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AN EVALUATION OF STATISTICAL RELIABILITY IN SMS's PRE-FELLING INVENTORY: THE CASE FOR CONFIDENCE AND ERROR LEVELS

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WAN RAZALI, W. M. & WAN MOHD. SHUKRI, W. A. 1999. An evaluation of statistical reliability in SMS's pre-felling inventory: the case for confidence and error levels. This study was carried out on a randomly chosen 40-ha (800 × 500 m) forest area within the 50-ha Demography Project of the Forest Research Institute Malaysia (FRIM) in Pasoh Forest Reserve, Negri Sembilan. Out of the 40-ha study area, an area of 30 ha was used as a calibration data set and the remaining 10 ha area as a validation data set. The percentage sample or intensity of sampling was determined at various confidence and error levels, viz. from 80 to 95% confidence with ± 5 to ± 20% error in estimating tree density, basal area and volume. Results obtained from both calibration and validation data sets were used to assess the notion that the statistical reliability of the SMS's Pre-felling inventory (by the Forestry Department Peninsular Malaysia) is at 95% confidence and ± 20% error levels. At 1% sampling intensity to inventory density of trees 5 - < 15 cm dbh in 10 × 10 m plot, the confidence and error levels of respectively 95% and ± 15% or 90% and ± 10% would be more reliable. The 95% and ± 15% levels are also true for estimating basal area and volume. At 5% sampling intensity of trees 15 - < 30cm dbh (20 × 25 m plot), its reliability is at 90% confidence and ± 10% error limits for either tree density, basal area or volume estimation. However, at 10% sampling intensity of trees ≥ 30 m dbh (20 × 50 m plot), the 95% confidence and ± 20% error hold true in estimating tree volume. The implications of attaching confidence and error levels to the sampling intensity are also discussed.

Keyword: SMS's pre-felling inventory - statistical reliability - confidence levels - error levels

WAN RAZALI, W. M. & WAN MOHD. SHUKRI, W. A. 1999. Penilaian kesahihan data dalam inventori sebelum tebangan Sistem Pengurusan Memilih: tahap keyakinan dan tahap ralat. Kajian ini dijalankan di kawasan seluas 40 ha (800 × 500 m) yang dipilih secara rawak yang terletak di dalam kawasan Projek Demografi 50-ha oleh Institut Penyelidikan Perhutanan Malaysia (FRIM) di Hutan Simpanan Pasoh, Negeri Sembilan. Seluas 30 ha daripada kawasan seluas 40 ha tersebut digunakan sebagai kawasan set data kalibrasi dan 10 ha sebagai kawasan set data kesahihan. Intensiti pensampelan ditentukan pada pelbagai tahap keyakinan dan tahap ralat iaitu daripada 80 hingga 95% keyakinan dengan ± 5 hingga ± 20% ralat dalam menganggarkan pensampelan bilangan pokok, luas pangkal dan isipadu. Keputusan yang diperoleh daripada kedua-dua set data kalibrasi dan set data kesahihan digunakan bagi menentukan bahawa inventori sebelum tebangan yang diamalkan oleh Jabatan Perhutanan Semenanjung Malaysia ialah pada tahap keyakinan 95% dan tahap ralat ±20%. Tahap keyakinan 95% dan ralat ±15% atau 90% dan ralat ±10% didapati lebih menghampiri pada intensiti pensampelan 1% yang digunakan bagi pensampelan bilangan pokok 5-< 15 cm garis pusat aras dada dalam petak 10 × 10 m. Tahap keyakinan 95% dan ralat ±15% juga didapati boleh digunakan bagi pensampelan luas pangkal dan isipadu. Pada intensiti pensampelan 5 % bagi pokok bersaiz 15-< 30 cm garis pusat aras dada (petak 20 × 25 m) untuk menganggarkan bilangan, luas pangkal dan isipadu adalah lebih teliti sekiranya dilakukan pada tahap keyakinan 90% dan ralat ± 10%. Walau bagaimanapun, intensiti pensampelan 10% adalah benar bagi menyampel pokok ≥ 30 cm dpd. pada plot 20 × 50 m. Implikasi hubungan tahap keyakinan dan ralat dengan intensiti pensampelan turut dibincangkan.

Introduction

The forestry sector in Malaysia has always played an important role in the national economy. In 1995 it contributed about RM11 billion in export earnings to the country. This constituted 7% of the total export earnings. It also provided direct employment to about 243 000 persons (KPU 1996).

