Comparison of relative accuracy and time requirement between the caliper, the diameter tape and an electronic tree measuring fork

by Jean-Marie Binot, David Pothier[1] and Jeannot Lebel

This study compares the relative accuracy of diameters measured with the caliper, the diameter tape, and the electronic tree measuring fork (ETMF) Tally Boy[MC] with and without reflector. The time required for the measure and the data entry of diameters to computer for each instrument was also evaluated. Significant differences in mean DBH (diameter outside bark at breast height — 1.3 m above ground) generally occurred among instruments. Nevertheless, even if these differences were significant, they were less than 1 cm for five of the six species tested. For white pine (*Pinus strobus* L.), however, the use of the ETMF without reflector led to an important overestimation of the DBH in comparison to the caliper, the diameter tape and the ETMF with reflector. The typical fissured bark observed on white pines could probably explain that overestimation. For all species, the addition of the reflector to the ETMF decreased the differences among instruments. The measures taken with the diameter tape were slightly larger than those made with the caliper. In comparison to the diameter tape and the caliper, the ETMF reduced the time required for date collection from 35 to 45%.

Key words: diameter measurement, timber inventory

Cette étude compare la précision relative du compas forestier classique, du ruban diamétrique, et du compas électronique Tally Boy[MC] avec et sans réflecteur. De plus, les temps de mesure et de transfert des données sur ordinateur pour chaque instrument ont été évalués. D'une façon générale, les DHP moyens diffèrent significativement entre les instruments. Toutefois, même significatives, ces différences sont généralement inférieures à un cm pour cinq des six espèces testées. Dans le cas du pin blanc, l'utilisation du compas électronique sans réflecteur a produit une surestimation importante du DHP comparativement au compas forestier, au ruban diamétrique, et au compas électronique avec réflecteur. L'écorce généralement crevassée du pin blanc semble être à l'origine de cette surestimation. Pour toutes les espèces, l'ajout du réflecteur au compas électronique a atténué les différences avec les autres instruments. Les mesures faites au ruban diamétrique ont été généralement supérieures à celles faites au compas forestier. Comparativement au ruban diamétrique et au compas forestier, le compas électronique a permis de réduire de 35 à 45% le temps nécessaire à la cueillette des données.

Mots clés: mesure du diamètre, inventaire forestier

Introduction

Timber inventory is a major management activity which mainly consists of measuring and grading trees in order to obtain information on the quantity and the quality of the timber resource. Tree diameter is an important variable of the inventory because it is strongly correlated to stem volume. For current volume inventory, tree diameter is generally measured with a caliper (Duplas and Perotte 1981), or with a diameter tape when accurate and consistent measurements are needed (Avery and Burkhart 1983). Using either a caliper or a diameter tape, the operator takes the measurement and transmits it to another person who notes the diameter on a tally sheet or records it on a portable data collector. Consequently, during the tree diameter measurement procedure, a crew of two members is in charge of this sole task.

Over the past few years, electronic instruments have been developed in order to reduce the time required for the measurement, transmission, and data entry of the tree diameter values (Zarnovican and Ouellet 1989). Among these instruments, an electronic tree measuring fork (ETMF), called the Tally Boy[MC] (Control One, Belgium), differs from electronic calipers by its geometric principles. This instrument is composed of two easy-to-change metallic arms with a 60° angle between them, an ultrasonic emitter-receiver located at the base of the fork, and a data collector. The arms are available in three different lengths allowing the measurements of trees in the following ranges of diameter: 80–460 mm, 80–690 mm and 80–920 mm. The 60° angle between the arms makes the distance between the ultrasonic emitter-receiver and the bark equal to the radius of a tree of circular cross section. Consequently, the time required for an ultrasonic wave to travel from the emitter to the bark, and then to come back to the receiver is directly proportional to the diameter of the tree. This ETMF is easy to use because the operator leans the fork against the tree, presses a trigger which controls the ultrasonic emission, and the diameter of the tree is automatically measured and recorded in computer memory. Moreover, only one crew member is required to measure and record tree diameters, leaving the other crew member to obtain other measurements. Therefore, use of the ETMF could save time during field work. It could also save time and avoid mistakes in measurement and computer data entry because all the diameters are automatically recorded when they are measured.

