STATISTICAL RELIABILITY IN SMS'S PRE-FELLING INVENTORY: INFERENCES AND IMPLICATIONS FOR SAMPLING TREE DENSITY, BASAL AREA AND VOLUME

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WAN MOHD SHUKRI, W. A. & WAN RAZALI, W. M. 2002. Statistical reliability in SMS's pre-felling inventory: inferences and implications for sampling tree density, basal area and volume. This study was carried out on a randomly chosen 30-ha (500 × 600 m) forest area within the 50-ha Demography Project of the Forest Research Institute Malaysia (FRIM) in Pasoh Forest Reserve, Negeri Sembilan. A 30-ha study area was used as data set. A higher sampling intensity was needed when sampling tree size classes and species groups that were lower in their frequency of occurrence. Dipterocarp species group (ALL DIPT) needed a higher sampling intensity to detect its occurrence compared to non-dipterocarp species groups (ALL NON-DIPT). A different intensity of sampling was required when considering either diameter classes, species groups, plot sizes or tree parameters separately, and also when different confidence and error levels were used. The implications of attaching confidence and error levels to the intensity of inventory by species group currently used in Selective Management System are also discussed.

Key words: Sampling intensities - species group - Selective Management System - pre-felling inventory - confidence (probability) level - error level - dipterocarp - non-dipterocarp - Malaysia

WAN MOHD SHUKRI, W. A. & WAN RAZALI, W. M. 2002. Kesahihan statistik bagi inventori sebelum tebangan Sistem Pengurusan Memilih: keputusan dan implikasi bagi intensiti pensampelan kepadatan, luas pangkal dan isipadu pokok. Kajian ini dijalankan di kawasan seluas 30-ha (500 × 600 m) yang dipilih secara rawak di kawasan Projek Demografi 50-ha Institut Penyelidikan Perhutanan Malaysia (FRIM) di Hutan Simpan Pasoh, Negeri Sembilan. Data dari kawasan 30-ha ini digunakan bagi analisis kajian ini. Keputusan menunjukkan intensiti pensampelan yang lebih tinggi diperlukan apabila pensampelan ke atas kelas saiz pokok dan kumpulan spesies yang kurang bilangannya dijalankan. Kumpulan spesies dipterokarp (ALL DIPT) memerlukan intensiti pensampelan yang lebih tinggi berbanding kumpulan spesies bukan dipterokarp (ALL NON-DIPT). Keputusan juga menunjukkan intensiti pensampelan yang berbeza diperlukan apabila faktor berlainan diambil kira, sama ada kelas diameter, kumpulan spesies, saiz plot atau parameter pokok. Ini juga berlaku apabila tahap keyakinan dan tahap ralat berbeza digunakan. Implikasi hubungan tahap keyakinan dan ralat dengan intensiti pensampelan bagi kumpulan spesies yang sedang digunakan dalam Sistem Pengurusan Memilih juga turut dibincangkan.

Introduction

Tropical rain forests have provided commercial timber and fuelwood for over more than two centuries and have been managed under several silvicultural systems for the last five decades. These systems were aimed at increasing the amount and the quality of timber produced by manipulating stand density and its composition. The systems often relied on rules concerning pre-felling (pre-f) and post-felling (post-f) inventories and timber stand improvements.

Various management systems have been tried out in Malaysia to manage the country's valuable forest. The Selective Management System (SMS) was introduced in the late 1978 to allow for a more flexible timber harvesting regime which is 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 a selection of a harvesting regime and hence a management system for a forest area based on pre-f inventory data. This will encourage the subsequent harvest of the same forest area as early as between 25 to 30 years, while maintaining species diversity as close to that of the original forest as possible. In practice, under the SMS, the next cut in areas enriched with dipterocarp species is expected 30 years after the first logging with an expected net economic extraction of 40 to 50 m^3 per ha based on current log prices and cost of logging, including land premium and royalty charge for logs (Thang 1997).

Current pre-f forest inventory practice in Peninsular Malaysia uses a systematic sample with different plot sizes resulting in different sampling intensities (Table 1).

