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NATURAL FOREST DYNAMICS. II. SAMPLING OF TREE VOLUME USING QUADRATS IN TROPICAL FORESTS OF PENINSULAR MALAYSIA

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WAN RAZALI ,W.M., WAN MOHD. SHUKRI, W.A. & ASHARI, M. 1997. Natural forest dynamics. II. Sampling of tree volume using quadrats in tropical forests of Peninsular Malaysia. This study was carried out on a randomly chosen 10-ha (200 × 500 m) forest area within the 50-ha area Demography Project of the Forest Research Institute Malaysia (FRIM) at Pasoh Forest Reserve, Negri Sembilan, Malaysia. A modified minimum-variance method was used to determine statistically the most efficient quadrat size among the eight quadrat sizes used. The minimum sampling intensity associated with each quadrat size, at 90% confidence and 10% error, was determined in estimating tree volume . In general, the 30 × 30 m quadrat was found to be statistically the most efficient in sampling tree volume ≥ 15 cm dbh at 90% confidence and 10% error levels. The percentage sample size requirement differed between species groups, size classes and quadrat sizes used. The implications of the result of the present study are discussed in relation to the current inventory methods used in Malaysia. For example, a 16% sampling intensity is required to inventory all trees ≥ 15 cm dbh with 90% confidence and 10% error levels using 30 × 30 m quadrat, increasing to 24% when using 20 × 50 m quadrat.

Key words: Sampling intensity - tree volume - efficient quadrat size - dipterocarp - non-dipterocarp

WAN RAZALI, W.M., WAN MOHD. SHUKRI, W.A. & ASHARI, M. 1997. Dinamik hutan semula jadi. II. Penyampelan isipadu pokok menggunakan kuadrat di hutan tropika Semenanjung Malaysia. Kajian ini dijalankan di kawasan yang dipilih secara rawak seluas 10 ha (200 × 500 m) di dalam kawasan 50 ha Projek Demografi oleh Institut Penyelidikan Perhutanan Malaysia (FRIM), di Hutan Simpanan Pasoh, Negri Sembilan, Malaysia. Satu modifikasi kaedah varian minima digunakan bagi menentukan kuadrat paling efisien dari segi statistik daripada lapan saiz kuadrat yang digunakan. Kepadatan penyampelan bagi setiap saiz kuadrat pada keyakinan 90% dan ralat 10% ditentukan dalam menaksirkan isipadu. Secara umumnya, kuadrat 30 × 30 m didapati paling efisien dari segi statistik dalam membuat penyampelan isipadu pokok ≥ 15 cm dpd pada tahap keyakinan 90% dan 10% ralat.

Peratusan saiz sampel yang diperlukan berbeza mengikut kumpulan spesies, kelas diameter dan saiz kuadrat yang digunakan. Implikasi keputusan kajian ini dikaitkan dengan kaedah inventori semasa yang dipraktikkan di Malaysia. Sebagai contoh, 16% kepadatan penyampelan diperlukan bagi inventori pokok bersaiz ≥15 cm dpd pada keyakinan 90% dan ralat 10% menggunakan kuadrat 30 × 30 m sementara 24% diperlukan apabila menggunakan kuadrat 20 × 50 m.

Introduction

The purpose of forest inventory is to provide forest managers and others concerned with forests with a clear summary of the quantities and distribution of such resources over an area of interest. Frequently, a summary is provided in the form of maps, tables and statistics. The need for quantitative tree data has made it necessary to give serious consideration to methods of forest sampling. It is important to recognise the need for adequate sampling and what constitutes an adequate sample.

A practice in any forest inventory work is to use a sample size that would provide an optimum precision to the estimate of the entire forest. It is also important to determine the most appropriate quadrat size (plot size) in a forest inventory work while adhering to a given precision. Statistical methods place great emphasis on the number of plots required in an inventory, since the measurements made on a single plot or comparisons drawn from a single contrasting pair of plots usually cannot be considered as indicative of a true population. The number of plots or quadrats required can be determined statistically. The most efficient quadrat size depends on the objective, the precision required and the cost to carry out such inventory work.

In the recent past, expression of wood volume has predominated because of the use of the stem for conventional wood products such as lumber, plywood, poles, pulp and paper, etc. The tree volume is considered an important parameter. Therefore, the analyses to determine the sample adequacy associated with the various quadrat sizes should be more advantageous if using tree volume.