To manage the country's valuable forest, various silviculture systems have been tried out in Malaysia. The Selective Management System (SMS) was introduced in 1978 to allow for more flexible timber harvesting regimes which are consistent with the need to safeguard the environment and at the same time to take advantage of the demand of the timber market.

The SMS requires the selection of management (harvesting) regimes based on inventory data which will encourage the subsequent harvest of the same forest area as early as between 25 years and 40 years while maintaining species diversity almost close to that of the original forest. Current pre-felling (Pre-F) forest inventory practice in Peninsular Malaysia uses different plot sizes resulting in different inventory intensities. Table 1 summarises briefly the inventory plot information of the current Pre-F inventory.

Table 1. Plot information in SMS's pre-felling inventory

Plot	Size (m)	Area (m^2)	Area (ha)	Inventory intensity (%)	Tree size class
First	20 × 50	1000	0.1000	10.00	≥ 45 cm dbh
					30 to < 45 cm dbh
Second	20 × 25	500	0.0500	5.00	15 to < 30 cm dbh
Third	10 × 10	100	0.0100	1.00	5 to < 15 cm dbh
Fourth	5 × 5	25	0.0025	0.25	1.5 m height to < 5 cm dbh
Fifth	2 × 2	4	0.0004	0.04	15 cm height to < 1.5 m height

As presented at the 32nd Majlis Urusan Silvikultur (MAJURUS, a Forestry Department council on forest management and silviculture) meeting in 1995, the confidence and error levels used are 95% and ± 20% respectively (Wan Razali *et al.* 1997). However, we are not sure on what tree parameters the percentage intensities were based. To date, we have been unable to verify or refute the above statistical reliability, namely confidence and error levels, and the tree parameters (density, basal area, or volume) used, hence this paper. Additionally, the objective of this paper was to verify the Pre-F sampling intensities associated with the 20 × 50 m, 20 × 25 m and 10 x 10 m plots.

Methodology

Overview

This study was carried out on a 40-ha (500 × 800 m) virgin forest area. The data were obtained from the 50-ha Demography Project established by the Forest Research Institute Malaysia (FRIM) in Pasoh Forest Reserve, Negri Sembilan.

The study area was divided into contiguous 5 x 5 m plots (quadrats). A 100 percent enumeration of all trees 1 cm dbh and above was carried out in this 50-ha Demography Project. However, due to the critical importance of trees ≥ 5 cm dbh as immediate future crop trees, we then concentrated on an evaluating of SMS's Pre-F statistical reliability of tree sizes as inventoried in 20 × 50 m, 20 × 25 m and 10 × 10 m plots. The commercial species classification, tree size class and inventory plot sizes currently used by the Forestry Department Peninsular Malaysia (FDPM 1986) were applied in our analyses. The species were grouped as follows:

1. Dipterocarp, meranti (DM)
2. Dipterocarp, non-meranti (DNM)
3. All dipterocarps (ALL DIPT.)
4. Non-dipterocarp, light hardwoods (ND. LHW)
5. Non-dipterocarp, medium hardwoods (ND. MHW)
6. Non-dipterocarp, heavy hardwoods (ND. HHW)
7. Miscellaneous (MISC.)
8. All non-dipterocarps (ALL NON-DIPT.)

The design of the 50-ha permanent plot is illustrated in Figure 1, and Figure 2 shows the topography map of the area. The data for the 20 × 50 m, 20 × 25 m and 10 × 10 m plots were obtained by adding the contiguous 5 × 5 m plots, the longer sides of the plots being perpendicular to the contour lines in order to capture as much ecological and topographical variations as possible.