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

Plot	Size (m)	Sampling intensity (%)	Tree size class
First	20 × 50	10.00	≥ 45 cm dbh
			30 cm to < 45 cm dbh
Second	20 × 25	5.00	15 cm to < 30 cm dbh
Third	10 × 10	1.00	5 cm to < 15 cm dbh
Fourth	5 × 5	0.25	1.5 m height, < 5 cm dbh
Fifth	2 × 2	0.04	15 cm to < 1.5 m height

Bonnor (1977) found that the application of systematic sampling in Malaysian forest inventories is generally sound. However, incomplete statistical knowledge has led to some specifications which cause problems in calculation of sampling errors. One of the specifications relates to the concept of sampling intensity. The design was mainly aimed at obtaining estimates of the resource only; the error of the estimates (sampling) was not questioned. Indeed, without statistical control of the sampling procedure, the sampling error cannot be calculated.

With increasingly intensive forest management and the accompanying need for detailed information, there is today a growing concern over the reliability of data collected in forest inventories. What is the sampling error, how can it be calculated, how can it be controlled and what requirements must be met to provide the necessary statistical control, are just some examples of questions raised.

The different intensities of inventorying forests in the pre-f inventory have been applied since SMS was introduced. Little research was done (e.g. Wan Mohd Shukri 1997, Wan Razali *et al.* 1997, Wan Razali & Wan Mohd Shukri 1999) to verify the accuracy of the sampling intensities used. Hence, this study, which complements previous work undertaken by Wan Razali and Wan Mohd Shukri (1999), was conducted to determine the accuracy of sampling intensity in the pre-f inventory and their statistical reliability (confidence and error levels) for two major species groups, namely, the dipterocarps and the non-dipterocarp, and for various dbh size classes (5–< 15 cm, 15–< 30 cm, 30–< 45 cm, ≥ 30 cm, ≥ 45 cm) associated with various plot sizes currently used in SMS pre-f inventory.

Materials and methods

Overview

This study was carried out on a 30-ha (500 5 600 m) forest area within the 50-ha Demography Project established by the Forest Research Institute Malaysia (FRIM) in a virgin forest at the Pasoh Forest Reserve, Negeri Sembilan. The methodology, including plot design and site descriptions for the 50-ha Demography Project, is outlined by Manokaran *et al.* (1990).

However, this study used only trees of ≥ 5 cm dbh to evaluate sampling intensity under SMS's pre-f inventory in 10 × 10 m, 20 × 25 m and 20 × 50 m plots with size classes as elaborated in Table 1. Detailed commercial species classification and tree size classes follow that of Forestry Department Peninsular Malaysia (FDPM) (Anonymous 1986) which are also described in Wan Razali & Wan Mohd Shukri (1999).

Analysis of data

Data for this study were selected from the 30-ha area starting at 100 to 700 m E and 0 to 500 m N (Figure 1). As the basic sampling plot (quadrat) in the above Demography Project was 5 × 5 m, data for the 10 × 10 m, 20 × 25 m and 20 × 50 m plots were obtained by adding the contiguous 5 × 5 m plots within the 30-ha study area. The data were used to calculate sampling intensities for different confidence and error levels based on tree density, basal area and volume.

Calculation of volume, basal area, plot variance and determination of sample size requirement has been discussed in Wan Razali and Wan Mohd Shuki (1999). However we repeat all the equations related to this study for the purpose of better understanding.

Volume per tree

Volume for each standing tree of 5 cm dbh and above was calculated using the volume equation as shown below. Gross volumes were calculated using the formula for a cylinder with a form factor of 0.65 for trees ≥ 15 cm dbh.

