IMPROVING ESTIMATES OF STAND BASAL AREA IN WORKING PLAN INVENTORIES

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Abstract

Theoretical advantages in using angle counting, post-stratification and sampling with partial replacement to improve estimates of mean basal area per unit area are briefly reviewed. Worked examples for Ashley Forest show empirically how to gain these improvements in accuracy and precision through post-stratification and sampling with partial replacement. Use of these sampling techniques would be even more worth while if regional inventories corresponding to regional planning units were to be carried out, rather than inventories in single forests.

INTRODUCTION

This article aims to show field foresters a few ways in which they can provide better management information when using the Forest Service exotic forest inventory method as outlined by Lees (1967). We hope to achieve this by first reviewing the means of estimating basal area per unit area, *G*, and then analysing a specific case by way of demonstration.

Stand basal area is a particularly important component of estimating mean total stem volume under bark, *V*, in the Forest Service method. For example, Whyte (1969) showed how both accuracy and precision of *V* of mature radiata pine is influenced more by accuracy and precision of *G* than by those of other components, except perhaps that accuracy depends equally on the representativeness of the tree volume function or functions used.

Estimates of *G* can be improved by using a sounder measuring technique, sensible stratification and, where continuous forest inventory is practised, sampling with partial replacement. All three are briefly reviewed and then the last two are analysed in more detail in actual examples.

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THEORETICAL CONSIDERATIONS

Although there is an option in the Forest Service inventory system to use angle counting, it has rarely been adopted (L. Spicer, pers. comm.). Neglect in New Zealand of this theoretically sounder and, in our opinion, practically more effective and efficient measuring procedure in favour of quadrat sampling is difficult to comprehend. It is even harder to believe that, whenever angle count and quadrat estimates of mean basal area per unit of area are compared, foresters almost invariably assume that the quadrat gives *the* correct value, which is then used to judge the accuracy of the angle count estimate. This assertion, of course, is quite wrong, since a theoretically unbiased estimate of mean basal area should sample in proportion to stem basal area, not stem frequency. Quadrat sampling does not achieve this, whereas angle counting does. Both samples, however, provide only estimates of the true population mean.

Fortunately, the availability of computers with large storage capacity makes it possible to clarify this misconception without becoming too involved in pure theory. The true population mean basal area can be obtained from complete, careful enumerations of the size and position of every tree in a given population. Then, one can examine the accuracy of any specified sample estimate with the true parametric value. Published examples of such simulations include those by Palley and O'Regan (1961), O'Regan and Palley (1965), Kulow (1966), and O'Regan and Arvanitis (1966). All point to the superiority of angle counting in accuracy and precision of estimating *G*.

Kulow, for example, was able to compare accuracy and precision in estimating *G* among 144 different designs: he considered three areas of mixed deciduous forest, six plot shapes (circular, triangular, square, rectangular — 1:2, 1:5, and 1:8), six plot sizes, 25 to 809 m^2, and six basal area factors, 5 to 50 (with and without adjustment in the field for edge effects). Analysis of variance of sampling errors was used to compare the precision of estimate, and average deviation, of an estimated mean from the true mean to compare the accuracy. Kulow concluded that, in the three populations he studied, unadjusted angle counts with a basal area factor of 10 should be used for maximum precision and accuracy in estimating basal area in ft^2/ac. Differences in accuracy between the best angle count and quadrat estimates were, however, significant at conventional significance levels on only one of the three populations, that with the greatest variation in basal area. The same findings were obtained by Whyte (1967, unpubl.) for a stand of mature Corsican pine in Golden Downs State Forest, Nelson Conservancy, in that angle counts gave better precision of *G* at less cost than quadrats.

All authors, including Kulow, acknowledged that quadrats were more efficient than angle counts in determining number of stems per unit area, but this statistic is not one which is involved in calculating *V*, whereas basal area is.

By adopting angle counting, therefore, instead of quadrats in exotic forest inventories, better use of manpower resources could be achieved and more reliable information could be provided, particularly in populations where there is little or no undergrowth.