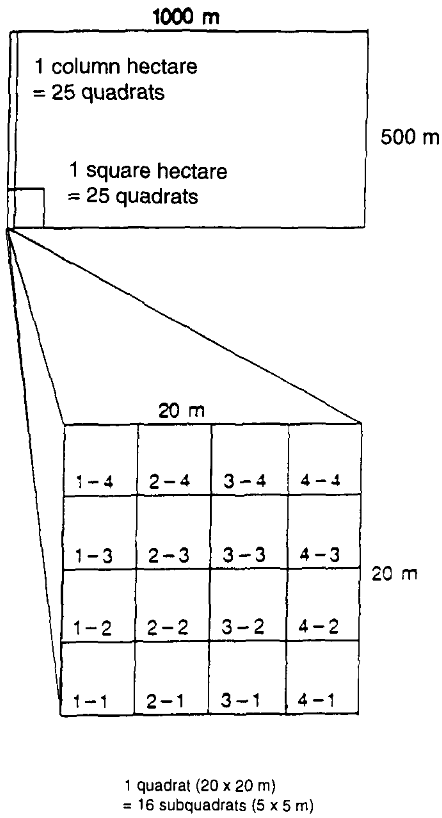

Figure 1. The 50-ha plot subdivided into columns (20 × 500 m), rows (20 × 1000 m), quadrats (20 × 20 m) and subquadrats (5 × 5 m)

Source: Manokaran *et al.* (1990).

Analysis of data

The original data for each tree were transferred from the field form to computer files in two steps. First, map coordinates were generated from the field map by digitising. A database program was used to generate sequential tag numbers. Tag number, species code, and diameter were then manually entered into a separate file. This system created a database file for each of the 20-m quadrat (Manokaran *et al.* 1990). For this study, the selected 40-ha area started from 100 to 900 m East and from 0 to 500 m North as shown in Figure 2.

Calibration data

Data from 30 ha out of the 40-ha study area were used to calculate sampling intensities for different confidence and error levels based on tree density, basal area and volume.

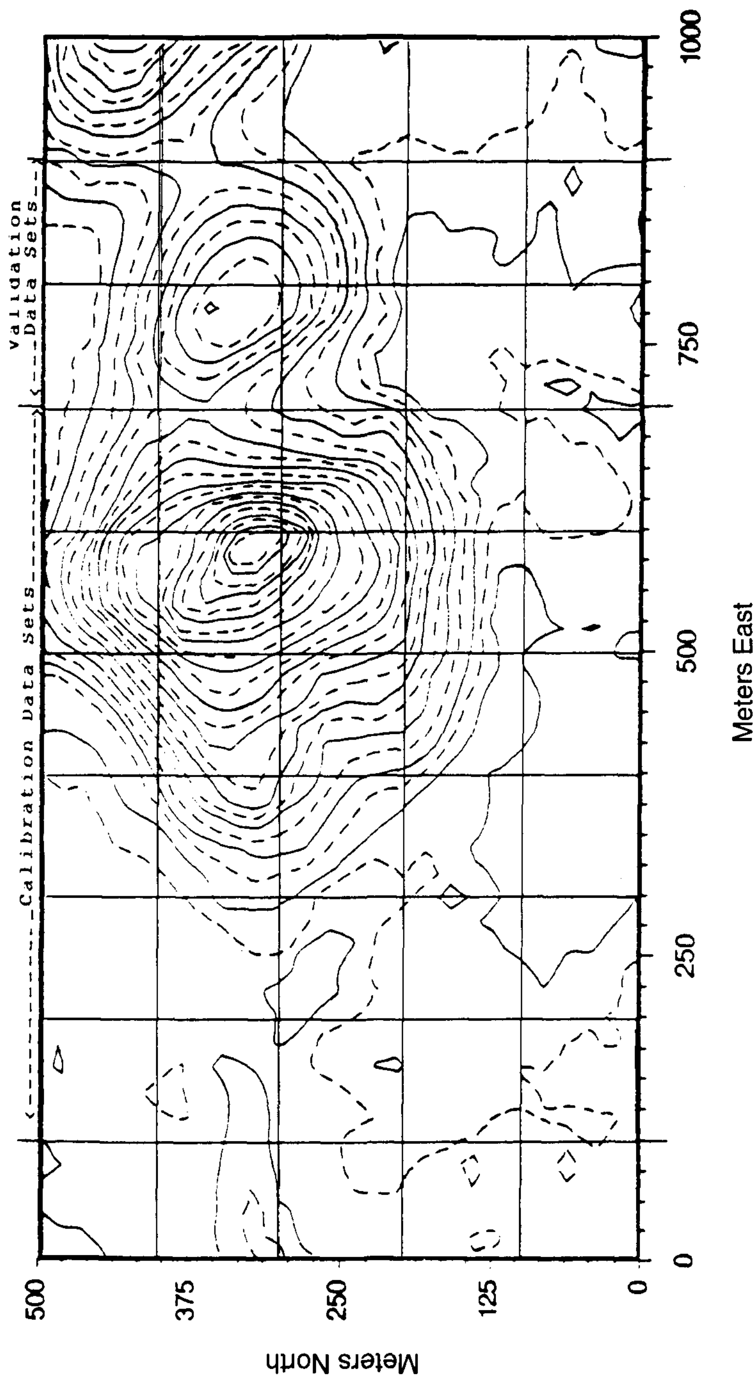

Figure 2. Topographic map of the PFR 50-ha plot, at 1 m contour intervals, and gridded at 1 ha units.