This study was done on a randomly selected 10-ha virgin forest area within the 50-ha Demography Project at Pasoh Forest Reserve, Negri Sembilan, Malaysia. From the view point of species distribution, 10-ha is already sufficiently large to reflect the homogeneity of species distribution (Wan Mohd Shukri *et al.* 1997).

The objectives of this paper are to determine statistically the most efficient quadrat size in sampling tree volume and to calculate minimum sampling intensity associated with each quadrat size at acceptable confidence and error levels.

Methodology

Overview

The raw data were obtained from the 50-ha Demography Project established at Pasoh Forest Reserve by the Forest Research Institute Malaysia (FRIM).

The study area was divided into 1000 contiguous 10 × 10 m quadrats or plots. One hundred percent enumeration data of all trees 1 cm diameter at breast height (dbh) and above were available from this Demography Project. However, due to availability of volume estimates, only trees 15 cm dbh and above were used in this study. The commercial species classification currently used by the Forestry Department Peninsular Malaysia (FDPM 1986a) was applied in this study. The species are grouped as follows:

Dipterocarp, meranti	(DM)
Dipterocarp, non-meranti	(DNM)
All dipterocarps	(ALL DIPT.)
Non-dipterocarp, light hardwoods	(ND. LHW)
Non-dipterocarp, medium hardwoods	(ND. MHW)
Non-dipterocarp, heavy hardwoods	(ND. HHW)
All non-dipterocarps	(ALL NON-DIPT.)
Other species including conifer	(MISC.)

Site description

The 50-ha Demography Project at Pasoh Forest Reserve was established in 1985. The project is similar to the one established and conducted on Barro Colorado Island (BCI), Panama, by the Smithsonian Tropical Research Institute (Hubbell & Foster 1983, Hubbell 1984).

Pasoh is located about 140 km southeast of Kuala Lumpur and consists of 650 ha of primary lowland mixed dipterocarp forest surrounded by another 650 ha of buffer zone of partly regenerated and partly virgin forests. A further 650 - 1000 ha of primary hill dipterocarp forest rises to about 600 m above sea-level.

This forest reserve is characterised by the family Dipterocarpaceae, and may be regarded as composed of three tree layers, namely, the emergent layer, the main-storey, and the understorey below the main canopy. It was classified as a part of the lowland evergreen rain forest formation by Burtt-Davy (1938) and as a lowland dipterocarp forest by Symington (1943).

Plot design

The choice of plot size used in enumeration and growth studies depends very much on objectives of study, nature of data to be measured and collected, techniques of analysis, the study site and other factors. In mixed tropical forests, the plot size (including permanent sample plot) varies from 0.4 ha to 300 ha, depending on the nature of study. The Centre Technique Forestier Tropical (CTFT) used 16-ha treatment plots in Ivory Coast (Ledoux 1950, as cited by Alder & Synott 1992) while treatment plot sizes ranging from 9 ha to 50 ha were used in Sarawak (Korsgaard 1982).

The International Tropical Timber Organization (ITTO) projects in Malaysia used as large as 300 ha as treatment plots. However, the measurement plots used by the CTFT above were 4 ha and those by the ITTO were 1 ha. Generally, 1-ha plots are used as measurement and permanent sample plots located at random within the treatment plots.

The Pasoh Demography plot was divided into quadrats and subquadrats. Each quadrat was 20 m on a side, a length chosen because it is the longest distance that can be surveyed accurately through dense forest cover while each subquadrat was 5 m on a side that provided the largest area within which plants could be accurately mapped (Manokaran *et al.* 1990).

In this present study, however, only an area of 10 ha was randomly chosen (within the 50-ha area) as the study site. The design of the 50-ha permanent plot is illustrated in Figure 1, and Figure 2 shows the topography map of the area. The contiguous 10 × 10 m plot in the 10-ha study area was established by combining the two 5-m subquadrats originally set-up in this 50-ha Demography Project.

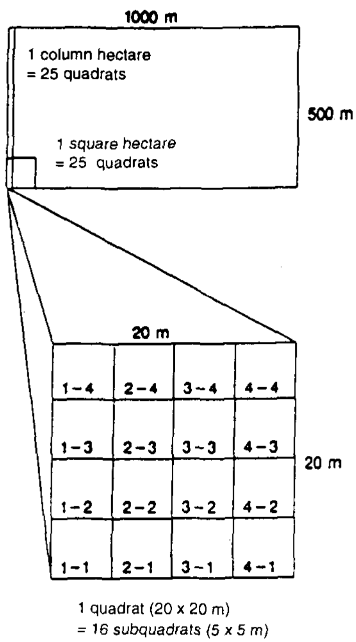

Figure 1. The 50-ha plot subdivided into columns (20 × 500 m), rows (20 × 1000 m), quadrats (20 × 20 m) and subquadrats (5 × 5 m)