Foresters in New Zealand have been using stratification in their inventories for years (*e.g.*, Duff, 1964). Usually, however, it has been pre-stratification for administrative convenience — *e.g.*, by species, age class, compartment, etc. — occasionally for different stockings (*e.g.*, Crequer, 1964), but rarely has account been taken of other sources of biological variation, except broadly in Kaingaroa and in some Auckland forests. Detailed mapping by "site" (*sic*) quality classes as practised in South Australia (*e.g.*, Keeves, 1966) is an example of extreme stratification; the often small and irregular boundaries of such divisions, however, may lead to practical difficulties in determining areas accurately and in identifying them on the ground, and to their suffering a lack of permanence with time.

Nothing has been published on the use of objective post-stratification in this country, but this technique of catering at the time of conducting the inventory for various possible stratifications at a later date can be easily accommodated by the Forest Service inventory system; indeed, the system was designed partly with this in mind. Cunia (1968) discussed various aspects of post-stratification: he advocated its adoption in inventories in North America and considered that pre-stratification is wasteful and irrelevant. This conclusion may well obtain in the natural and semi-natural forests he had in mind, but in pure, even-aged plantations a combination of pre- and post-stratification has obvious advantages as shown in the next section.

Ware and Cunia (1962) showed also that better accuracy and precision at less cost can be obtained for estimates of both current volume and volume growth in large North American forests, by using a combination of permanent and temporary sampling units. They have called this continuous forest inventory design sampling with partial replacement (SPR). For example, say inventories of a forest have been carried out on two occasions separated by a few years. At time 1, N_1 plots and, at time 2, N_2 plots were measured. N_1 consisted of m matched (or permanent) plots and u unmatched (or temporary) plots (*i.e.*, $m + u = N_1$); N_2 consisted of the same m matched plots plus a new sample of n temporary plots (*i.e.*, $m + n = N_2$). Volume at time 2 can be best estimated if information from all m, u, and n plots is used, even though the u plots are not remeasured at time 2. Thus, mean volume per unit area at time 2, V_2, is derived from the mean of the m plots on the second occasion, V_{2m}, the mean of the n plots, V_{2n} and the mean of the u plots on the first occasion updated to time 2 by means of a regression of V_{2m} on V_{1m}, the volume of matched plots at time 1.

Estimates of volume growth based on all three sets of sampling units can be similarly derived and these too provide better estimates more efficiently than could matched plots alone. Moreover, one can specify the numbers of m, u, and n needed to obtain least cost for a certain error or minimum error for a fixed expenditure.

Until recently SPR theory had to assume that population variances on successive occasions were equal, or that the total sizes of sample were the same, or else both constraints held; but Ware and Cunia (1962) evolved new theory which eliminated the need for these assumptions. The only problem in applying it to plantations is that the size of samples may not be large enough to satisfy the assumptions made by Ware and Cunia, who were concerned primarily with vast areas of natural forest and hundreds of sampling units at any one time. Cochran (1963, p. 336) shows that, if the number of matched plots, m, is greater than 50, then this size of sample should be large enough to allow satisfactory estimation of the required population parameters provided also that the initial samples were located randomly, the sub-samples of matched plots were drawn at random, and the V_{1m} were normally distributed. This aspect is discussed later, although with reference to only a small amount of basic data.

Recent inventories in exotic forests throughout the country have established reasonable quantities of data which should be scrutinized, analysed, and results from them then utilized to help design subsequent inventories more in accordance with local conditions. The examples given in the next section show the kind of analyses which could be undertaken, and possible improvements in the design of future inventories are then discussed.

Worked Examples

A working plan inventory of pre-1957 crops in Ashley State Forest, Canterbury Conservancy, was conducted in 1969 in accordance with methods laid down in the then current Forest Service manual on inventory (Lees, 1967) which requires 95% confidence limits of ± 10% for V. The whole area was stratified for administrative convenience into species and then age classes for some of the species. About 30 bounded plots of various sizes were established systematically throughout each stratum and diameters at breast height of all living stems in every plot measured by diameter tape. Information pertinent

TABLE 1: SUMMARY OF INFORMATION FOR 1969 INVENTORY

Stratum	*Species*	*Age Class (yr)*	*Area (ha)*	*Plot Size (m^2)*	*No. of Plots*	*PLE of* G (%)
6010	Radiata pine	31-34	416.0	1012	32	± 18.0
6009	Radiata pine	23-29	223.0	405	30	± 7.6
6013	Radiata pine	16-22	258.0	405	28	± 17.4
6014	Douglas fir	29-32	103.0	202	27	± 8.0
6015	Douglas fir	19-27	91.5	202	39	± 15.3
6017	Corsican pine	18-32	283.5	202	35	± 15.9
6012	Radiata pine	Mixed	85.5	405	31	± 18.2

to this study for each of the seven strata so delineated is summarized in Table 1.