Source: Manokaran *et al.* (1990).

Calculation of tree volume

Volume for each tree of 5 cm dbh and above was calculated using the volume equation as shown below. All measurements were in metric units. Gross volumes were calculated using the formula (FDPM 1985) for a cylinder with a form factor (f) of 0.65.

All species groups: $\geq$ 5 cm dbh

$$V = (\pi \times dbh^2 \times L \times f) / (40\,000)$$

where

V = gross volume in m^3
π = 3.1416
dbh = diameter at breast height in cm
L = merchantable height in m

Average merchantable heights (L) were based on the various dbh classes:

5 m (1 log-length) for the 5 - < 15 cm dbh class
10 m (2 log-length) for the 15 - < 60 cm dbh class
15 m (3 log-length) for the 60 - < 75 cm dbh class
20 m (4 log-length) for trees 75 cm dbh and above

However, for trees 5 - < 15 cm dbh, merchantable height was considered as 1 log-length with the form factor of 0.75.

Calculation of tree basal area

The basal area of all trees for all species groups included in this study was calculated using the general formula as stated below:

$$BA = \frac{\pi\, dbh^2}{40\,000}$$

where

BA = basal area in m^2

Calculation of plot variance

The population variance (V) for each quadrat size was computed since the exact tree parameter (Y) in each quadrat was known. The process was repeated for each species group and size class.

Cochran (1977) stated that if $\bar{y}$ denotes the observed parameter sample mean and $\hat{Y} = N\bar{y}$ estimates the population total, the variance of $\bar{y}$ is:

$$V_{\bar{y}} = V/n\ (1 - n/N)$$

where n is the number of quadrats sampled and N the total population of a particular sized quadrat. (1 - n/N) is the finite population correction.

Hence,

$$V_{\hat{Y}} = \frac{N^2 V}{n} \frac{(N - n)}{N}$$

$$= V/n\ N(N - n)$$

The distribution of $\hat{Y}$ will be approximately normal, even for a small number of n, and the error of the estimate will be less than

$$Z_{1-\alpha/2} \sqrt{V/n\ N\ (N/n)} \quad \ldots\ldots\ldots\ldots \quad (1)$$

with the confidence $(1-\alpha)100$ percent; $Z_{1-\alpha/2}$ is the value from a table of standard normal.

Determination of sample size requirement

If we want the percentage error to be less than $E = \rho Y$ with $(1-\alpha)100$ percent confidence, where ρ is the percentage error as a proportion and thus making E the true desired error in absolute units, then the sample size required can be obtained from equation (1) as given by Lang *et al.* (1971):

$$n = \frac{Z^2_{1-\alpha/2}\ N^2\ V}{Z^2_{1-\alpha/2}\ NV + E^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Equation (2) can be simplified to give the proportion of the area sampled as:

$$\frac{n}{N} = \frac{Z^2_{1-\alpha/2}\ NV}{Z^2_{1-\alpha/2}\ NV + E^2} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Equation (3) was used to determine the minimum percentage sample required with various confidence and error levels (80 to 95% and ± 5 to ± 20% respectively) for each plot.

Validation data

In general, when sampling intensities have been calculated, it must be evaluated to determine how well they fit if applied to different areas. The purpose of model evaluation is to increase one's confidence in the predictive capabilities of the model. Gass (1977) pointed out that model evaluation focuses on some checks of its validity-validation process.

Most of the work on validation is not to accept or reject the model as true or false but to determine the quality of predictions (Goodall 1972); hence it is very subjective and there is no absolute test of validity or accuracy of a model (Holdaway & Brand 1983). Thus in the validation process, one should use subjective judgements based on the proposed use of the model, the acceptable level of errors, the availability of alternative models, and other practical considerations rather than to be concerned with hypothesis testing.

