Personal Bias in Forest Measurements¹

by
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Abstract

The assumption that measurement errors are negligible during a forest inventory was tested using forestry students. The magnitude of personal bias in measuring tree diameter at breast height (dbh), total height, and basal area per hectare was obtained. Bias was negligible in dbh measurements and the among-crew coefficient of variation (CV) was 8.16%. Heights were significantly underestimated and the among-crew CV was 21.86%. The percentage error in basal area per hectare determination was 4.09% at the 95% probability level, using a prism of basal area factor 6. Measurement errors are, in general, not negligible. Their magnitude should be estimated per inventory and included in the total error of the inventory estimate.

Résumé

Le fait que les erreurs de mesurage s'avèrent négligeables lors d'inventaire forestier a été vérifié avec des étudiants en foresterie. On calcula l'importance de l'influence du personnel mesurant le diamètre de l'arbre à hauteur de poitrine (1,30 m), la hauteur totale et la surface terrière à l'hectare. Celle-ci fut donc négligeable pour les mesures du diamètre et le coefficient de la variation (CV) entre les membres d'une même équipe se chiffra à 8.16%. Par contre les prises de la hauteur furent fortement sous-estimées et le coefficient de la variation (CV) entre les membres d'une même équipe se fixa à 21.86%. Le pourcentage d'erreur enregistré pour le calcul de la surface terrière à l'hectare fut de 4.09% suivant le taux de probabilité de 95% et utilisant un prisme facteur 6 pour cet item. En général, les erreurs de mesurage ne sont pas négligeables. Leur importance devrait être estimée pour chaque inventaire en plus d'être incluse dans l'erreur totale de l'inventaire.

Introduction

Most forest inventory field work includes the measurement of tree and stand dimensions. These measurements, such as tree diameter at breast height (dbh), are expected to be accurate. However, significant variations of independent measurers have been observed. Most of these variations are a result of measurement (non-sampling) errors caused by measurer bias or faulty instruments. A measurement error is the difference between the true value and an inexact measurement of an object, and is measured in terms of bias and variance. In this respect, bias refers to a systematic distortion of a measurement from the true value of the object being measured, and variance refers to the spread of several measurements of the same object around their mean.

Although measurement errors have long been known to contribute significantly to the total error of a forest inventory, few empirical studies have been done to determine the extent of these errors. This is mainly because of the difficulty in obtaining well-founded quantitative estimates of the errors and the lack of generalities in the results. Estimates of measurement errors in point sampling have been obtained among others, by Ker et al. (1957); Carow (1958); Kendal et al. (1959); Munro (1966); Carow and Rickerd (1969); and Laar (1970) for some specific situations. Studies in height

measurement biases are summarized by Loetsch et al. (1973); and for dbh, the most notable is the work of Myers (1961).

It has been suggested that if the measurement errors occur randomly, their effect approaches zero. In this paper, the assumption that measurement errors are negligible during a forest inventory was tested. Specifically, the magnitude of personal bias and variation in measuring tree dbh, tree total height, and stand basal area was determined.

Method of Data Collection

Data for the study were collected at the University of British Columbia Research Forest, Maple Ridge, B.C., during the third year forestry students' field school in mensuration. Sixty sampling points were systematically set at about 80-m intervals in a 70-year-old second growth stand containing mainly Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western red cedar (*Thuja plicata* Donn.) in intimate mixture. Site index ranged from 15 to 50 m at 100 years and gross volume averaged 650 m³/ha. Topography varied from flat to rolling hills with slopes of about 50%, and underbrush and the weather, at the time of study, did not restrict line-of-sight visibility.