Table 1 reveals that precision in estimating the important parameter *G* appeared to be unsatisfactory for the intensity of sampling adopted in all strata except for 6009 and 6014. Obviously some of the variability could be ascribed to differences in age (*e.g.*, there was a span of 15 years included in stratum 6017), but this factor alone was unlikely to explain enough of the variation in stand basal area for other strata such as 6010, part of which was due to be harvested and for which, therefore, more accurate and precise information would have been highly desirable.

In 1972, we investigated various reasons for this variability in stand basal area, including year of establishment, degree of stocking, soil type, position on the slope, aspect, and compartment. Year of establishment and compartment number were easily obtained from the relevant plot field sheets. Degree of stocking was assessed mainly from aerial photographs taken just after the inventory was completed in 1969, but also from compartment records on thinning and from inspections on the ground. Windthrow was particularly prevalent in the oldest radiata pine, but was taken into account only if the affected area was greater than 2 ha. Three positions on the slope — (1) ridge tops and upper slopes, (2) mid-slopes, and (3) lower slopes and valley bottoms — were identified from contour maps. This classification, of course, is not altogether satisfactory since it is recognized that productivity varies, for example, between main and secondary ridges, and also depends on interactions with factors such as drainage and aspect, but it was considered a means of accounting for some of the variability. Aspect was noted from the aerial photographs, but proved difficult to accommodate on account of the small subdivisions involved.

The boundaries of all sub-strata were mapped, then adjusted to ensure that enclosed areas were greater than 2 ha, not too

TABLE 2: COMPARISON OF ESTIMATES OF MEAN BASAL AREA/HECTARE IN 1969 (*G*), ITS STANDARD ERROR (s_G) AND ITS 95% CONFIDENCE LIMITS (PLE) WITH AND WITHOUT SUB-STRATIFICATION

Stratum	No. of Sub-strata Used	G (m^2/ha) With	G (m^2/ha) Without	s_G (m^2/ha) With	s_G (m^2/ha) Without	PLE (%) With	PLE (%) Without
6010	6	32.5	29.1	± 1.35	± 2.57	± 8.5	± 18.0
6009	3	50.2	50.2	± 2.07	± 1.86	± 8.4	± 7.6
6013	4	29.0	27.3	± 1.03	± 2.32	± 7.3	± 17.4
6014	2	49.7	49.9	± 2.02	± 1.95	± 8.4	± 8.0
6015	3	26.6	25.7	± 1.03	± 1.95	± 7.9	± 15.3
6017	5	34.2	34.2	± 1.40	± 2.69	± 8.4	± 15.9
6012	5	45.0	39.4	± 3.60	± 3.51	± 16.4	± 18.2

difficult to distinguish on the ground, and that their outlines were not too irregular, which could adversely affect the accuracy of determining their areas. Areas of all finally chosen sub-strata were determined by careful planimetering.

Variability of stand basal area within and among these sub-strata was examined in detail to see which factors would significantly reduce the standard error of estimating mean basal area per unit area of the whole stratum. Obviously a compromise had to be struck between what was theoretically desirable and practically expedient. The maximum number of sub-strata chosen, therefore, was arbitrarily limited to six, since more degrees of freedom lost for the error term would generally be detrimental to the precision of an estimate for a total sample of round only 30.

The success of the empirically derived sub-stratifications in increasing precision of estimate can be judged from Table 2. In four of the five strata with unsatisfactory precision in estimating *G*, sub-stratification resulted in a reduction of the standard error of estimate by a factor of about 2. Moreover, in some of these strata mean basal area/hectare itself changed substantially, particularly for stratum 6010. Standard errors for strata 6009 and 6014, however, remained the same. Thus 95% confidence limits for the best estimate of *G* in all these strata became about ± 8%. Sub-stratification increased mean basal area of the stratum of mixed ages by over 14%, but it did not alter the precision, and so the PLE % for this stratum remained high.