Analysis of validation data

The remaining 10-ha data of the study area were used as a validation data. The area selected was from 700 to 900 m East. Data of ALL SPECIES group were used in this validation analysis. Systematic line plots with a random start were used to lay out the sample plots of 10 × 10 m, 20 × 25 m and 20 × 50 m. The inventory on validation data was repeated three times.

For the purpose of comparing calibration with validation data, tree frequency was used in 10 × 10 m plot and tree volume in 20 × 25 m and 20 × 50 m plots.

Results and discussion

General

The 30-ha study area contained 42 700 trees of 5 cm dbh and above. A total of 4104 (9.61%) trees were of dipterocarps and 38 596 (90.39%) trees of non-dipterocarps. The total tree basal area was 900.87 m^2 comprising 263.70 m^2 (29.27%) dipterocarps and 637.17 m^2 (70.73%) non-dipterocarps. In terms of volume, a total of 6594.76 m^3 was found in this area with dipterocarps having 2586.37 m^3 (39.22%) and non-dipterocarps 4008.40 m^3 (60.78%). Table 2 shows the tree numbers, basal areas, volumes and percentages by species groups of this area.

Table 2. Total tree numbers, basal area and volume by species group ≥ 5 cm dbh for the 30-ha study area (calibration data)

Species group	Tree number	%	Tree basal area (m^2)	%	Tree volume (m^3)	%
DM	2 113	4.95	136.72	15.17	1 280.93	19.43
DNM	1 991	4.66	126.98	14.10	1 305.43	19.79
ALL DIPT.	**4 104**	**9.61**	**263.70**	**29.27**	**2 586.36**	**39.22**
ND.LHW	13 710	32.11	232.66	25.83	1 491.65	22.62
ND.MHW	12 852	30.10	231.32	25.68	1 487.54	22.56
ND.HHW	7 481	17.52	130.03	14.43	804.22	12.19
MISC.	4 553	10.66	43.16	4.79	224.99	3.41
ALL NON-DIPT.	**38 596**	**90.39**	**637.17**	**70.73**	**4 008.40**	**60.78**
ALL SPECIES	**42 700**	**100.00**	**900.87**	**100.00**	**6 594.76**	**100.00**

Other information of trees in this 30-ha area is shown in Table 3 and Table 4.

Table 3. Total tree numbers, basal area and volume by species group ≥ 5 cm dbh for the 30-ha study area (calibration data)

Size class (dbh)	Tree number	%	Tree basal area (m^2)	%	Tree volume (m^3)	%
5 - < 15 cm	33 779	79.11	190.23	21.12	713.69	10.83
10 - < 3 cm	6 528	15.29	220.08	24.43	1 430.28	21.69
30 - < 45 cm	1 422	3.33	144.90	16.08	941.92	14.30
≥ 5 cm	42 700	100.11	900.87	100.00	6 594.76	100.00
≥ 3 cm	2 393	5.60	490.57	54.45	4 450.79	67.48
≥ 45 cm	971	2.27	345.66	38.37	3 507.07	53.18

Table 4. Number of species in the 30-ha study area

Species group	Number of species	%
DM	10	1.40
DNM	18	2.51
Dipterocarps	**28**	**3.91**
ND. LHW	257	35.89
ND. MHW	233	32.54
ND. HHW	99	13.83
MISC.	99	13.83
Non-dipterocarps	**688**	**96.09**

Sampling intensity and reliability standards

The variance of tree parameter (V) associated with each of the quadrat sizes in the pre-felling inventory in SMS is shown in Table 5. The percentage samples required differed between species groups, size classes and plot sizes used. They also differed among the three parameters used in the calculation, i.e. tree density, basal area and volume. Table 5 shows the percentage samples required by tree size class at various pre-determined confidence and error levels.

In general, about 0.1 to 39% sampling intensity is required in order to enumerate tree density (of all trees) of different size classes using various confidence and error levels, about 1 to 54% intensity to sample its basal area, and about 0.2 to 66% intensity to sample its volume (Table 5).

The percentage of sample size required was shown to increase as tree diameter size increased and hence less number of large diameter trees per unit area. Lang *et al.* (1971), Wan Razali (1980) and Wan Mohd Shukri (1993) also found similar patterns in their studies. The increase in sample size requirement is to be expected as the confidence level increases or as error level decreases. For example, only 9.86% sampling intensity was needed when sampling tree density ≥ 30 cm dbh at 90% confidence and 10% error as compared to 13.51% sampling intensity at 95% confidence and 10% error, and 38.45% sampling intensity at 95% confidence and 5% error levels.

