VOLUME ESTIMATION OF EXPORT PULPLOGS

J. C. ELLIS and M. O. KIMBERLEY

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

(Received for publication 17 May 1995; revision 21 August 1995)

ABSTRACT

Stratified sampling has been applied to the estimation of volume in export consignments of pulplogs from New Zealand. Minimal bias and greatly improved precision were demonstrated when this type of sampling was compared with the alternative cluster sampling procedure. Adoption of stratified sampling techniques has reduced the cost and increased the precision of average piece volume estimates used to derive overall volumes from a total piece count.

Keywords: scaling; pulplogs; sampling; pulp volume.

INTRODUCTION

Logs exported from New Zealand to Asia are usually sold on the basis of the Japanese Agricultural Standard (JAS) (Ellis 1994) which estimates volume in cubic metres from the measurement of small-end diameter (inside bark) and the nominal length of each log. The basic equation is:

$$V = \frac{D^2L}{10\,000}$$

where V = log volume in cubic metres JAS for lengths <6 m
D = small-end diameter (cm) rounded down to the nearest even centimetre
L = log length (m) rounded down to the nearest tenth of a metre.

The small-end diameter used is that of the shortest axis through the centre. There are adjustments for non-circular sections but the longest diameter must be at least 6 cm longer than the shortest for these to come into effect. The equation for lengths of 6 m and greater includes a taper term based on length. Truckloads of logs are generally scaled at the wharf marshalling point prior to stockpiling. For sawlogs, all logs are scaled and ticketed at the small end.

Measurement of pulpwood has always been difficult and costly because of the small size of pieces and the corresponding larger number per load (Belanger 1991). Pulpwood volume estimates are also notable for their lack of precision (Kärkkäinen 1983). A typical consignment of pulplogs comprises 30 000 pieces made up of about 500 truck or trailer loads at approximately 15 m^3 (JAS) per load. Individual truckloads average 60 to 80 logs, although they can contain up to 200 logs. Small-diameter logs are difficult to measure in a log stack or truckload because of the proximity of other logs. The measurement of each piece on the load takes so long that truck operators can be disadvantaged financially. Scaling of a load takes about 20 minutes on average, whereas an average load of sawlogs takes about 5 minutes. The scaling cost, including the cost of ticketing each pulp piece, is approximately five times that for sawlogs.

Until 1991, exported pulpwood either was fully scaled or the volume was estimated from sample truckloads in which every piece was measured for JAS volume. From the sample truckloads a mean piece size was derived for each length class and species, but practical problems made it difficult to maintain an unbiased average piece size. Examples of such problems are:

(1) About 20 truckloads were needed in each length class in order to derive mean piece size with a reasonable degree of precision (volume estimate within plus or minus 10% at the 95% confidence level).

(2) Sample loads had to be treated differently from normal loads. Careful loading was required to make the log ends flush enough for small-end-diameter scaling. Unless the large end of each piece was marked on the bush skids before loading, scalers could not identify the small end on the truck. Sample loads also took longer to process through the marshalling point at the wharf.

(3) Where consignments were made up of several log sizes, volume estimates of some log categories were sometimes poor unless the whole population was measured. Where there were only a few total truckloads in a species-length class, the mean piece was not based on an adequate number of truckloads.

(4) Up to 10% of logs were measured at the large end because of inaccurate end-marking in the bush. This resulted in over-estimation of average piece size.

Sale by weight would appear to be attractive for pulpwood sales. However, most overseas customers of pulpwood currently purchase logs on a volume basis. Weigh scaling, in which sample loads are measured to obtain a conversion factor for estimating JAS volume from weight, could be a cost-efficient solution (Smith 1978), but would incur many of the drawbacks of the current procedure. Accurate piece counts of complete shipments would also be required by vendor and purchaser.

This paper describes the development, implementation, and evaluation of a new method for sampling pulpwood and deriving a mean piece size for each length class.