Sub-stratification was successful on the basis of easily recognized differences in stocking for strata 6010, 6015, and 6017; on the basis of position on the slope for *6010*, *6013*, and *6015*, on the basis of soil type for 6013 and 0617, and on the basis of year of establishment for 6013, 6015, and 6017. Neither aspect nor compartment proved particularly useful for sub-stratification.

TABLE 3: VARIABILITY IN BASAL AREA/HECTARE IN 1969 (G_h) AND ITS VARIANCE (s^2_{Gh}) WITHIN STRATA 6010 AND 6009

Stratum	*Sub-stratum*	*Area (ha)*	*No. of Plots*	G_h (m^2/ha)	s^2_{Gh}
6010	1	28.9	4	2.0	7.33
	2	177.0	10	40.3	62.92
	3	53.0	6	26.6	73.11
	4	62.1	4	42.9	46.00
	5	39.1	3	23.6	13.63
	6	55.9	5	23.7	55.46
6009	1	53.6	7	51.1	103.52
	2	151.4	18	49.9	133.11
	3	18.0	5	50.0	43.29

A more detailed breakdown of variability within and among sub-strata is presented in Table 3 for the two oldest radiata pine strata, 6010 and 6009. In stratum 6010 sub-stratum 1 represented areas of heavy windthrow on ridges, sub-stratum 2 areas mainly on lower slopes with little or no windthrow, sub-stratum 3 areas on lower slopes of uneven stocking with incipient windthrow too scattered and too small to be worth delineating, sub-stratum 4 areas of high stocking on upper slopes, sub-stratum 5 wind-thrown areas exposed to the west, and sub-stratum 6 areas on mid-slope with patches of windthrow. In stratum 6009 sub-strata 1, 2 and 3 represented lower slopes, mid-slopes and ridges, respectively.

Sub-stratification based on differences in stocking was particularly useful in reducing the standard error of G for stratum 6010, but position on the slope and stocking often confounded each other. Better weighting of areas of different types within this stratum, achieved by sub-stratification raised the estimate of G by 11.5%. On the other hand, since there was little variation in the mean or the range of basal area among the three sub-strata in 6009, G and s_G were the same with or without sub-stratification.

The criteria for sub-stratifying strata 6010 and 6009 were then implemented in a new sample of plots measured in 1972 to test the applicability of these criteria for future inventories. In this test the objective was set of attaining an estimate of G with 95% confidence limits of ± 9%. Calculations were then made to ascertain from standard formulae (see *e.g.*, Freese, 1962, pp. 32 and 34) the total number of sampling units, n, needed to achieve this precision for each of the two strata and the optimum number (assuming equal costs) per sub-stratum, n_h.

$$i.e.,\ n = (\sum_{h=1}^{k} N_h\ s_h)^2/(N^2D^2 + \sum_{h=1}^{k} N_h\ s^2_h)$$

$$\text{and } n_h = (N_h\ s_h/(\sum_{h=1}^{k} (N_h\ s_h)))n$$

where N is the total possible number of sampling units in the whole population,

N_h is the total possible number of sampling units in the h^{th} sub-stratum

s^2_h is the estimated variance of the h^{th} sub-stratum

D is the allowed standard error for G

and k is the number of sub-strata.

Values for n and n_h were calculated for both strata from the data collected in the 1969 inventory. Thus, for stratum 6009,

$$n = ((53.6 \times \sqrt{103.52}) + (151.4 \times \sqrt{133.11}) + (18 \times \sqrt{43.29}))^2/(223^2 \times 2.3^2 + (53.6 \times 103.5 + 151.4 \times 133.11 + 18 \times 43.28)) = 20$$

where 2.3 is a PLE of ± 9% expressed in m^2/ha and all other figures shown can be obtained from Table 3

$$n_1 = ((53.6 \times \sqrt{103.52})/2410.53) \times 20 = 4.5$$

$$n_2 = ((151.4 \times \sqrt{133.11})/2410.53) \times 20 = 14.5$$

$$n_3 = ((18 \times \sqrt{43.29})/2410.53) \times 20 = 1.0$$

Since at least two samples must be taken from each sub-stratum before its variance can be estimated, it was decided to place 4, 14, and 2 sample plots in sub-strata 1, 2, and 3, respectively, of stratum 6009.

