ESTIMATING STAND WEIGHT—THE IMPORTANCE OF SAMPLE SELECTION

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ABSTRACT

Simulated sampling showed that, in determining estimated stand component weights, sampling method and estimating techniques were of less importance than the sample of trees selected. There is a need for more work on the variables used to predict tree weight. Some problems arise with sequential sampling but it has the advantage that aberrant estimates based on small sample sizes are revealed.

Keywords: stand weight; estimation.

INTRODUCTION

Over the past 20 years there has been much interest in methods of estimating stand weight (Ovington *et al.* 1968; Madgwick & Satoo 1975; Madgwick 1981, 1983a; Snowdon 1985, 1991).

These studies have concentrated on sampling strategies and methods of predicting tree weights from sample trees using simulated sampling of plot data for which component weights of all trees are known. Mean bias depends on the combination of methods chosen. Depending on age of the publication, "best" methods have been advocated.

In a number of studies of forest biomass I have routinely estimated stand component weight using each of three methods—namely, basal area ratio, ln-ln regression, and regression of weight on the square of diameter at breast height. Examples have been published by Beets & Pollock (1987). The similarity of estimates using the three methods is impressive. The ratio of maximum to minimum estimates was less than 1.05 in three-quarters of the 12 examples used by Beets & Pollock and there was no consistent ordering of results by method used. Consequently, it appears desirable to examine the relative contributions of sample and prediction method on estimates of stand weight.

MATERIAL AND METHODS

The sample stand of Ovington *et al.* (1968) consisting of 100 weighed trees of *Pinus radiata* D. Don was used in simulated sampling. One hundred samples of 20 trees were used to estimate each of five components using five estimating techniques. Components were foliage, live branches, total branches, stems, and roots. Estimating techniques were ordinary least squares, weighted least squares, regression after square root transformation or logarithmic transformation, and the basal area ratio method. Both random sampling and stratified random sampling were used. Stratification was on dbh^2.height with five strata containing equal numbers of trees.

RESULTS

Mean bias was less than 1% for all methods except logarithmic transformation (Table 1). Variability of estimates was greater among components than among methods (Table 2). Smallest mean biases and variability were usually found for either ratio estimates or regression with square root transformation.

TABLE 1–Bias of estimated plot weights (%) as affected by estimating and sampling procedures, using data of Ovington *et al.* (1968)

Estimating method	Sampling method	Component				
		Foliage	Branches		Stem	Root
			Live	Total		
Ordinary	Random	–0.56	–0.78	–0.82	0.58	0.32
	Stratified	–0.12	–0.95	–0.97	0.14	0.38
Weighted	Random	–0.39	–0.56	–0.57	0.57	0.28
	Stratified	0.05	–0.70	–0.74	–0.10	0.32
Square root	Random	–0.36	–0.41	–0.46	0.54	0.43
	Stratified	0.08	–0.60	–0.63	0.09	0.47
Logarithm	Random	0.56	1.94	2.14	1.72	1.21
	Stratified	1.15	0.97	1.17	1.37	1.10
Ratio	Random	–0.30	–0.41	–0.42	0.50	0.31
	Stratified	0.05	–0.70	–0.74	–0.10	0.32

TABLE 2–Coefficient of variation (%) of estimated plot weight as affected by estimating and sampling procedures, using data of Ovington *et al.* (1968)

Estimating method	Sampling method	Component				
		Foliage	Branches		Stem	Root
			Live	Total		
Ordinary	Random	4.72	6.51	6.38	2.72	4.54
	Stratified	3.87	5.75	5.68	3.01	4.24
Weighted	Random	4.67	6.54	6.39	2.91	4.50
	Stratified	3.97	5.91	5.84	3.11	4.21
Square root	Random	4.74	6.53	6.39	2.73	4.57
	Stratified	3.97	5.88	5.80	3.01	4.27
Logarithm	Random	5.14	7.99	7.84	3.05	5.05
	Stratified	4.23	6.89	6.68	3.10	4.62
Ratio	Random	4.67	6.62	6.47	3.16	4.44
	Stratified	3.97	5.86	5.72	3.19	4.20

While estimated stand weights were significantly affected by estimating procedures, variation among replicate samples was of overwhelming importance, accounting for at least 92% of the variance in stand estimates (Table 3).

TABLE 3–Fraction of variation in estimated plot weight due to estimating method and replicate for two sampling procedures, using data of Ovington *et al.* (1968)

Sampling method	Source of variation	Component				
		Foliage	Branches		Stem	Root
			Live	Total		
Random	Method	0.01	0.02	0.03	0.03	0.01
	Replicate	0.96	0.93	0.92	0.92	0.97
Stratified	Method	0.01	0.01	0.02	0.03	0.00
	Replicate	0.95	0.96	0.95	0.95	0.98

DISCUSSION

The relative importance of the particular set of trees sampled, even with a sample size of one-fifth of the stand, indicates that the choice of estimating technique is of minor importance. Repeating the exercise reported here and using basal area for stratification and regressor variable led to substantially the same results. It appears that material improvement in estimating stand weight will probably come from better ways of estimating weight from size using additional variables or using more-intensive sampling.