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

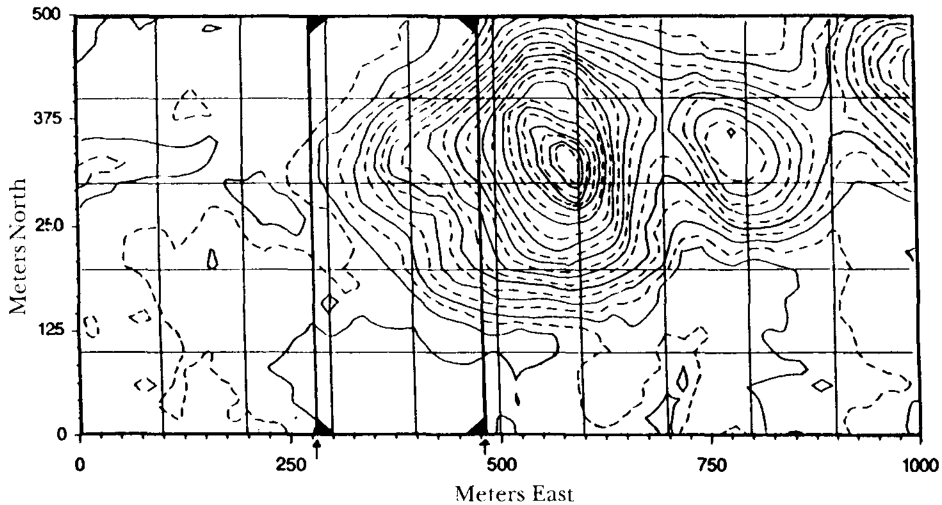

Figure 2. Topographic map of the PFR 50-ha plot, at 1-m contour intervals, and gridded at 1-ha units

10-ha study area

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 dBASE III program was then used to generate sequential tag numbers, and to direct the digitiser's output to the appropriate record. Second, the tag number, species code, and diameter were manually entered into a separate file. This system created a dBASE III file for each 20-m quadrat (Manokaran *et al.* 1990). For this study, the selected data for an area of 10 ha started at 280 to 480 m East and 500 m North as shown in Figure 2.

Determination of statistically most efficient quadrat size

The statistical efficiency of a quadrat size can be obtained from observations on quadrats of different sizes. The use of the minimum-variance method with modification (reduced to the basis of 10 × 10 m) for comparing various quadrat sizes would eliminate statistical bias. Many workers (Yates & Zacopany 1935, Hasel 1938, Lang *et al.* 1971, Wan Razali 1980) have found that the smallest plot size usually has the smallest variance and that the variance increases with increasing plot size. Therefore such modification is required.

Eight quadrat sizes were used, viz. 10 × 10 m, 10 × 30 m, 20 × 20 m, 20 × 40 m, 20 × 50 m, 20 × 60 m, 30 × 30 m and 40 × 40 m. These sizes were obtained by contiguous combination of the smallest quadrat size, i.e. 10 × 10 m. The combination of smallest quadrat size to the other sizes was done by using the longest side of the quadrat laid perpendicular to the contour lines in order to capture most variability in the species and the topographic features respectively.

Calculation of tree volume

Only trees with a minimum of 15 cm dbh were used to calculate their volumes. These tree volumes were calculated using the volume equations as stated below (all measurements in metric units):

a) For all species groups: 15 cm - ≤ 50 cm dbh

$$V = 0.8602 - 0.03872\,D + 0.0013164\,D^2$$

(FAO 1973)

b) For specific species group: > 50 cm dbh

DM	: $V = -21.07 - 0.96325\,D + 0.32397\,D^2$
DNM	: $V = -235.12 + 13.94562\,D + 0.09364\,D^2$
ND. LHW	: $V = 464.84 - 33.94734\,D + 0.85925\,D^2$
ND. MHW	: $V = -155.66 + 8.84486\,D + 0.13759\,D^2$
ND. HHW	: $V = 106.53 - 7.50393\,D + 0.33038\,D^2$
MISC.	: $V = -13.12 + 0.23651\,D^2$

(Canonizado & Buenaflor 1977)

In the above equations, D = dbh(cm), V = volume (m^3) and DM, DNM, ND. LHW, ND. MHW, ND. HHW and MISC. are as defined before.