DEVELOPMENT OF THE NEW METHOD

Trucks are generally loaded with logs as they are taken out of the stockpile in the bush. For pulpwood, pieces within a truckload appear to be more or less randomly distributed, although the size and number of pieces can vary greatly between truckloads. The distribution of small-end diameter and volume of pulp pieces is skewed, with the average diameter and volume being close to the minimum, and the maximum size extending considerably above the mean (Fig. 1).

The first step was to examine the nature of the errors in the existing method of estimating mean piece volume. Four pulpwood datasets, each consisting of complete scaling of about 20 truckloads of logs in a single species-length class, were used to investigate alternative

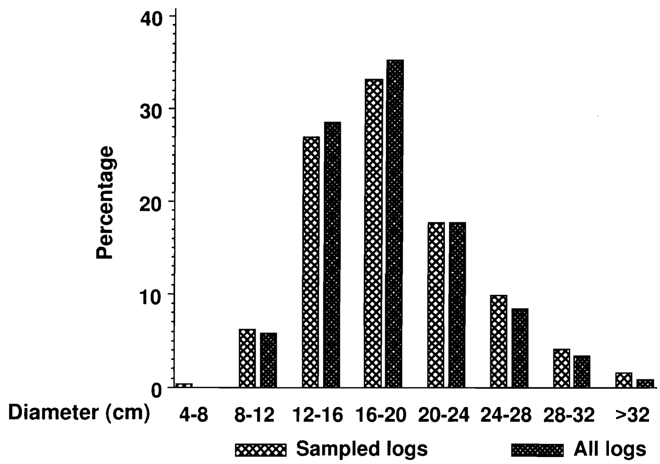

FIG. 1–Diameter distribution of all logs and sampled logs from validation Study 3

sampling approaches (Table 1). Log measurements included length, small-end diameter, and the corresponding volume in JAS (m³). This provided basic data for comparing whole truck sampling with partial sampling of every truckload.

Analyses of variance were carried out on log volume comparing truckloads for each dataset. Variance components (e.g., Searle 1971) were derived for the variance between logs within truckloads (σ^2_e, error), between truckloads (σ^2_l, load), and the sum of the two components (total). Although σ^2_e made up at least 86% of the variance, the σ^2_l was statistically highly significant ($p<0.001$) and contributed to the overall variance in average piece volume (Table 2). Dataset 4 had a between-load variance lower than the other three strata. This is partly explained by the small overall range of piece volumes in this set.

TABLE 1–Numbers of loads and logs in datasets used for preliminary analysis

Dataset	Log length (m)	Number of:		Number of logs per load			JAS diameter (cm)			Mean JAS volume (m³)
		Loads	Logs	Min.	Max.	Mean	Min.	Max.	Mean	
1	6	26	1739	28	134	67	8	44	19.4	0.267
2	4	24	2090	44	176	87	6	48	16.0	0.115
3	6	19	1262	39	143	66	6	40	16.6	0.198
4	8	23	2154	47	139	94	6	32	15.1	0.243

TABLE 2–Actual variance components of JAS log volumes

Dataset variance	Total	Load, σ^2_l	Percentage of total	Error, σ^2_e	Percentage of total
1	0.0227	0.00305	13.5	0.0196	86.5
2	0.0072	0.00081	11.3	0.0063	88.7
3	0.0114	0.00155	13.5	0.0099	86.5
4	0.0096	0.00026	2.7	0.0094	97.3

From these data it was possible to compare the efficiency of the existing method of measuring all logs in a sample of truckloads with that of an alternative method in which a percentage of the logs in every truckload is sampled. The existing method is essentially a form of cluster sampling, with each load forming a cluster, while the alternative method can be regarded as a form of stratified sampling with each load forming a stratum. The standard errors of the mean log volume using cluster and stratified sampling are (e.g., Cochran 1977):

$$se_{cluster} = \sqrt{\left[\frac{\sigma_l^2}{pa} + \frac{\sigma_e^2}{paN}\right](1-p)}$$

$$se_{stratified} = \sqrt{\frac{\sigma_e^2}{paN}(1-p)}$$

where p = the proportion of loads sampled
a = the total number of loads
N = the mean number of logs per load.