Similarly, n for stratum 6010 was 22 and optimum allocation was 2, 10, 4, 2, 2, and 2 for sub-strata 1, 2, 3, 4, 5, and 6, respectively.

Eight sample plots in each of strata 6010 and 6009 were permanent plots, first measured in 1969 and remeasured in 1972. The remaining 14 plots in stratum 6010 and 12 plots in stratum 6009 were located at random within the appropriate sub-strata. Basal area of all these plots was calculated from tape measurements of diameter at breast height over bark.

The results of the sampling are shown in Tables 4 and 5.

There was a 20% reduction in the standard error of G for stratum 6010 with sub-stratification but, as could be expected, precision was the same with and without sub-stratification for stratum 6009. With sub-stratification the PLEs actually obtained were ± 9.4% for stratum 6010 and ± 8% for 6009, compared with the objective of ± 9%.

As each of the two strata assessed in 1972 contained a mixture of newly established as well as remeasured plots, it was

TABLE 4: VARIABILITY IN BASAL AREA/HECTARE IN 1972 (G_h) AND ITS VARIANCE (s^2_{Gh}) WITHIN STRATA 6010 AND 6009

Stratum	*Sub-stratum*	*No. of Plots*	G_h (m^2/ha)	s^2_{Gh}
6010	1	2	40.5	50.32
	2	10	44.6	20.86
	3	4	50.8	42.65
	4	2	42.4	142.35
	5	2	26.0	7.35
	6	2	21.7	79.42
6009	1	4	58.5	61.11
	2	14	61.3	134.19
	3	2	58.8	35.88

TABLE 5: ESTIMATES OF MEAN BASAL AREA/HECTARE IN 1972 (G), ITS STANDARD ERROR (s_G) AND 95% CONFIDENCE LIMITS (PLE) FOR STRATA 6010 AND 6009 WITH AND WITHOUT SUB-STRATIFICATION

	G (m^2/ha)		s_G (m^2/ha)		*PLE (%)*	
Stratum	*With*	*Without*	*With*	*Without*	*With*	*Without*
6010	40.3	41.4	± 1.78	± 2.23	± 9.4	± 11.2
6009	60.5	60.5	± 2.28	± 2.29	± 8.0	± 7.9

possible to calculate G and s_G in another way, from the formulae for sampling with partial replacement advocated by Ware and Cunia (1962).

$$G_2 = (G_r/s^2_{Gr} + G_n/s^2_{Gn})/(1/s^2_{Gr} + 1/s^2_{Gn})$$

where $G_r = G_{2m} + b_{21}(G_1 - G_{1m})$

G_n = mean basal area per hectare of new plots

s^2_{Gr} and s^2_{Gn} are their respective error variances.

As three of the temporary plots were clearfelled between 1969 and 1972 they were not updated in the analysis.

Thus, for stratum 6010, mean basal area per hectare in 1972,

$$G_2 = (35.9/1.431 + 46.2/2.942)/(1/1.431 + 1/2.942)$$
$$= 39.3 \text{ m}^2/\text{ha}.$$

The standard error of this estimate is given by the formula,

$$s_{G2} = \pm\ ((s^2_{G2}(1 - u/(m + u) \cdot s_{12}/s_1 s_2))/(m + n - n\,u/(m + u) \cdot s_{12}/s_1 s_2))^{1/2}$$
$$= \pm\ ((41.183\ (1 - 21/29 \times 0.9976)/(8 + 14 - 14 \times 21/29 \times 0.9976))^{1/2}$$
$$= + 0.96 \text{ m}^2/\text{ha}.$$

For stratum 6010, that is, there were 21 unmatched plots (u), 8 matched plots (m), and 14 new plots (n).