Calculation of plot variance

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

Cochran (1977) stated that if $\bar{y}$ denotes the observed volume 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, $V_{\hat{Y}} = \frac{N^2V}{n} \frac{(N-n)}{N}$

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

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

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

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

Determination of minimum sample size requirement

If we want the percentage error to be less than $E = \rho Y$ with (1-α) 100 percent confidence, where ρ is the percentage 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 sample required with 90% confidence and 10% error for each quadrat.

Results and discussion

Statistically most efficient quadrat size in sampling tree volume

The 10-ha area contained a total volume of 3557.28 m^3 of all trees having 15 cm dbh and above. The present study shows that the smallest quadrat (10 × 10 m) has the least variance and variance increases with increasing plot size (Table 1).

Table 1. Population variance for eight quadrat sizes

Species group/ size class	Total volume per 10 ha (m^3)	Variance for the quadrat size in metres							
		10 × 10	10 × 30	20 × 20	20 × 40	20 × 50	20 × 60	30 × 30	40 × 40
Trees ≥ 15 cm dbh									
DM	607.61	4.28	12.18	16.02	36.11	39.63	53.65	27.14	57.92
DNM	626.76	5.75	19.95	30.23	66.93	78.58	105.54	74.92	146.06
ALL DIPT.	**1234.37**	**9.45**	**28.17**	**42.51**	**88.56**	**102.79**	**134.14**	**83.94**	**161.62**
ND LHW	598.69	1.29	3.83	4.96	9.63	13.03	14.47	8.85	22.33
ND MHW	841.49	2.24	6.93	8.97	19.37	23.76	32.10	16.26	31.23
ND HHW	767.27	0.97	2.88	3.68	8.56	10.17	11.98	10.65	20.89
ALL NON-DIPT.	**2207.45**	**4.54**	**14.74**	**18.87**	**44.37**	**59.74**	**74.67**	**44.73**	**102.98**
MISC.	**115.45**	**0.11**	**0.31**	**0.43**	**0.78**	**1.00**	**1.24**	**1.05**	**1.53**
ALL SPECIES	**3557.28**	**13.72**	**41.21**	**53.53**	**109.31**	**142.19**	**166.56**	**87.22**	**212.04**
Trees size class(cm dbh)									
15 - <30	1365.41	0.88	2.83	3.97	9.85	13.71	16.30	9.81	18.42
30 - <45	528.01	0.64	1.84	2.48	5.22	6.71	8.73	5.03	9.86
45 - <60	480.87	1.35	4.41	5.11	11.39	14.19	14.81	13.76	22.33
≥ 15	3557.28	13.72	41.21	53.53	109.31	142.19	166.56	87.22	212.04
≥ 30	2191.86	13.17	41.12	54.18	110.92	152.92	184.35	95.70	202.74
≥ 45	1663.85	12.57	39.50	51.00	101.23	144.21	169.65	95.90	190.12
≥ 60	1182.98	11.34	35.73	49.48	94.89	133.63	164.19	92.43	179.63

This seems to be true for all species groups and size classes. Wan Razali (1980) found a similar trend in Sungai Tekam Forest Reserve.

In order to eliminate the statistical bias, the variance associated with each quadrat was reduced to the basis of the smallest quadrat (10 × 10 m) before the variance of each quadrat was directly compared (Table 2). For example, the variance of 10 × 30 m quadrat in Table 1 was obtained by dividing by 3 and that of 40 × 40 m quadrat by 16. The results indicate that 30 × 30 m quadrat has the least variance for most species groups and diameter classes. Therefore, 30 × 30 m quadrat is statistically the most efficient quadrat size in sampling tree volume. It was shown by Wan Razali (1980) that a 10 × 10 m quadrat was statistically the most efficient quadrat in estimating tree density.

Percentage sample requirement

The percentage sample required differs among species groups, size classes and quadrat sizes used as shown in Table 3. The 30 × 30 m quadrat requires at least 59% of the population to be enumerated when sampling for dipterocarps (ALL DIPT.), only 20% for non-dipterocarps (ALL NON-DIPT.) and 16% for all species (ALL SPECIES) when sampling for volume of trees ≥ 15 cm dbh, all with 90% confidence and 10% error.

Similarly when sampling by size classes for ALL SPECIES, for example, a 12% sample is required for trees 15 to < 30 cm dbh, 16% for trees ≥ 15 cm dbh, 48% for trees ≥ 45 cm dbh and 63% for trees ≥ 60 cm dbh (Table 3).