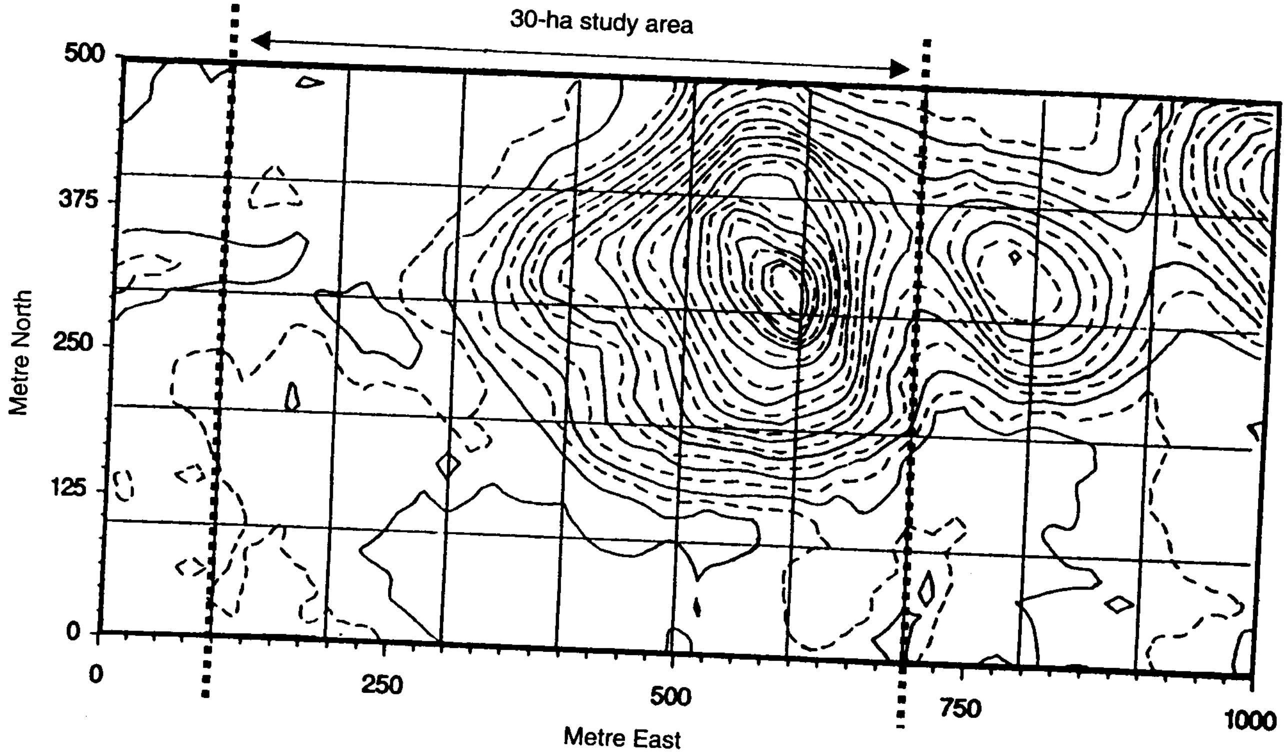

Figure 1 Topographic map of the Pasoh Forest Reserve 50-ha plot, at 1-m contour intervals, and gridded at 1-ha units

Source: Manokaran *et al.* (1990)

$$\text{Volume} = (\pi \times \text{dbh}^2 \times L \times f)/(40\,000)$$

where

Volume = standing volume in m^3,
π = 3.1416,
dbh = diameter at breast height in cm,
L = merchantable height in m and
f = form factor.

Average merchantable height (L) was based on the FDPM rules (Anonymous 1997):

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

For trees 5– < 15 cm dbh, volume is normally not calculated under the present pre-f inventory. However, in this paper, volume for each tree was calculated by assuming merchantable height (L) as 1 log-length (5 m) with a form factor of 0.75.

Basal area per tree

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

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

where

BA = basal area in m^2,
π = 3.1416 and
dbh = diameter at breast height in cm.

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:

$$V_{\bar{y}} = \frac{V}{n}\left[1 - \frac{n}{N}\right]$$

where

n is the number of quadrats sampled,
N the total population of a particular sized quadrat and
$1 - \frac{n}{N}$ is the finite population correction.

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

$$= \frac{V}{n}\,N\,(N-n)$$

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

$$Z_{1-\alpha/2}\sqrt{\frac{V}{n}\,N(N-n)} \qquad (1)$$

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

Determination of sample size requirement

If we want the percentage of error to be less than $E = \rho Y$ with $(1-\alpha)100\%$ confidence, where ρ is the percentage of error as a proportion and thus making E as 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):

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

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

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

Equation (3) was used to determine the minimum percentage of sample required with various probability (confidence) and error levels (90 to 95% and ± 10 to 20% respectively) for each plot.

Results and discussion

Number and distribution of trees

Table 2 shows the tree density, basal area and volume by species group and tree size class of this study area. Number of species in this study area has been described in Wan Razali and Wan Mohd Shukri (1999).