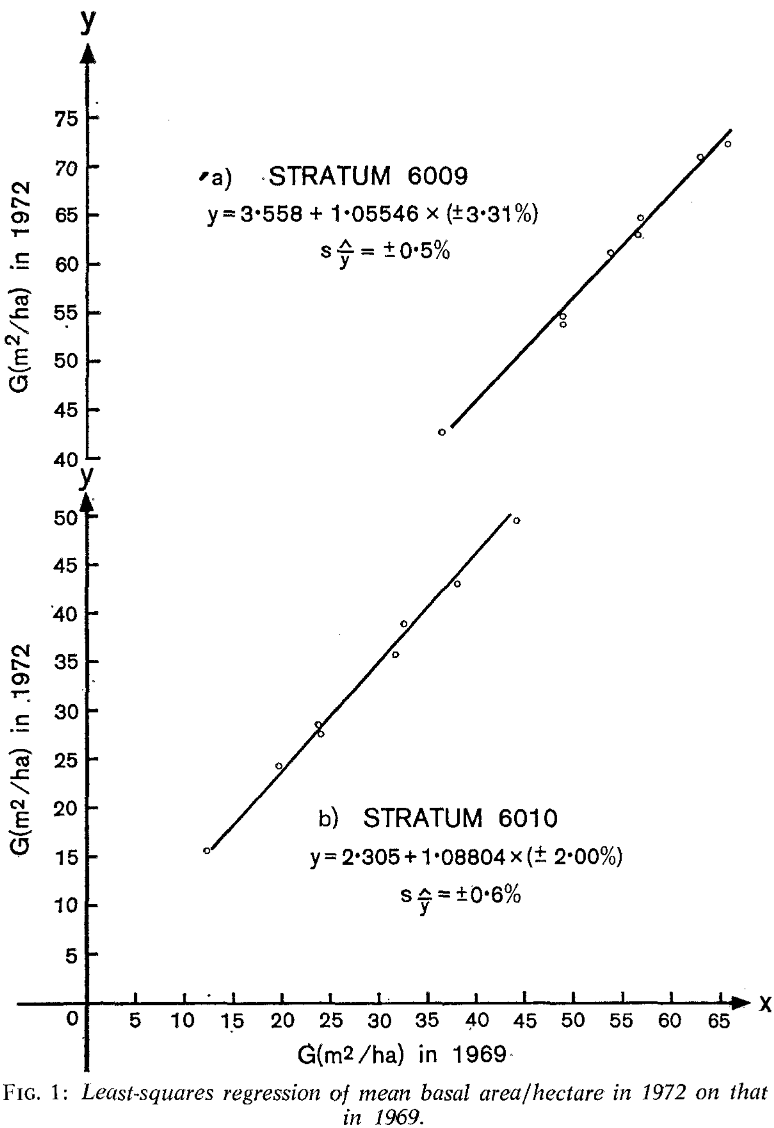

FIG. 1: *Least-squares regression of mean basal area/hectare in 1972 on that in 1969.*
(a) for stratum 6009 and (b) for stratum 6010.

The estimates so obtained for both strata are summarized in Table 6, and the straight line regressions of basal area/hectare in 1972 on basal area/hectare in 1969 are shown in Fig. 1.

Figure 1 shows how good the straight line fit is. Consequently, the precision attained in estimating G_2 is high, higher than with sub-stratification.

TABLE 6: MEAN BASAL AREA/HECTARE IN 1972 (G), ITS STANDARD ERROR (s_G) AND 95% CONFIDENCE LIMITS (PLE) FOR STRATA 6010 AND 6009 FROM SPR ESTIMATES

Stratum	G (*m²/ha*)	s_G (*m²/ha*)	*PLE* (%)
6010	39.3	± 0.96	± 5.3
6009	56.7	± 1.70	± 6.5

DISCUSSION

Pre-stratification for mainly administrative convenience in the 1969 inventory of Ashley Forest did not always produce accurate and precise estimates of mean basal area per unit area, as can be seen from Table 1. Accuracy in estimating G in these strata appeared to be adversely affected sometimes (*e.g.* in stratum 6010), by too low a sampling intensity of quadrats which did not provide a representative weighting for the distinct components of variation within the whole stratum. Intuitively, the sub-stratification used in 1972 should have improved the accuracy of the 1969 estimates by providing better weighting factors, but there are no actual data available to substantiate this claim.

The accuracy in estimating G for the stratum of mixed ages could not be improved by sub-stratification. A better estimate of G for this stratum could have been achieved by using angle counting with a high basal area factor and many sampling points together with sub-stratification. Nevertheless, even this would fail to achieve a satisfactory estimate of V, since the use of a stand volume function of the form $V/G = b_0 + b_1 H_s$ requires that the population be even-aged for stand height H_s, to be a valid predictor of mean volume per unit of basal area.