Cousens (1958) found that in the Coastal Hill Forest of Symington (1974), 10% would be sufficient to systematically enumerate all trees greater than 40.6 cm dbh with 95% confidence and 12.5% error. If volumes of all trees of this size were to be sampled in this area, using 30 × 30 m quadrat, a sample of 34 - 48% is required. Wan Razali (1980) found that 40 - 60% is required to sample the density of all trees of this size using 10 × 10 m quadrat. Nevertheless, in the case of Cousens (1958), there was no indication whether one would be sampling tree density or tree volume.

Again one must remember that in an inventory work, statistically the most efficient quadrat size need not be the most optimum quadrat size. What one would like to do is to choose a quadrat that minimises the cost of the inventory while adhering to a given precision. Many methods to determine an optimum quadrat size have been developed in forest inventory works (Tardif 1965, Hazard & Promnitz 1974).

Implications to forest inventory in Malaysia

Generally in Malaysia forest sampling to determine the amount of stocking available before and after commercial felling (pre-felling & post-felling inventories) usually varies between 5 and 10% intensity (FDPM 1986a, b). The present practice in forest inventory work in Malaysia is to use 20 × 50 m quadrat for all trees ≥ 30 cm dbh. Assuming this quadrat size to be optimum for Malaysian

Table 2. Adjusted variance for different quadrat sizes to determine the statistically most efficient quadrat size

Species group/ size class	Adjusted variance for the quadrat size in meters Θ							
	10 × 10	10 × 30	20 × 20	20 × 40	20 × 50	20 × 60	30 × 30	40 × 40
Trees ≥ 15 cm dbh								
DM	4.28	4.06	4.01	4.51	3.96	4.47	3.02*	3.62
DNM	5.75*	6.65	7.56	8.37	7.86	8.80	8.32	9.13
ALL DIPT.	**9.45**	**9.39**	**10.63**	**11.07**	**10.28**	**11.18**	**9.33***	**10.10**
ND LHW	1.29	1.28	1.24	1.20	1.30	1.21	1.81*	1.40
ND MHW	2.24	2.31	2.24	2.24	2.38	2.68	1.18*	1.95
ND HHW	0.97	0.96	0.92*	1.07	1.02	1.00	4.97	1.31
ALL NON-DIPT.	**4.54***	**4.91**	**4.67**	**5.55**	**5.97**	**6.22**	**4.97**	**6.44**
MISC.	**0.11**	**0.10***	**0.11**	**0.10***	**0.10***	**0.10***	**0.12**	**0.10***
ALL SPECIES	**13.72**	**13.74**	**13.38**	**13.66**	**14.22**	**13.88**	**9.69***	**13.25**
Trees size class (cm dbh)								
15 - <30	0.88*	0.84	0.89	1.23	1.37	1.36	1.09	1.15
30 - <45	0.64	0.61	0.62	0.65	0.67	0.73	0.56*	0.62
45 - <60	1.35	1.47	1.28*	1.42	1.42	1.23	1.53	1.40
≥ 15	13.72	13.74	13.38	13.66	14.22	13.88	9.69*	13.25
≥ 30	13.17	13.71	13.55	13.87	15.29	15.36	10.63*	12.67
≥ 45	12.57	13.17	12.75	12.65	14.42	14.14	10.66*	11.88
≥ 60	11.34	11.91	12.37	11.86	13.36	13.68	10.27*	11.23

Θ variance was adjusted so that it is comparable with the variance of 1 × 10 m quadrat.
* indicates the minimum variance.

Table 3. The percentage sample required for the 90% confidence and 10% error in estimating tree volume of species groups and size classes

Species group/ size class	Total volume per 10 ha (m^3)	Percent sample required for the quadrat size in metres							
		10 × 10	10 × 30	20 × 20	20 × 40	20 × 50	20 × 60	30 × 30	40 × 40
Trees ≥ 15 cm dbh									
DM	607.61	76	74	74	76	75	76	66	72
DNM	626.76	80	82	84	85	85	86	84	86
ALL DIPT.	**1234.37**	**63**	**62**	**66**	**66**	**65**	**66**	**59***	**64**
ND LHW	598.69	50	48	49	47	50	47	39	51
ND MHW	841.49	46	46	46	47	48	50	38	52
ND HHW	767.27	31	30	30	32	32	31	32	37
ALL NON-DIPT.	**2207.45**	**20**	**21**	**21**	**23**	**25**	**25**	**20***	**26**
MISC.	**115.45**	**69**	**67**	**69**	**66**	**69**	**67**	**67**	**65**
ALL SPECIES	**3557.28**	**23**	**22**	**23**	**22**	**24**	**22**	**16***	**22**
Trees size class(cm dbh)									
15 - <30	1365.41	12	12	13	15	17	16	12*	14
30 - <45	528.01	39	37	38	38	40	41	32	37
45 - <60	480.87	61	63	60	62	63	58	61	61
≥ 15	3557.28	23	22	23	22	24	22	16*	22
≥ 30	2191.86	43	43	44	43	47	46	34	41
≥ 45	1663.85	55	56	56	55	59	57	48*	53
≥ 60	1182.98	69	69	71	69	72	72	63	68