Table 2 Total tree numbers, basal area and volume by species group and size class of trees ≥ 5 cm dbh for the 30-ha study area

Species group / size class	Tree density	%	Tree basal area (m^2)	%	Tree volume (m^3)	%
Species group						
DM	2113	4.95	136.72	15.17	1280.93	19.43
DNM	1991	4.66	126.98	14.10	1305.43	19.79
ALL DIPT	4104	9.61	263.70	29.27	2586.37	39.22
ND LHW	13 710	32.11	232.66	25.83	1491.65	22.62
ND MHW	12 852	30.10	231.32	25.68	1487.54	22.56
ND HHW	7481	17.52	130.03	14.43	804.22	12.19
MISC	4553	10.66	43.16	4.79	224.99	3.41
ALL NON-DIPT	38 596	90.39	637.17	70.73	4008.40	60.78
ALL SPECIES	42 700	100.00	900.87	100.00	6594.76	100.00
Size class (cm dbh)						
5 – < 15 cm	33 779	79.11	190.23	21.12	713.69	10.83
15 – < 30 cm	6528	15.29	220.08	24.43	1430.28	21.69
30 – < 45 cm	1422	3.33	144.90	16.08	941.92	14.30
≥ 5 cm	42 700	100.00	900.87	100.00	6594.76	100.00
≥ 30 cm	2393	5.60	490.57	54.45	4450.79	67.48
≥ 45 cm	971	2.27	345.66	38.37	3507.07	53.18

DM = Dipterocarp, meranti
DNM = Dipterocarp non-meranti
ALL DIPT= All dipterocarps
ND LHW = Non-dipterocarp, light hardwoods
ND MHW = Non-dipterocarp, medium hardwoods
ND HHW = Non-dipterocarp, heavy hardwoods
MISC = Miscellaneous
ALL NON-DIPT = All non-dipterocarps

Sampling intensity for species group and size class in pre-f sample plots

The use of different sampling intensities to estimate either tree density, basal area or volume are associated with different confidence and error levels when interpreting results of an inventory. In Peninsular Malaysia, pre-f sampling intensities of the current SMS's are 1, 5 and 10% for trees 5– < 15 cm dbh (10 × 10 m plot), 15– < 30 cm dbh (20 × 25 m plot) and ≥ 30 cm dbh (20 × 50 m plot) respectively.

Tables 3, 4, 5, 6 and 7 show the intensity of sampling within different plot sizes using different confidence and error levels. The intensity was calculated according to tree size class associated with its corresponding plot sizes and species groups currently used in the pre-f inventory. The 95% probability (confidence) and ± 20% error level were chosen in the following discussion as they are the current levels of reliability used by the FDPM (Wan Razali *et al.* 1997).

10 × 10 m plot

Table 3 shows that an intensity of 5 to 8% was required to sample ALL DIPT trees of 5– <15 cm dbh in 10 × 10 m plot size. For ALL NON-DIPT and ALL SPECIES the intensity for groups with 95% confidence and ± 20% error was less than 1%. Therefore, the 1% intensity used in the pre-f inventory was inadequate to estimate the density, basal area and volume of trees in ALL DIPT group but was statistically adequate to make inventory of trees in NON-DIPT and ALL SPECIES groups. However, a higher sampling intensity was required if a lower error level of less than ± 20% for the three species groups was used.

Table 3 The percentage sample required by species groups in 10 x 10 m plot (tree size class 5– < 15 cm dbh)

Species group	Confidence ± error level (%)	Tree density	Tree basal area (m^2)	Tree volume (m^3)
		Percentage sample required		
ALL DIPT	90 ± 10	13.28	17.48	20.05
	95 ± 10	17.95	23.22	26.37
	95 ± 15	8.86	11.85	13.73
	95 ± 20	5.19	7.03	8.22
ALL NON-DIPT	90 ± 10	0.92	1.30	1.84
	95 ± 10	1.30	1.84	2.60
	95 ± 15	0.58	0.83	1.17
	95 ± 20	0.33	0.47	0.66
ALL SPECIES	90 ± 10	0.85	1.10	1.56
	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 m plot