The efficiency of the stratified method relative to the cluster method can be measured by the ratio of their standard errors:

$$\frac{se_{stratified}}{se_{cluster}} = \sqrt{\frac{\sigma_e^2}{N\sigma_l^2 + \sigma_e^2}}$$

This efficiency ratio ranged from 0.29 to 0.53 for the four datasets and averaged 0.35, suggesting that stratified sampling should offer a substantial improvement in precision over cluster sampling. This implies that, for an equal number of log measurements, stratified sampling will give probable limits of error (PLE) (defined as the 95% confidence interval expressed as a percentage of the mean volume) one-third of that for cluster sampling. Alternatively, to get the same PLE, stratified sampling will require only one-tenth the number of log measurements needed for cluster sampling.

A new average piece method was proposed in which sample pieces must be obtained from every truckload. Sampling was considered to be most practical and efficient if it was on a fixed percentage for all loads. The recommended intensity of sampling was derived from studying the effect of varying the sampling percentage for varying numbers of loads, using the mean values from the four datasets (Fig. 2). The results are presented in terms of the PLE. It was concluded that a 10% sample would provide adequate precision while being efficient in effort and a simple sampling fraction to apply.

OPERATIONAL IMPLEMENTATION

In order to implement the new method of sampling, it was necessary to develop an unbiased system for selecting a percentage of logs from each truckload. Observation suggested that log size does not affect the placement of logs on a truck. This is because it is not practical for loader operators to place individual pieces on the truck. Occasionally larger logs are placed at the bottom and the top of the bolster, to contain the smaller pieces. For the new method placed logs should be avoided and the scaler should be able to check along the length of a log to ensure that the small end is being measured and not the large end. It was

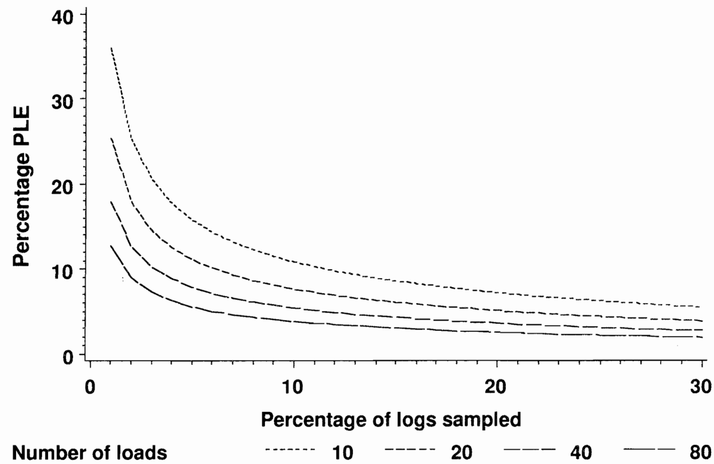

FIG. 2–Effect of sampling percentage on the precision of the estimated volume

decided that the easiest way to sample each load was to select and measure logs lying against the bolster on the outside of the load.

Field instructions for sampling and measurement were issued to scaling personnel. Briefly, they were as follows:

> For every truckload arriving at the wharf each piece is to be counted. To give adequate precision for a typical consignment, one-tenth of the pieces (10%) on each truck is to be measured for JAS. The scaler must calculate the number of whole logs which represent 10% of the total number. The method of rounding used is to select two logs from a total number of 16 to 25 logs, three logs from 26 to 35, and so on. Loads with less than 16 logs (very rare in practice) are 100% scaled, because such loads tend to contain a few large logs which are easily measured. It should be noted that the system can accommodate a combination of fully scaled and sample scaled loads. This implementation results in a maximum sampling rate of 12.5% (two in 16) and a minimum of 8% (two in 25). Sample pieces must be those pieces resting against the bolster of the truck/trailer unit so that small end can be positively identified. Selection of sample pieces should begin on one side of every load. The first sample log should be at the bottom of the bolster, and the next logs taken in order up the side of the load until the required number of samples are chosen. This procedure minimizes the effect of any placed logs at the top or bottom of loads. Any log selected as a sample is measured at the small end regardless of which direction it was loaded. Truck and trailer units should be treated as two units and sampled accordingly, even if logs are the same length. Sampling continues at the bottom of the other side of the load if there are insufficient logs on the first side, then along the top of the load, rather than the bottom.

In Fig. 3 sample logs on a pulpwood load are shown being measured by a scaler. The sample logs were selected first and marked with a diagonal stripe.

FIG. 3–Measuring sampled pulpwood

CALCULATION OF VOLUME AND LIMITS OF ERROR

Initially mean log volume was estimated using the simple mean of sampled logs. With the new method it became apparent that the average piece estimate could be biased if the mean piece was not weighted by truckload. The scaler tended to select more than 10% on loads with less than 40 pieces, and less than 10% on loads with more than 120 pieces. The method was therefore modified to incorporate weighted means and variances. A check of the truckloads left on the wharf (identified by docket numbers) allowed volume to be recalculated. Using the weighted approach also meant that fully scaled loads and sampled logs did not need to be separated in the database. Equations 1 and 2 below provide estimates of pulp volumes and variance of the mean piece, weighted by truckload. Error limits are calculated using Equation 3. These equations are essentially those used in stratified random sampling (e.g., Cochran 1977).

$$\overline{V} = \frac{\sum_{i=1}^{a} (\overline{V}_i \times N_i)}{\sum_{i=1}^{a} N_i} \qquad \text{... Equation 1}$$

$$\operatorname{Var}(\overline{V}) = \frac{\sum_{i=1}^{a} \left[\frac{s_i^2}{n_i} N_i^2 \left(1 - \frac{n_i}{N_i} \right) \right]}{\left(\sum_{i=1}^{a} N_i \right)^2} \quad \text{... Equation 2}$$

$$\text{PLE} = \frac{100 \times t_{n-a} \times \sqrt{\operatorname{Var}(\overline{V})}}{\overline{V}} \quad \text{... Equation 3}$$

where

$\overline{V}$ = weighted average piece size (m^3 JAS)
$\operatorname{Var}(\overline{V})$ = estimated variance of average piece size
$\overline{V}_i$ = average piece size of sampled logs in load i
N_i = total number of pieces in load i
n_i = number of pieces sampled in load i
a = number of truckloads
n = $\sum_{i=1}^{a} n_i$ total number of sample pieces
s_i^2 = variance between sample logs in load i
PLE = 95% confidence interval of mean piece size expressed as a percentage of the mean
t_{n-a} = t-value with n-a d.f. (2-tailed, $p = 0.05$)

VALIDATION OF METHOD

For validation of the method, measurements were obtained from seven individual stacks of pulpwood on New Zealand wharves (Table 3). For each study, all logs in a stack were laid out and their diameters measured at the small-end. A total JAS volume was derived for each stack. Individual logs in five of the stacks were ticketed so that they could be traced back to the original truckload. The other two stacks were not ticketed. Actual volume was compared with the estimate derived from sampling loads as they arrived on the wharf (Table 4). Over all studies the volume estimate from 1036 sample logs was 2.1% higher than the actual volume of the total of 10 496 logs. The over-estimate was caused principally by a large bias

TABLE 3–Number of loads and logs and mean log volume of validation studies

Study	No. loads	No. logs	No. sample logs	Diameter (cm)			Mean JAS volume (m^3)
				Min.	Max.	Mean	
1	28	1502	149	7	48	19.9	0.173
2	26	1589	158	8	50	19.5	0.167
3	17	1223	119	8	42	19.6	0.270
4	24	1411	134	8	48	19.3	0.165
5	20	1107	109	8	56	17.8	0.227
6	25	2151	216	4	36	16.0	0.108
7	19	1513	151	7	28	15.0	0.160