At each sampling point, up to six three-man student crews established prism (basal area factor (BAF) = 6) plots at the 30 odd-numbered points and relascope plots (BAF = 9) at the 30 even-numbered points. Thirty-one crews were involved in the exercise: in 30 plots there were six crews, in 10 plots five crews, in 10 plots four crews, and one crew in the remaining 10 plots. Each crew adhered to identical procedures of plot establishment. All "in" trees were tallied, and the dbh of every "in" tree was measured to the nearest mm with a linen diameter tape. The total height of the first "in" tree was measured to the nearest 0.1 m by trigonometric principles (using a Sunto and a nylon chain). Total height was defined as the vertical distance between the ground level and the tip of the tree. Each crew made measurements of trees in the same plot independently of other crews, and had to complete the exercise within a specified time limit. The students had a theoretical background in point sampling and many of them had varied field experience in prism and relascope plot establishment. Furthermore, the students were made aware of the precautions to be borne in mind during plot establishment and measurement.

As a control to the study, I made independent measurements, by carefully establishing prism and relascope plots in each of the pre-set sampling points and abiding by the same procedures the student crews had been instructed to follow. Some of the precautions taken to insure proper plot establishment were: (i) the prism always to be held directly above the sampling point; (ii) the prism to be held so that its base was perpendicular to the stem of the tree being sighted (except when the line of sight to the tree exceeded a slope of 10% from the horizontal, when slope correction would be needed); (iii) the prism to be held so that its face was perpendicular to the line of sight; (iv) all hidden trees to be sighted by moving the observation point provided the exact distance from the sampling point to the tree was maintained; (v) all "doubtful" trees to be checked by applying the appropriate plot radius factor; (vi) the relascope to be held such that it was slope correcting; and (vii) observe the tree at 1.3 m above germination point. These measurements were assumed to be free of measurement errors.

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Analyses and Results

There were three separate analyses of variance: for tree count, for dbh, and for total height. The among-crew variation in tree count per point was assessed by the method of analysis of variance; and the among-crew variation in measuring tree dbh and total height was assessed by calculating the crew variation for each tree and then pooling these to obtain a weighted average variation per tree. The data set from the plots with only one crew measurement was discarded from the analysis. Measurements in which different crews measured total height or dbh of different trees in the same plot were also discarded from the analysis. Personal bias in tree count, dbh or height measurements was determined by comparing the crew measurements with those of the control. The comparison was made by testing for parallelism and coincidence between the linear regression of the crew measurements on the corresponding control measurements and the expected line of correspondence. Details of the analyses were given by Omule (1978).

The crew average tree count was 9.5 trees per point in the prism plots and 7.4 trees in the relascope plots. The control average tree count was 8.9 and 7.4 trees per point in the prism and relascope plots, respectively. The among-crew coefficient of variation was 10.44% using the prism and 4.93% using the relascope. The among-crew variation was significant in the prism plots but not significant in the relascope plots at $\alpha = 0.05$ significance level. About 37% of the tree counts in the relascope plots and 25% in the prism plots were measured without error. The maximum tree count error was ± 6 trees per plot. Overall, crews counted trees with a negligible negative bias (0.43%) with a relascope, but with a significant negative bias (7.08%) with the prism, at $\alpha = 0.05$. (Negative bias refers to an overestimate.)

The crew average tree dbh was 52.67 cm and 52.72 cm by the control. The among-crew coefficient of variation was 8.16%. Only 6% of the measurements were exactly correct; however, 95% of them were within 5 cm of the control measurements. There were biases as large as ± 30 cm, and bias tended to be higher at large tree dbhs. On the average, at $\alpha = 0.05$, crews measured tree dbh with only a negligible positive bias³ of 0.09%.

The crew average tree total height was 31.38 m and 32.33 m by the control. The among-crew variation was 21.86%. Two per cent of all measurements were correct and over 15% were in error by ± 6.0 m or more. Crews measured tree heights with a significant positive bias of 2.93% ($\alpha = 0.05$). There was no trend in variation of the height measurements with increase in tree height.