10 × 10 m plot

The current Pre-F inventory of 1% sampling intensity is used to sample density of trees 5 to <15 cm dbh in 10 × 10 m plot. The 95% confidence and ± 15% error levels are a better reliability standard than the 95% confidence and ± 20% error levels when sampling intensity is 1% in estimating either tree density or basal area or volume (Table 5).

20 × 25 m plot

For plot 20 × 25 m, the 5% sampling intensity is judged adequate at 90% confidence and ± 10% error for either tree density or basal area or volume. At 95% confidence and ± 20% error as currently being advocated, a 2% sampling intensity is statistically adequate (Table 5).

20 × 50 m plot

Similarly, for 20 × 50 m plot, the 10% sampling intensity is judged adequate at 95% confidence and ± 20% error for its volume. However, if one wishes to adopt a 10% sampling intensity as adequate for its basal area, then its reliability is at 90% confidence and ± 15% error; for its tree density the reliability is better at 90% confidence and ±10% error (Table 5).

Other reliability standards in forest inventory

The ASEAN Institute of Forest Management (AIFM) suggested that forest management inventories for estimating commercial timber volume should be at 95% confidence and ± 15% error (TWC 1996). The Forest Management Project in Sabah aimed to achieve 95% confidence with ± 5% error level. If these are the reliability standards, then Table 5 indicates an adequate percentage sample required (sampling intensity) for various tree parameters.

The percentage sample required (sampling intensity) shown in Table 5 has a direct relationship with the use of confidence and error levels, i.e. higher confidence and lower error levels will require a higher sampling intensity. The decision then affects the economics (cost, labour, time, etc.) and the degree of confidence to which the results of forest inventory are attached.

Table 5. The percentage samples required by tree size class for all species groups at various confidence and error levels

Tree size class (cm dbh)	Confidence & error level (%)	Plot size (m)	Tree density (no. of trees in plot)	Tree basal area (m^3)	Tree volume (m^3)
			Percentage sample required		
		10 × 10	V = 12.16	V = 0.0005	V = 0.01
5 - <15	80 - 5	(N = 3000)	2.05	2.64	3.72
	80 - 10		0.52	0.67	0.96
	80 - 15		0.23	0.30	0.43
	80 - 20		0.13	0.17	0.24
	90 - 5		3.33	4.27	5.96
	90 - 10		0.85	1.10	1.56
	90 - 15		0.38	0.49	0.70
	90 - 20		0.21	0.28	0.39
	95 - 5		4.68	5.99	8.30
	95 - 10		1.21	1.57	2.21
	95 - 15		0.54	0.70	1.00
	95 - 20*		0.31	0.40	0.56
		20 × 25	V = 11.47	V = 0.0147	V = 0.62
15 - < 30	80 - 5	(N = 600)	9.57	10.66	10.65
	80 - 10		2.58	2.90	2.89
	80 - 15		1.16	1.31	1.31
	80 - 20		0.66	0.74	0.74
	90 - 5		14.80	16.38	16.36
	90 - 10		4.16	4.67	4.66
	90 - 15		1.89	2.13	2.13
	90 - 20		1.07	1.21	1.21
	95 - 5		19.88	21.86	21.84
	95 - 10		5.84	6.54	6.53
	95 - 15		2.68	3.02	3.01
	95 - 20*		1.53	1.72	1.72
		20 × 50	V = 7.76	V = 0.6043	V = 80.91
> 30	80 - 5	(N = 300)	21.04	33.05	44.54
	80 - 10		6.24	10.99	16.72
	80 - 15		2.88	5.20	8.19
	80 - 20		1.64	2.99	4.78
	90 - 5		30.43	44.76	56.86
	90 - 10		9.86	16.85	24.79
	90 - 15		4.63	8.26	12.78
	90 - 20		2.66	4.82	7.61
	95 - 5		38.45	53.62	65.31
	95 - 10		13.51	21.97	32.01
	95 - 15		6.49	11.40	17.30
	95 - 20*		3.76	6.75	10.53

*The existing confidence and error levels used by FDPM.

Comparing calibration and validation data sets

It is of interest to see how the results obtained from the calibration data set can be applied to forest inventory in other areas. For this purpose, results of calibration data and an independent validation data sets were then compared. The validation data set was sampled three times with a random start using a systematic line plots layout.