To sample either tree density or basal area or volume, an intensity of 20% was required for ALL DIPT trees 15– < 30 cm dbh in the 20 × 25 m plot size with 95% confidence and ± 20% error (Table 4). Therefore, the 5% intensity used in the present pre-f inventory would not accurately estimate the density, basal area and volume of trees 15– < 30 cm dbh of ALL DIPT species group. However, for ALL NON-DIPT and ALL SPECIES only 2% intensity was required and hence the 5% intensity used in the current pre-f inventory was judged as more than enough to inventory trees of 15– < 30 cm dbh. Maintaining the sampling intensity at 5% for ALL NON-DIPT and ALL SPECIES would allow us to interpret the inventory results at 95% confidence and ± 15% error level. However, reduction to 2% sampling intensity would save time and money for inventory of these two groups.

Table 4 The percentage sample required by species groups in 20 × 25 m plot (tree size class 15– < 30 cm dbh)

Species group	Confidence ± error level (%)	Tree density	Tree basal area (m^2)	Tree volume (m^3)
		Percentage sample required		
ALL DIPT	90 ± 10	40.20	42.36	41.47
	95 ± 10	48.98	51.21	50.30
	95 ± 15	29.91	31.81	31.03
	95 ± 20	19.36	20.79	20.19
ALL NON-DIPT	90 ± 10	4.75	5.38	5.38
	95 ± 10	6.65	7.51	7.51
	95 ± 15	3.07	3.48	3.48
	95 ± 20	1.75	1.99	1.99
ALL SPECIES	90 ± 10	4.16	4.67	4.66
	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 m plot

(1) Trees 30– < 45 cm dbh

A higher sampling intensity was required to sample tree density, basal area or volume of all trees 30– < 45 cm dbh accurately in the 20 × 50 m plot. About 33% was required for ALL DIPT, 8% for ALL NON-DIPT and 7% for ALL SPECIES, all with 95% confidence and ± 20% error (Table 5). Again at 10% sampling intensity, the current pre-f inventory would not give a correct estimate of the parameters concerned for ALL DIPT, but was acceptable to inventory trees in ALL NON-DIPT and ALL SPECIES groups between 30– < 45 cm dbh.

Table 5 The percentage sample required by species groups in 20 × 50 m plot (tree size class 30– < 45 cm dbh)

Species group	Confidence ± error level (%)	Tree density	Tree basal area (m^2)	Tree volume (m^3)
		Percentage sample required		
ALL DIPT	90 ± 10	57.99	57.49	57.49
	95 ± 10	66.34	65.89	65.89
	95 ± 15	46.70	46.19	46.19
	95 ± 20	33.01	32.56	32.56
ALL NON-DIPT	90 ± 10	19.34	19.34	19.37
	95 ± 10	25.51	25.51	25.55
	95 ± 15	13.21	13.21	13.24
	95 ± 20	7.89	7.89	7.90
ALL SPECIES	90 ± 10	16.27	16.47	16.48
	95 ± 10	21.73	21.97	21.99
	95 ± 15	10.98	11.12	11.13
	95 ± 20	6.49	6.58	6.58

Generally, a higher sampling intensity was required to attach a better confidence and error level, for example, 12% for ALL SPECIES at 95% confidence and ± 15% error level as well as 22% for ALL SPECIES at 95% confidence and ± 10% error level.

(2) Trees ≥ 30 cm dbh

About 15–25% intensity was needed to sample trees ≥ 30 cm dbh of ALL DIPT, 7–17% ALL NON-DIPT and 4–11% for ALL SPECIES in 20 × 50 m plots with 95% confidence and ± 20% error (Table 6). Certainly, the 10% sampling intensity currently used could not accurately estimate the volume and basal area of ALL DIPT and ALL NON-DIPT trees and of density of ALL DIPT trees ≥ 30 cm dbh. However, it was sufficient to inventory the density, basal area and volume of all trees (ALL SPECIES) and of tree density of ALL NON-DIPT ≥ 30 cm dbh, all with 90% confidence and ± 20% error.