In four of the five strata with insufficiently precise estimates of G, sub-stratification reduced the standard error of estimate by a factor of about 2. In these cases it had been possible to recognize sub-strata which were more uniform within themselves than within the whole stratum and which frequently differed considerably in G_h. Foresters often look for too close correlations between the statistic they seek and the various criteria for stratification, without considering how the statistic is to be used. This is an unfortunate approach to adopt, as it usually yields too many, ill-defined boundaries on the map and on the ground, with all the impracticalities that this affords, and it also neglects to consider how the data collected are to be utilized. Presently, good estimates of the overall G, H_s, and their standard errors are sufficient, but future planning tools may require these statistics to be broken down further and also the recognition of others, particularly when growth functions are to be applied.

Thus, the sub-stratification carried out at Ashley was sufficiently detailed to allow a large amount of the total variation in basal area to be ascribed to differences between sub-strata, but at the same time it was broad enough to be practicable. A suitable compromise appears to have been achieved since PLEs of both the uneven strata when sub-stratified, and the even strata (6009 and 6014) with or without sub-stratification were all round ± 8%. To strive for greater precision by looking for closer correlations and becoming more detailed would probably have been a fruitless exercise. It is important, therefore, to distinguish the two approaches and then ensure that any sub-stratification actually employed is a practical proposition and not a tedious exercise in correlation.

Post-stratification could be catered for in future inventories at Ashley or any other forest by noting the various criteria on the second line of the field sheet (see Lees, 1967). Year of establishment and compartment are headings already there: degree of stocking could be given a numerical classification under the heading of management unit and position on the slope, or alternatively a combination of aspect and position on the slope could be simultaneously accommodated under the heading of site. It is not necessary to measure the actual areas of all such possible sub-strata until the need arises. To increase precision one can examine the preliminary results and then decide by trial and error which criteria are likely to increase precision of the stratum mean, before any determination of areas need be carried out.

Alternatively, when a specific management question arises, the inventory data can easily be manipulated to answer that question. For example, suppose a gale occurred after an inventory had been run, and resulted in windthrow on ridges and upper slopes facing the north-west among crops of 29 and 30 years of age. Aerial reconnaissance would be needed to assist in delineating boundaries of the blowdown on photographs. These boundaries when transferred to a map would provide an estimate of the area and location involved, and a good estimate of the total amount blown down could then be obtained from this and the mean per unit area for those particular ages and site types affected. This estimate would be better than that using the overall stratum mean, which would include other years of establishment, positions on the slope, and aspects. Similarly, one could arrange to have a stratum coded with methods of logging to be used in various parts of it, so that the resource could be broken down into how much would be logged by each method, or even from each setting, if necessary.

Post-stratification, then, is a powerful and flexible tool able to be of assistance in providing answers to various management problems even if these change from time to time. If the kinds of information likely to be needed can be pre-specified it is possible to cater for them in a carefully chosen set of codes on the Forest Service inventory field sheets, without expenditure of much effort until specific needs arise.

Sampling with partial replacement offers another way of improving the quality of management information efficiently. There is a danger that the examples worked out here are not really valid, because the theory assumes larger sample sizes. But, the most encouraging feature is the close relationships between basal area in 1972 and 1969, which makes SPR look to be a promising technique for inventories of plantations.

Both post-stratification and sampling with partial replacement would become more relevant if used in regional inventories rather than those of individual forests. This development seems logical, however, in view of the trend within the Forest Service in preparing regional management plans (see *e.g.*, Trotman, 1973). Regional inventories could result in larger sizes of sample being taken in each administrative stratum (*i.e.*, broad planning unit) for a given region, but still achieve an economy of total effort within the organization. Sub-stratification in terms of "forest" is already available in the existing inventory system, and so the only real problem is in choosing suitable criteria of sub-stratification for management needs.

CONCLUSIONS

Estimates of basal area per unit area could be improved in the inventory system if angle counting, post-stratification, and sampling with partial replacement were adopted for regional working plan inventories. Angle counting (which is a form of sampling with probability proportional to size) provides theoretically better estimates of *G*; and evidence from other sources shows that it is also more efficient in practice than are quadrats. Post-stratification of variable administrative units can result in better precision of estimate and offers flexibility in serving management needs. Sampling with partial replacement promises to be a useful technique in inventories of plantations, despite the small number of sampling units involved, because stand basal areas from one sampling occasion to the next are very closely related.

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