TABLE 4—Precision and bias of estimated volumes in validation studies

Study	Total JAS volume (m^3)		Stratified sample (%)		Ratio of s.e.: new *v.* old methods*
	Population	Sample	Bias	PLE	
1	260.1	261.6	+0.6	±7.6	0.15
2	265.9	270.3	+1.6	±9.9	0.11
3	330.7	314.1	–5.3	±7.2	0.36
4	232.3	247.4	+6.1	±11.8	–
5	251.4	285.6	+12.0	±12.1	–
6	233.4	232.6	–0.4	±4.4	0.17
7	242.2	242.9	+0.3	±5.7	0.13
Overall	1816.0	1854.5	+2.1		

* The standard error of the new method is based on measurement of a 10% sample of logs from each load; in the original method the standard error is based on all the logs in one load in 10.

in Study 5. All of the stack estimates were within the 95% confidence intervals, although these were large for Studies 4 and 5. A comparison of the diameter distributions of sampled logs with all logs in each study suggested that logs were equally sampled across all size classes (e.g., Fig. 1). In most of the studies, the reduction in the standard error using the new method (Table 4) was better than the one-third reduction calculated for the preliminary datasets.

Means and standard deviations of piece volumes for complete loads and samples were compared on a load-by-load basis in the five studies where logs could be traced to individual loads (Fig. 4 and 5). Estimates of mean piece volume did not show any obvious bias (Fig. 4), but there was a tendency for standard deviations of sample log data to be under-estimated by about 5% (Fig. 5). In practice, this is considered to be an acceptable error.

DISCUSSION

Since 1991 many exporters have used the within-load sampling technique to estimate log volume. Generally, the procedure has worked well and caused few difficulties. Log scalers must be properly trained in its application to avoid the possibility of bias and to prevent local variations in systematic percentage sampling. It is also important that the numbers of logs on each truck are correctly tallied.

There have been problems in applying the procedure to extremely variable pulp shipments where individual pieces may vary in size from 8 to 100 cm in small-end diameter (0.026 to 4 m^3 for a 4-m log). The new method gives unacceptably high PLEs (e.g., 10%) and is therefore considered inappropriate for such shipments.

It is possible that if logging and trucking contractors are paid on a volume basis there would be an incentive to place large pieces on the edge of loads where they have a greater chance of being sampled. There is evidence that this occurred in validation Study 5 which showed the greatest bias. It is therefore a good idea to have both the logging and trucking contractors paid on a weight basis.

Overall, the validation studies have shown the method to have minimal bias. Load variance and therefore confidence limits were understated by about 5% but it is possible to

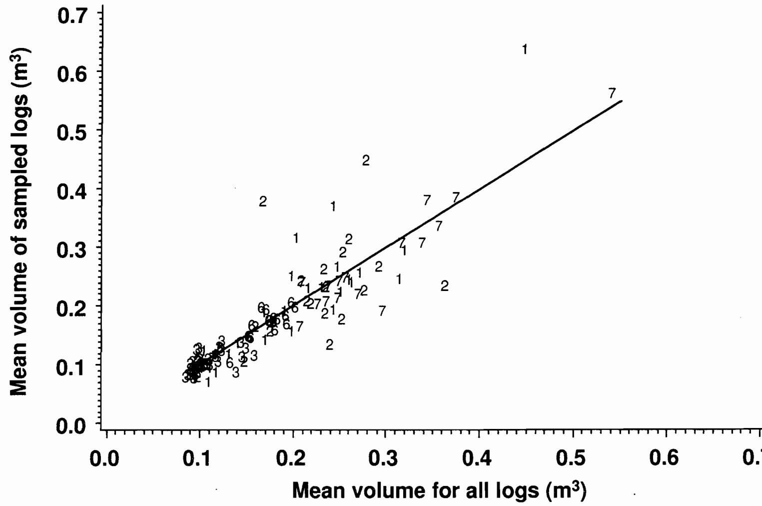

FIG. 4–Mean volumes for all logs *v.* sampled logs by load. Plotting symbols indicate study number.