Six linear measures of tree size were obtained by Ovington *et al.* (1968) namely, three stem diameters (at breast height, ground level, and the base of the live crown), total height, crown depth, and crown diameter. When considered in conjunction with five of their weight measures (foliage, live branches, total branches, stem, and roots) correlation after logarithmic transformation indicated that dbh was consistently the best single estimator of weight (r^2 0.90 to 0.95). Measurement of dbh will be subject to at least three sources of error. These are misreading of the diameter tape, rounding, and the effects of shape variation such as swelling around the branch clusters. Rounding errors were negligible (about 1% in the worst example). Errors due to misreading or to shape variation would give errors in estimates for the various weight components which would be positively correlated. Such positive correlations would also occur if the regressions were not linear. Linear regressions of ln(weight) on ln(dbh) were calculated for each component and the differences were very weakly correlated with $[\ln(\text{dbh})]^2$ with absolute values of r less than 0.04 suggesting that linear regression was a good assumption. Correlations among the differences between actual and estimated ln(weight) for foliage, live (or total) branches, stems, and roots were positive except for branches *v.* stems, and half were close to the 1% significance level. In an attempt to test whether the positive correlations were due to errors in measuring dbh, regressions were calculated using the sum of the logarithms of the three stem diameters as regressor variable. At best only negligible improvement occurred.

A further cause of correlated errors in weight estimates could be differences in tree form. Measures of form have been widely used in estimating stem volume (Assmann 1970). I have found that genotypes can be rated in terms of relative branchiness as well as over-all size

(Madgwick 1983b). In the present study, adding a second regressor variable, ln(height), substantially improved estimates only for stem weight. The best improvement in estimates of crown components occurred with stem diameter below the crown as a second variable but was of little practical significance. A measure of branchiness or of crown density could be considered.

An alternative is to increase the intensity of sampling. The basal area ratio technique is computationally easy and lends itself to sequential sampling. In order to explore this alternative, 20 samples of stem weight were taken sequentially and the ratio of estimated to actual stand weight was calculated. Four examples from the 20 are illustrated in Fig. 1. The four were chosen to emphasise the variation in results.

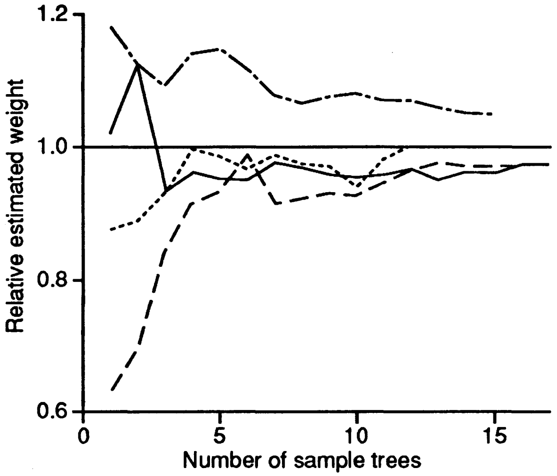

FIG. 1–Examples of four simulated sequential samplings chosen from a random selection of 20, using data of Ovington *et al.* (1968)

In most calculations there was a more or less rapid convergence of estimates towards the stand value as sample size increased to 10 trees (a 10% sample). However, some samples tended towards a stable value several percentage points from the stand value. No obvious rule for terminating sampling was revealed. In the examples given a limit was set based on an approximate estimate of standard deviation which is known to be biased for small samples (Cochran 1963). The limit chosen was 5% of the total estimated weight. This resulted in a sample size ranging from 12 to 17 trees. Since the estimate of standard deviation is strongly dependent on sample size, sampling continued in one case long past the point where a more or less stable stand estimate had been obtained. Sequential sampling had the advantage that aberrant estimates based on small sample sizes were revealed. Increased application of sequential sampling in a variety of conditions could lead to improved understanding of sample sizes required in estimating stand weights.

REFERENCES

ASSMANN, E, 1970: "The Principles of Forest Yield Study". Pergamon Press, Oxford, England.

BEETS, P.N.; POLLOCK, D.S. 1987: Accumulation and partitioning of dry matter in *Pinus radiata* as related to stand age and thinning. *New Zealand Journal of Forestry Science 17*: 246–71.

COCHRAN, W.G. 1963: "Sampling Techniques". 2nd edition. Wiley, New York.

MADGWICK, H.A.I. 1981: Estimating the above-ground weight of forest plots using the basal area ratio method. *New Zealand Journal of Forestry Science 11*: 279–86.

———1983a: Above-ground weights of forest plots—Comparison of some methods of estimation. *New Zealand Journal of Forestry Science 11*: 100–5.

———1983b: Differences in growth and weight of genotypes of pine with special reference to clones of *Pinus radiata*. *New Zealand Journal of Forestry Science 13*: 115–24.

MADGWICK, H.A.I.; SATOO, T. 1975: On estimating the aboveground weights of tree stands. *Ecology 56*: 1446–50.

OVINGTON, J.D.; FORREST, W.G.; ARMSTRONG, J.E. 1968: Tree biomass estimation. Pp. 3–31 *in* Young, H.E. (Ed.) "Symposium on Primary Productivity and Mineral Cycling in Natural Ecosystems". University of Maine Press, Orono, Maine, United States.

SNOWDON, P. 1985: Alternative sampling strategies and regression models for estimating forest biomass. *Australian Forest Research 15*: 353–66.

———1991: A ratio estimator for bias correction in logarithmic regressions. *Canadian Journal of Forest Research 21*: 720–4.