*Minimum sampling % required to estimate tree volume of certain species groups and size classes using the most statistically efficient quadrat size.

forest, then Table 3 gives a guide to the percentage sample required. In order to sample all trees ≥ 30 cm dbh using 20 × 50 m quadrat, 47% sample is required for the 90% confidence and 10% error in estimating tree volume.

Wan Razali (1980), in estimating tree density, found that it requires 43 to 62% sample using 20 × 40 m quadrat and 54 to 61% sample using 20 × 60 m quadrat. Note that, by approximation, if a quadrat size of 20 × 50 m is used, the percentage sample required would be between 43 and 62% in order to sample density of trees ≥ 30 cm dbh only.

Also under the current inventory techniques in Malaysia, a 5% sample is used to enumerate all trees 15 to < 30 cm dbh but using 20 × 25 m quadrat (plot) size. If Table 3 is used as a guide (approximating by 20 × 20 m and 20 × 40 m quadrats), about 13 - 15% is required to sample such tree volumes. Wan Razali (1980) found that about 16% is required, using 20 × 20 m quadrat, in estimating tree density of about 15 to ≤ 30 cm dbh.

However, the original parameter estimate is not clearly known – either volume or tree density – when adopting 10% and 5% intensities in the current inventory techniques in Malaysia. Neither is it scientifically known and published as to the confidence and error levels at which the estimate was based, even though we have been informed at the 32nd MAJURUS (Majlis Urusan Silvikultur or Silviculture Management Council) meeting in 1995, that the confidence and error levels used are 95% and 20% respectively. Therefore it is rather difficult for anyone to judge the level of accuracy when interpreting the results of both the pre-felling and post-felling inventories. We can subjectively conclude here that, irrespective of either volume or tree density, the present 10% and 5% sampling intensities used are at a much lower confidence level or at a higher error level, or a combination of both, the quantum of which we cannot ascertain at the moment.

The issue of what percentage of the forest must be sampled is directly related to the size of the quadrat and how widely the quadrat should be spaced within and between sampling lines. Even the question of spacing of the quadrat is a function of many other factors such as the structure of the forest (patchiness), the distribution of species to be sampled, and the sampling design itself - a subject which needs to be addressed separately and beyond the objectives of this paper.

The results of this analysis could provide us the opportunity to further analyze the 50-ha Demography plot data. For example, it would be of interest to look specifically at the 20 × 50 m and 20 × 25 m quadrats currently being used in the pre-felling inventory in Malaysia and to simulate the respective 10% and 5% intensities associated with the quadrats in order (i) to find out whether volume or tree density is the best approximation of the present sampling intensity used in the pre-felling inventory, and (ii) to infer at what accuracy levels, such as from 80% probablity and 10% error levels to 95% probability and 5% error levels, the parameter estimate is based.

Conclusion

Based on eight quadrat sizes tested and their respective adjusted variance, 30 × 30 m quadrat gives the smallest variance, hence statistically the most efficient quadrat size in sampling tree volume for most species groups and size classes.

Many workers (Hasel 1938, Greg-Smith 1964, Krebs 1978) have found that rectangular plots are more efficient than square plots of equal area. However, this is not true in the present study area if we consider all trees 15 cm dbh and larger. Further decrease in variance would probably be expected with larger quadrat. This phenomenon was shown by Cousens (1958); the observations in his study were normally distributed by the time the plot size was increased to a 1:5 unit ratio. He recommended that five chains (100 m) should be the minimum length of one chain (20 m) strip that should constitute a sample unit; other things being equal, the longer the strip the better.

Based on the results of the present study, we can conclude that for a statistically unbiased sample, a minimum sampling intensity of 16% is required to sample volumes of all trees ≥ 15 cm dbh with 90% confidence and 10% error levels using 30 × 30 m quadrat, increasing to 24% intensity when using 20 × 50 m quadrat.

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