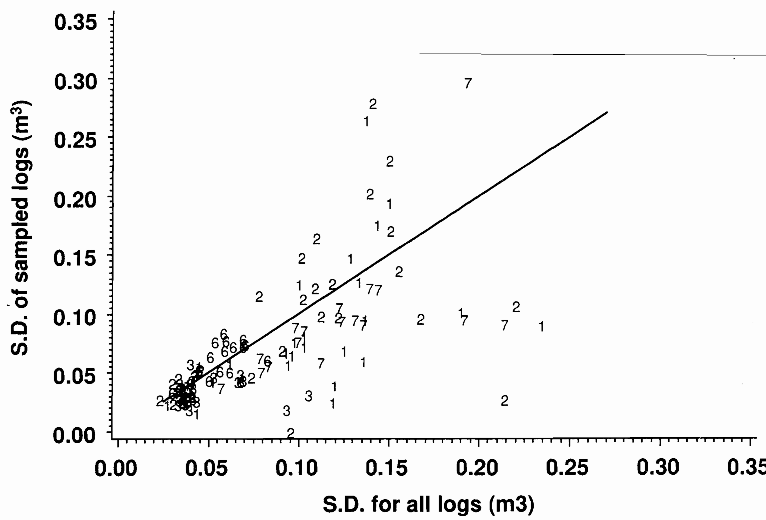

FIG. 5–Standard deviations for all logs *v.* sampled logs by load. Plotting symbols indicate study number.

alter the calculations to adjust for this. Alternatively, it can be acknowledged that a calculated PLE of 10% should be closer to 10.5%.

The sampling of a percentage of pieces on every consigned truckload is a more efficient method of measuring pulp volume than total piece measurement on a sample of truckloads. Truck waiting time has been reduced from an average of 20 minutes for each scaled load to less than 5 minutes. This is little more than the time taken to count and tag the logs as required for all loads under both methods. Each truckload is now processed in the same manner. There has been a reduction in the number of logs sampled and a further reduction in the cost of scaling logs of the order of $\$1/m^3$ scaled.

ACKNOWLEDGMENTS

This project was initially funded by the New Zealand Forestry Corporation. The authors are grateful to Keith Smith (then Manager, export operations for the Forestry Corporation) for the initiation of this project. Ken Crean (Manager) and staff of Owen's Services, Alec Cassie and staff of Wenita Forest Products Ltd, and Bruce Easton of Carter Holt Harvey have given freely of their time and plant in the testing and implementation of this scaling system. We also thank Ian Andrew, Alec Cassie, Chris Goulding, and Ruth Gadgil for helpful comments on the manuscript.

REFERENCES

BELANGER, J. 1991: Stem count sampling—A profitable method for scaling tree-length. Technical Conference on Wood Measurement Systems. Woodlands Section, Canadian Pulp and Paper Association, Montreal, Quebec.

COCHRAN, W.G. 1977: "Sampling Techniques", 3rd edition. John Wiley and Sons, New York, London, Sydney & Toronto.

ELLIS, J.C. 1994: "Procedures for the Measurement of Roundwood", 2nd edition. New Zealand Forest Research Institute, Rotorua.

KÄRKKÄINEN, M. 1983: Studies on the measurement of pulpwood bolts. *Folia Forestalia 542.*

SEARLE, S.R. 1971: "Linear Models". John Wiley & Sons, New York, London, Sydney & Toronto.

SMITH, V.G. 1978: Minimum total cost: An improved weigh scaling strategy. *New Zealand Journal of Forestry Science 8(2)*: 269–76