (Draper and Smith, 1981). The r-test performed in this study was intended to measure whether the linear association between x and y is significant ($r > 0$). The coefficient regression and coefficient of regression are closely related but provide different interpretation. The coefficient of regression is a measure of the size of the change in *y* that can be predicted when a unit change is made in *x*.

RESULTS AND DISCUSSION

Coefficient correlation

Table 3. Simple regressions using CAP

Linear regression equation	Coefficient correlation (r)	r_{table} (0.05)	r_{table} (0.01)
$V = 32.4 – 0.246\ C$ $R\text{-}Sq = 69.1\%$	0.831	0.374	0.478
$V = 0,98 + 0.474\ H$ $R\text{-}Sq = 43.3\%$	0.658		
$V = 3.93 + 1.46\ D$ $R\text{-}Sq = 52.4\%$	0.724		
$V = 18.9 – 0.628\ N$ $R\text{-}Sq = 51.2\%$	0.716		

Table 4. Simple regressions using SFNAP

Linear regression equation	Coefficient of correlation (r)	r_{table} (0.05)	r_{table} (0.01)
$V = 54.2 – 0.469\ C$ $R\text{-}Sq = 76.2\%$	0.873	0.381	0.487
$V = -0.29 + 0.584\ H$ $R\text{-}Sq = 36.2\%$	0.602		
$V = 3.77 + 1.34\ D$ $R\text{-}Sq = 49.1\%$	0.601		
$V = 18.4 – 0.425\ N$ $R\text{-}Sq = 59.7\%$	0.773		

In Table 3 it was shown that the calculated r-values of *C*, *H*, *D* and *N* are all higher than r_{table} both at the 95% (0.374) and 99% (0.478) confidence levels. These mean that the relationships between *V* and *C*, *H*, *D* or *N* measured from conventional aerial photo (CAP) are closely related at the 95% and 99% confidence levels.

In comparison with the use of SFNAP, all of the *C*, *H*, *D* and *N* variables measured on SFNAP (Table 4) also have calculated r-value higher than r_{table} value of 0.381 at the 95% confidence level or 0.487 at the 99% confidence levels. This describes that the relationship between V and *C*, *H*, *D* and *N* measured on the SFNAP are statistically close. Among the r-values obtained, the r-values between *V* and *H* either measured on SFNAP or CAP somehow lower. This is might due to the difficulty in measuring *H* precisely on the photos, especially to place the floating mark exactly at the base of the tree. Measuring *C* and/or *N* is a little bit easier than measuring *H*. Using the SFNAP, the correlation between *D* and *V* is also lower than the correlation between *V* and *N*; and *V* and *C*.

Table 5. Multiple regressions

	Multiple Regression	Coefficient of correlation (*r*)	r_{table} *(0.05)*	r_{table} *(0.01)*
SFNAP	*V* = 40.3 - 0.309 *C* - 0.070 *N* *R-Sq* = 65.4 %	0.808	0.381	0.487
	Log V = 4.50 - 1.70 *Log C* - 0.100 *Log N*	0.633	4.25	
	Ln V = 4.51 - 0.0221 *C* - 0.00594 *N*	0.653		
CAP	*V* = 33.0 - 0.204 *C* - 0.363 *N* *R-Sq* = 52.0 %	0.721	0.374	0.487
	Log V = 3.52 - 1.08 Log *C* - 0.393 *Log N*	0.496	4.23	
	Ln V = 4.04 - 0.0145 *C* - 0.0358 *N*	0.482		

To compare their relationship, the use of multiple regression was also reformed. Table 5 shows that r-values of multiple regression derived either from CAP or SFNAP is higher than r_{table}. In comparison with the simple regression, the multiple regression in predicting using *C* and *N* variables decrease r-values from 0.873 to 0.808. The same pattern was also found on multiple regressions derived from the CAP, where the calculated r-values decrease significantly from 0.831 to 0.721. These results explained that the addition of *N* variable degraded the estimation accuracy. Ultimately, it could be concluded that the use of only *C* variable could provide better estimation.

In comparison with the previous research, Suar (1993) found that the best model for estimating teak stand volume in BKPH Cikampek, KPH Purwakarta is $V = -10.2 + 0.169$ N + 8.2*D* having $r^2 = 0.538$, while Effendi (1998) found the best model for estimating teak stand volume in KPH Jombang is of $V = 0.0013182\ C^{0.989}\ D^{2,5}$, having $r^2 = 0{,}851$. The work of Perum Perhutani and Fakultas Kehutanan IPB (1998) in KPH Nganjuk, Madiun and Jombang, found that the best models were made using variables *C* and *D*. The above results coincided with the study results obtained in this study, in which the inclusion of *C* always performs the best model.

Test for significance of regression

Statistical test for evaluating the significance of regression was performed. As described in Table 6, the calculated F value of *C*, *H*, *D* and *N* variables exceed the critical F value in table (F_{table}) either at the 95% or 99% confidence level. This means that each variable has a significant role in estimating stand volume. The *C* variable is the most significant variable than *H*, *D* or *N*. The test for evaluating coefficient of regression for predicting stand volume using *C*, *H, and D* & *N* variables measured on the SFNAP is shown in Table 7.