Firstly, we noted the differences between the two data sets as shown in Table 6. The average value differences between the two data sets were between -4 and 10% for different tree parameters under consideration.

Secondly, if we sample the 10 × 10 m plot at 1% intensity repeatedly (in this case three samplings with a random start), the difference between actual and estimated tree densities is less than 1% within 90 - 95% confidence and ± 5 - 20% error levels. However, the best reliability standard would be at 95% confidence and ± 15% error or at 90% confidence and ± 10% error levels (Table 7).

Thirdly, repeated sampling at 5% intensity using 20 × 25 m plot would produce about 8.4% difference between actual and estimated tree volumes with 90% confidence and ±10% error. Reducing the error limit to 5% (still at 90% confidence level), though resulting in 7.5% difference between actual and estimated tree volumes, would mean a need to increase the sampling intensity to 16% which is an expensive proposition (Table 7).

Lastly, a 10% sampling intensity at 95% confidence and ±20% error levels produced the least difference (<1%) between actual and estimated tree volumes.

Table 6. The value differences between calibration and validation plots of the study area

DBH class/ parameter	Development plot (calibration plot)		Validation plot	% difference based on 10 ha
	Total 30 ha	Average 10 ha	10 ha	
5 - < 15 cm				
Number of trees	33 779	11 260	10 921	3.10
Total volume (m^3)	713.69	237.90	227.99	4.35
Avg. volume tree^{-1} (m^3)	0.021	0.021	0.021	0.00
15 - < 30 cm				
Number of trees	6528	2176	1992	9.24
Total volume (m^3)	1430.28	476.76	433.84	9.89
Avg. volume tree^{-1} (m^3)	0.219	0.219	0.218	0.46
> 30 cm				
Number of trees	2 393	798	774	3.10
Total volume (m^3)	4450.79	1483.60	1497.95	- 0.97
Avg. volume tree^{-1} (m^3)	1.860	1.859	1.935	- 3.93

Table 7. Comparison of model development and model validation of the study area

10-ha plot 100%	Plot size (m)	Confidence & error levels[1]	Actual % sampling[1]	Modified % sampling[2]	Actual number of trees or volume based on modified % sampling	Average estimate based on repeated sampling[3]		% Difference between estimated and actual values
10921 trees (frequency) dbh 5 - < 15	10 × 10	95 - 20*	0.31	1	109	(99,128, 104)	110	+ 0.9
		95 - 15	0.54	1	109	(99,128, 104)	110	+ 0.9
		95 - 10	1.21	1	109	(99,128, 104)	110	+ 0.9
		90 - 10	0.85	1	109	(99,128, 104)	110	+ 0.9
		90 - 5	3.33	4	437	(440,425,445)	437	+ 0.0
433.84 m^3 (volume) dbh 15 - < 30	20 × 25	95 - 20*	1.72	2	8.68	(15.69, 12.87, 10.64)	13.07	+ 33.58
		95 - 15	3.01	3	13.02	(15.19, 14.61, 18.50)	16.10	+ 19.13
		95 - 10	6.53	7	30.37	(34.35, 37.19, 41.95)	37.83	+ 19.72
		90 - 10	4.66	5	21.69	(25.29, 23.18, 22.54)	23.67	+ 8.37
		90 - 5	16.36	16	69.41	(75.34, 74.08, 75.78)	75.07	+ 7.54
1497.95 m^3 (volume) dbh ≥ 30	20 × 50	95 - 20	10.53	11	164.77	(164.34, 186.42, 173.19)	174.65	+ 5.66
		95 - 15	17.30	17	254.65	(324.31, 284.66, 345.15)	318.04	+ 19.93
		95 - 10	32.01	32	479.34	(532.64, 537.94, 501.26)	523.95	+ 8.51
		90 - 10	24.79	25	374.49	(311.38, 337.29, 453.20)	367.29	- 1.92
		95 - 20*	10.53	10	149.80	(158.02, 141.60, 154.10)	151.24	+ 0.95

[1] Defined from calibration data analysis.
[2] For practical reason when establishing line plots, i.e. distance between line and distance between plot.
[3] Based on three samplings with a random start (systematic line plot).
*Existing confidence and error levels used by FDPM.