Discussion and Conclusion

The assumption that the control measurements were free of measurement errors implied that the control measurements were the true values. Although these measurements were made with special care, strictly speaking they are not the true values. However, it is almost impossible to know the true values, and in similar studies elsewhere, estimated true values have been used. Therefore, for purposes of comparison, the control measurements were assumed to be the true values in this paper.

Crews estimated the tree count with less bias with a relascope than with the prism, probably because the relascope had a larger BAF. However, the relascope is known to be more precise than the prism. (This is mainly because the relascope makes adjustments automatically to correct for distortions in the instrument readings caused by variations in slopes.) In addition, crews found it easier to

align the relascope with the potential "in" tree.

Basal area per hectare is directly related to tree count per point. Therefore, the amount of crew variation in tree count is an indication of the crew variation in the determination of basal area per hectare. The 10.44% and 4.93% coefficients of variation in the 25 relascope and 25 prism plots, respectively, indicate that the percentage error ($\alpha = 0.05$) in determining basal area per hectare using the BAF = 6 and 9 is $\pm 4.09\%$ and $\pm 1.93\%$, respectively. Furthermore, since basal area per hectare is a function of volume, for most practical use, it can be said that the among-crew variation in tree count also indicates the among-crew variation in estimating volume per hectare. It is assumed here that total height does not enter into the volume per hectare calculation, that is, local volume tables were employed. If volume per hectare was calculated by other means, such as standard volume tables, the among-crew variation would probably be higher, since other sources of error would be present.

Measurements of dbh and heights of standing trees are useful in the construction of stand tables, height-diameter relationships and, sometimes, stand volume tables. Although dbh measurements were negligibly biased, there was a significant bias in tree height measurement. In fact, errors in the measurement of dbh and height are higher than the British Columbia Forest Service (B.C.F.S.) allowable errors of 1% and 3% for dbh and height, respectively. If a height-diameter relationship was fitted by linear least squares regression, the assumption that measurements of dbh (the independent variable) were free of measurement errors would be violated. And, if stand and volume tables were constructed, they would be biased to a degree proportional to the bias of dbh and height measurements.

The technique used for measuring height in this study necessitated the measurement of horizontal distances. It is suspected that the distance measurement errors contributed significantly to the high bias in height measurement. Furthermore, total height was obtained from two additive components (both subject to measurement error) which are found by separate readings, one to the top and the other to the base of the tree. Probably the use of those height measuring techniques (such as the Christen hypsometer) not requiring horizontal distance measurement and in which only one reading is taken could reduce the bias. Furthermore, when using a Sunto, it is difficult to sight the top or base of a tree and read the scale in the Sunto at the same time. A relascope would have probably given more precise results.

Bias in dbh measurements is attributed mostly to errors inherent in determining breast height (bh). The B.C.F.S. defines bh as a standard height 1.3 m above germination point. Germination point is difficult and inconvenient to locate. Furthermore, particularly on steep slopes and for large trees, the uphill side of the tree may be more than 1.3 m above the germination point. It is, therefore, suggested that the B.C.F.S. redefine bh as "The standard height, 1.30 m above ground level, at which the diameter of a standing tree is measured. On sloping ground, bh is usually measured on the uphill side of the tree" (Bonnor, 1978, p. 18).

The errors and biases in all these measurements originate from various sources and are listed in most of the references given earlier. The sources of error committed by an individual depend on personal aptitude and the work environment. In general, however, crews commit less measurement errors if they are well-trained and experienced and the forest and weather conditions are favourable. An investigation into the value of various levels of field training (and perhaps weather conditions) on a cost-effectiveness basis would be useful.

The workers in this study were forestry students who are often employed to undertake cruising for various forestry agencies. The extent of bias in basal area determination and in dbh and height measurement clearly demonstrates the need for caution in using untrained crews in forest inven-

³ Positive bias refers to an under-estimate.

tory. There is obviously a need for rigorous field training programs, and the establishment and implementation of check cruising guidelines. Estimates of measurement errors and biases should be determined per inventory and included in the total error of the inventory estimate.

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