Table 6. F-test for significance of simple regression using CAP

	Source	*DF*	*SS*	*MS*	F_{cal}	$F_{(0.05)}$	$F_{(0.01)}$
V = f (C)	Regression Error	1 16	151.26 67.53	151.26 4.22	35.84	4.23	7.72
	Total	17	218.78				
V = f (H)	Regression Error	1 24	213.54 279.17	213.54 11.63	18.36	4.23	7.72
	Total	25	492.71				
V = f (D)	Regression Error	1 24	258.17 234.54	258.17 9.77	26.42	4.23	7.72
	Total	25	492.71				
V = f (N)	Regression Error	1 22	172.05 163.85	172.05 7.45	23.10	4.23	7.72
	Total	23	335.90				

Remarks:
DF = degree of freedom; SS = sum of square; MS = mean of square; F cal = F calculate; F (0.05) = F table at 95% confidence level; F (0.01) = F table at 99% confidence level.

Table 7. F-test for significance of simple regression using SFNAP

	Source	*DF*	*SS*	*MS*	F_{ocal}	$F_{(0.05)}$	$F_{(0.01)}$
V = f (C)	Regression Error	1 19	260.70 81.28	260.70 4.28	60.94	4.25	7.87
	Total	20	341.98				
V = f (H)	Regression Error	1 22	159.65 281.45	159.65 12.79	12.48	4.25	7.87
	Total	23	441.10				
V = f (D)	Regression Error	1 23	233.53 241.66	233.53 10.51	22.23	4.25	7.87
	Total	24	475.19				
V = f (N)	Regression Error	1 19	123.33 83.20	123.33 4.38	28.16	4.25	7.87
	Total	20	206.53				

Remarks:
DF = degree of freedom; SS = sum of square; MS = mean of square; F cal = F calculate; F (0.05) = F table at 95% confidence level; F (0.01) = F table at 99% confidence level.

As also described in Table 7, the calculated F values of *C*, *H* and *D* and *N* variables are higher than F_{table} either at the 95% or 99% confidence level. This expresses that on the 95% and 99% confidence levels the *C*, *H*, *D* and *N* are good predictor of stand volume. According to Drapper and Smith (1981) the estimator model is feasible to be used when the value of $F_{calculate}$ is four time larger than the F_{table}. As shown in Tables 6 and 7, except using *H* variable for SFNAP, all stand variables either measured on the SFNAP or the CAP are feasible to be used to estimate stand volume using simple linear regression. This concludes that the stand volume in the study site can be predicted by using crown cover (*C*), tree height (*H*) and crown diameter (*D*) measured on the SFNAP. The models are depicted in Table 4. Among these variables, the *C* variable was the most recommended variable for predicting stand volume through the SFNAP. The use of multiple regression could not be recommended since it reduces the accuracy.

The best model

For practical purposes, Jaya (1986) expressed that the best model should be simple; using only few numbers of independent variables and those variables should be easy to be measured. For practical reason, the easiest variables include *C* (crown cover) and *N* (number of tree). Both *C* and *N* variables are easy to be measured providing consistent interpretation result. Based on r-values and F-test, the best models for the study site are:

$V = 54.2 – 0.469\ C$ for the SFNAP and

$V = 32.4 – 0.246\ C$ for the CAP

The aerial volume tables for these equations are shown in Tables 8 and 9.

Table 8. Aerial stand volume table of teak wood using the SFNAP

Crown cover (%)	Crown cover (%)								
	1	2	3	4	5	6	7	8	9
10	490	486	481	476	472	467	462	458	453
20	444	439	434	429	425	420	415	411	406
30	397	392	387	383	378	373	368	364	359
40	350	345	340	336	331	326	322	317	312
50	303	298	293	289	284	279	275	270	265
60	256	251	247	242	237	232	228	223	218
70	209	204	200	195	190	186	181	176	171
80	162	157	153	148	143	139	134	129	125
90	115	111	106	101	96	92	87	82	78
100	68								

Remarks: The values inside the table express the stand volume (m^3/ha).
Example: the volume of stand having crown cover 65% is 237 m^3/ha

Table 9. Aerial stand volume table of teak wood using the CAP

Crown cover (%)	Crown cover (%)								
	1	2	3	4	5	6	7	8	9
10	297	294	292	290	287	285	282	280	277
20	272	270	267	265	263	260	258	255	253
30	248	245	243	240	238	235	233	231	228
40	223	221	218	216	213	211	208	206	203
50	199	196	194	191	189	186	184	181	179
60	174	171	169	167	164	162	159	157	154
70	149	147	144	142	140	137	135	132	130
80	125	122	120	117	115	112	110	108	105
90	100	98	95	93	90	88	85	83	80
100	76								

Remarks: The values inside the table express the stand volume (m^3/ha).
Example: the volume of stand having crown cover 65% is 164 m^3/ha

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results obtained in this study, the following conclusions were derived:

1. The SFNAPs are technically feasible to be used for estimating stand volume of teak forest, through establishment of aerial stand volume table.
2. Either on the conventional aerial photo or small format non-metric aerial photograph the study found that there are a strong correlation between the stand volume and *C*, *H*, *D* and *N* variables.
3. The most accurate model for estimating the stand volume are:
   V = 54.2 – 0.469 C (r^2 = 76.2%) for SFNAP, and
   V = 32.4 – 0.246 C (r^2 = 69.1%) for CAP

Recommendation

1. The research result obtained in this study is specific to the study area. The model verification in other site should be performed. The quality of photos must also be analyzed before it used at the operational scale.

2. For application, a comparison study to evaluate the efficiency of SFNAP & CAP is recommended to be conducted