Table 6 The percentage sample required by species groups in 20 × 50 m plot (tree size class ≥ 30 cm dbh)

Species group	Confidence ± error level (%)	Tree density	Tree basal area (m^2)	Tree volume (m^3)
		Percentage sample required		
ALL DIPT	90 ± 10	34.14	40.68	47.69
	95 ± 10	39.68	49.48	56.56
	95 ± 15	22.62	30.33	36.66
	95 ± 20	14.12	19.67	24.56
ALL NON-DIPT	90 ± 10	16.11	25.39	35.67
	95 ± 10	21.52	32.71	44.20
	95 ± 15	10.87	17.77	26.04
	95 ± 20	6.42	10.84	16.53
ALL SPECIES	90 ± 10	9.86	16.85	24.79
	95 ± 10	13.51	22.44	32.01
	95 ± 15	6.49	11.40	17.30
	95 ± 20	3.76	6.75	10.53

(3) Trees ≥ 45 cm dbh

For trees ≥ 45 cm dbh, which were also enumerated in 20 × 50 m plots, 18–27% intensity was required to sample trees in ALL DIPT, 17–30% ALL NON-DIPT and 8–16% ALL SPECIES (Table 7), all within the accuracy of ± 20% error at the 95% confidence level. Therefore, the current 10% sampling intensity was sufficient to inventory density of all trees (ALL SPECIES) ≥ 45 cm dbh. In general, a higher intensity was needed when sampling trees in ALL DIPT and ALL NON-DIPT. A higher sampling intensity was also required if a higher confidence level and a lower error level were used.

Table 7 The percentage sample required by species groups in 20 × 50 m plot (tree size class ≥ 45 cm dbh)

Species group	Confidence ± error level (%)	Tree density	Tree basal area (m^2)	Tree volume (m^3)
		Percentage sample required		
ALL DIPT	90 ± 10	38.14	45.70	51.04
	95 ± 10	46.83	54.59	59.82
	95 ± 15	28.13	34.83	39.82
	95 ± 20	18.04	23.11	27.13
ALL NON-DIPT	90 ± 10	35.86	45.21	54.67
	95 ± 10	44.40	54.10	63.27
	95 ± 15	26.20	34.37	43.36
	95 ± 20	16.64	22.76	30.10
ALL SPECIES	90 ± 10	19.94	27.10	33.98
	95 ± 10	26.24	34.69	42.37
	95 ± 15	13.65	19.10	24.63
	95 ± 20	8.17	11.72	15.53

Implications of sampling intensity to the SMS

In Malaysia, the SMS has some pre-requisites and the critical ones pertaining to sampling intensity are:

(1) the minimum residual stocking after harvesting should not be less than 32 trees ha^{-1} of sound marketable and of good form (preferably undamaged and commercial) from dbh class 30–45 cm or its equivalent, and
(2) for the next cut the percentage of dipterocarp species in the residual stand for trees having dbh ≥ 30 cm should not be less than that of the original stand.

Other details and its technical requirements, issues and problem as well as future direction and improvements in SMS are elaborated in Abdul Rashid and Mokthar (1997), Appanah *et al.* (1997), Shaharuddin (1997) and Thang (1997). Basically, all discussions point to the concept of the sustainability of forests by ensuring an adequate and sound marketable residual stock. How does then the issue of sampling intensity in the pre-f inventory pertain to the overall concept of implementing SMS?

We wish to make the following observations with respect to the above critical pre-requisites:

(1) Minimum 32 trees ha^{-1} in the residual stand from trees of 30– < 45 cm dbh or its equivalent

The issue is related to tree density and size class. Technically, from our results, a sampling intensity of 7% was required to accurately inventory all trees (ALL SPECIES) 30– < 45 cm dbh class with 95% confidence and ± 20% error (Table 5).

Therefore, the current pre-f inventory intensity of 10% was judged sufficient. However, this figure is debatable as trees in ALL SPECIES group also consist of trees in MISC species group which are not fully marketable now but will be marketable in the next cut, at least 25 years from now.

Nevertheless, if one considers that there are not enough 32 trees ha^{-1} from 30– < 45 cm dbh class, then the "equivalence" rule has to be applied (Thang 1997). In this case, we considered dbh classes of 15– < 30 cm and ≥ 45 cm separately. From our results a 2% intensity was required to inventory all trees (ALL SPECIES) 15– < 30 cm dbh with 95% confidence and ± 20% error (Table 4). The current pre-f inventory of 5% intensity has met the requirement of this sampling intensity, albeit with a higher reliability, i.e. 95% confidence and ± 15% error or 90% confidence and ± 10% error (see Wan Razali & Wan Mohd Shukri (1999) for statistical discussion).