Conclusion

The use of different sampling intensities to estimate either tree density, basal area, or volume is associated with different confidence and error levels when interpreting results of an inventory. In Peninsular Malaysia, the results of the current SMS's Pre-F sampling intensity of 1% for trees 5 - <15 cm dbh (10 × 10 m plot), 5% for trees 15 - < 30 cm dbh (20 × 25 m plot), and 10% for trees ≥ 30 cm dbh (20 × 50 m plot) are interpreted with a confidence level of 95% and error level of ± 20%. We have statistically calculated that the confidence and error levels are generally not constant (95% confidence, ± 20% error) as originally indicated for the different sampling intensity associated with the SMS's Pre-F inventory.

The following can be concluded regarding SMS's Pre-F:

(1) At 1% sampling intensity, the best statistical reliability in estimating tree density, basal area or volume is at 95% confidence and ± 15% error although the 95% confidence and ± 20% error levels remain as an acceptable, albeit less reliable, option. However, comparison between actual and estimated sample measurements of tree density confirms that the confidence and error levels of either 95% , ± 15% or 90% , ± 10% are more appropriate;

(2) At 5% sampling intensity, the reliability is at 90% confidence and ± 10% error in estimating tree density, basal area, or volume. If 95% confidence and ± 20% error remain to be advocated, then a 2% sampling intensity is statistically adequate. Comparison between actual and estimated tree volumes strengthens the statistical reliability at 90% confidence and ±10% error limits; and

(3) At 10% sampling intensity to estimate tree volume, the 95% confidence and ± 20% error are the most reliable limits as shown by the comparison between actual and estimated tree volumes.

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References

COCHRAN, W. G. 1977. *Sampling Technique*. 3rd edition. Wiley and Sons, Inc., New York, United States of America.

FDPM. 1985. *Panduan Penentuan Had Batas Tebangan dari Maklumat-maklumat Inventori sebelum Tebangan (Kiraan Manual)*. Unit Pengurusan Hutan. Ibu Pejabat Perhutanan. Kuala Lumpur. 42 pp.

FDPM. 1986. *Panduan Kerja Luar Inventori sebelum Tebangan (Pengemaskinian I)*. Unit Pengurusan Hutan. Ibu Pejabat Perhutanan Semenanjung Malaysia. Kuala Lumpur. 50 pp.

GASS, S. T. 1977. Evalution of complex model. *Computer & Ops. Res.* (4):27–35.

GOODALL, D. W. 1972. Building and testing ecosystem models. Pp. 173–194 in Jeffers, J.N.R. (Ed.) in *Mathematical Models in Ecology*. Blackwell Science Publications, Oxford, United Kingdom.

HOLDAWAY, M. R. & BRAND, G. J. 1983. An *Evaluation of the STEMS Tree Growth Projection System*. USDA Forest Service Research Paper NC - 234. 20 pp.

KEMENTERIAN PERUSAHAAN UTAMA (KPU). 1996. *Statistics on Commodities*. Ministry of Primary Industries, Malaysia. 153 pp.

LANG, G. E., KNIGHT, D. H. & ANDERSON, D. A. 1971. Sampling the density of tree species with quadrats in a species-rich tropical forest. *Forest Science* 17:395–400.

MANOKARAN, N., LAFRANKIE, J. V., KOCHUMMEN, K. M., QUAH, E. S., KLAHN, J. E., ASHTON, P. S. & HUBBELL, S. P. 1990. *Methodology for the Fifty Hectare Research Plot at Pasoh Forest Reserve*. Research Pamphlet 104. Forest Research Institute Malaysia, Kepong, Malaysia. 69 pp.

TWC. 1996. *Third Meeting of the Technical Working Comittee for the Malaysian-German Project Sustainable Forest Management and Conservation in Peninsular Malaysia*. Kuala Terengganu.

WAN MOHD. SHUKRI, W. A. 1993. Species distribution and sampling tree volume: an investigation using quadrats in tropical forest. B.Sc. thesis, Universiti Pertanian Malaysia. 68 pp.

WAN RAZALI, W. M. 1980. Species distribution and sampling tree density: a preliminary investigation using quadrats in a tropical high forest. *Malaysian Forester* 43:452–464.

WAN RAZALI, W. M., WAN MOHD. SHUKRI, W. A. & ASHAARI, M. 1997. Natural forest dynamics. II. Sampling of tree volume using quadrats in tropical forests of Peninsular Malaysia. *Journal of Tropical Forest Science* 10(2):141–154.