Similarly, considering all trees (ALL SPECIES) ≥ 45 cm dbh, a 10% sampling intensity was judged sufficient and this conforms to the current pre-f inventory of tree density (see Table 7).

(2) Dipterocarp species in residual stand from trees ≥ 30 cm dbh

From the results of our analysis, at least a 15% intensity was required to inventory tree density of dipterocarp species (ALL DIPT) with 95% confidence and ± 20% error (Table 6). Therefore, a 10% intensity, as advocated in the current pre-f inventory, would not provide an accurate estimate of tree density of ≥ 30 cm dbh of ALL DIPT within the precision requirements. Hence, the tree density obtained from the current pre-f inventory might not fulfil the requirement of maintaining at least the same percentage of dipterocarp species in the residual stand as in the original stand. Based on our experience, a likely situation is where the residual stand has less proportion of dipterocarp compared to the original stand, even though a 5 cm higher cutting limit in the dipterocarp species is imposed over the non-dipterocarp species. Hence, lengthening the next cut beyond 30 years becomes unavoidable because the non-dipterocarp species in tropical rain forests grow slower than the dipterocarp species (Wan Razali 1989, Ashari *et al.* 1992, Yong 1996, Chung 1994, Abdul Rahman *et al.* 1994). Slower growth implies that the anticipated net economic cut of 40–50 $m^3 ha^{-1}$ will not be attainable in 25–30 years. Therefore, a more precise estimate of the dipterocarp component of the stand, which can be achieved by having an adequate sampling intensity in the pre-f inventory, is necessary.

Conclusions

Considering the results of the present study, we concluded that a different intensity of sampling was required when diameter class, species groups, plot size, various tree parameters or confidence and error levels was considered. Generally, the dipterocarp species group (ALL DIPT) needed a higher sampling intensity to inventory its density compared with the non-dipterocarp species groups (ALL

NON-DIPT). Sampling for tree volume required higher percentage sample compared with basal area and tree density at any level of probability (confidence) and error.

The following conclusions could be made with respect to the pre-f inventory in SMS:

(1) The 1% intensity, used in the 10 × 10 m plot, was statistically enough to inventory tree density or basal area or volume of all trees (ALL SPECIES) 5– < 15 cm dbh at 95% confidence and ± 20% error level. Even at ± 15% error level such conclusion was still valid.

(2) Similarly, the 5% intensity to inventory tree density or basal area or volume of all tree species (ALL SPECIES and ALL NON-DIPT) 15– < 30 cm dbh in the 20 × 25 m plot, met its minimum statistical reliability. However, a reduction to an intensity of 2%, which also met the 95% confidence and ± 20% error level, had the advantages of saving time and cost in conducting such pre-f inventory. In addition, the 2% intensity could meet the requirement of addressing the rule of tree equivalence in SMS, whereby if 32 trees ha^{-1} from 30– < 45 cm dbh class are not enough, then the 15– < 30 cm dbh class trees will have to be considered as "equivalent" trees. Therefore the 2% intensity would still be statistically acceptable at 95% confidence and ±20% error level.

(3) The 10% intensity in the 20 × 50 m plot was only statistically enough to sample tree density or basal area or volume of all trees 30– < 45 cm dbh of ALL SPECIES and ALL NON-DIPT at 95% confidence and ± 20% error. If we wish to draw some inferences to the pre-f inventory in SMS, then a 10% intensity is statistically enough to sample all trees ≥ 30 cm dbh for tree density of ALL SPECIES and ALL NON-DIPT groups only. However, to ensure the requirement in the SMS is met in order to maintain at least the same percentage of dipterocarp species in the residual stand as in the original, we recommend that a 15% intensity be inventoried of all trees ≥ 30 cm dbh and 20% intensity of all trees ≥ 45 cm dbh for ALL DIPT. This is important so that a statistically determined inventory intensity is applied to ALL DIPT group and hence the equivalence rule can be applied justifiably with at least 95% confidence and ± 20% error level.

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