However, the use of ultrasonic waves for measuring tree diameter could induce some errors which will not occur when a caliper or a diameter tape is used. Rough bark could interfere with the ultrasonic waves, leading to erratic measurements of tree diameter. Before an ETMF could be considered as a replacement instrument for caliper or diameter tape in forest inventory, it is important to test the accuracy of the diameter measure and also the time-saving potential of the ETMF. In order to make these comparisons, a study was undertaken with several tree species common to the forests of Eastern Canada.

Materials and Methods

Trees tested during this study were located in different areas of New Brunswick, Canada. One stand was selected on

Ecole de sciences forestières, Université de Moncton (CUSLM), Edmundston, Nouveau-Brunswick, Canada E3V 2S8.
[1]Present address: Ministère des forêts du Québec, Service de la recherche, 2700 rue Einstein, Sainte-Foy, Québec, Canada G1P 3W8.

a freehold of J.D. Irving Ltd near St-Léonard (47° 10′ N 67° 50′ W). A second stand was located at the Experiemental Forest of the School of Forest Science of the Université de Moncton (47° 20′ N 67° 55′ W). The white pine stand was located near Doaktown (46° 35′ N 66° 05′ W) in the central area of New Brunswick.

In order to have different bark characteristics which could interfere with ultrasonic waves of the ETMF, six tree species were selected: balsam fir (*Abies balsamea* (L.) Mill.), white spruce (*Picea glauca* (Moench) Voss), eastern white pine (*Pinus strobus* L.), American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), and trembling aspen (*Populus tremuloides* Michx.). For each species, 45 to 85 trees were selected from a range of DBH (diameter outside bark at breast height — 1.3 m above ground) measures, varying from 10 to 45 cm. Each selected tree was marked with paint at breast height in order to compare the measures among instruments. For each selected species, the measurement procedure was as follow: (1) two readings of DBH at right angles were taken with the ETMF, (2) the DBH of the same tree was measured with the diameter tape, (3) the caliper was then used to take two measures of DBH at right angles and (4) two other measures of DBH were taken with the ETMF modified to have a reflector (plastic band) at the surface of the bark which could eliminate potential problems associated with ultrasonic waves. For each instrument, all the readings were taken to the nearest mm.

In order to compare the DBH measurements among instruments, data of each species were subjected to an analysis of variance for a randomized block design where the number of blocks corresponded to the number of measured trees. Multiple comparisons were calculated according to Tukey's test (Scherrer 1984) at the 95% level when the analysis of variance detected a significant difference between instrument means.

During the course of the experiment, we became aware of the sensitivity of the ETMF to the eccentricity of tree cross sections, here defined as the ratio of the largest to the shortest diameter. Consequently, a geometric analysis (Matern 1956; Grosenbaugh 1980) of the actual instrument measurement was made to assess the error percentage of the diameter of an ellipse measured with a caliper, a diameter tape and a ETMF for a range of cross section eccentricity. Since the arithmetic mean rather than the geometric mean is generally calculated as a result of the two measured diameters of a tree (Bary-Lenger *et al.* 1979; Husch *et al.* 1982), the diameter associated with the caliper (D_c) was simply defined as:

$$D_c = a + b$$

where a is the radius of the major axis of an ellipse and b is the radius of the minor axis (Fig. 1).

To simulate the diameter tape, the calculated diameter was defined as the perimeter of an ellipse divided by π. Hence, the simulated diameter for the diameter tape (D_{dt}) can be written as:

$$D_{dt} = (a+b)\left[1+\frac{1}{4}\left(\frac{a-b}{a+b}\right)^2+\frac{1}{64}\left(\frac{a-b}{a+b}\right)^2\right]$$

Because of the 60° angle between its arms, the ETMF cannot directly measure the major and the minor axis of an ellipse as the caliper does. Instead, the measurement taken with the ETMF corresponds to the diameter at a given angle θ_1 (Fig. 1) which

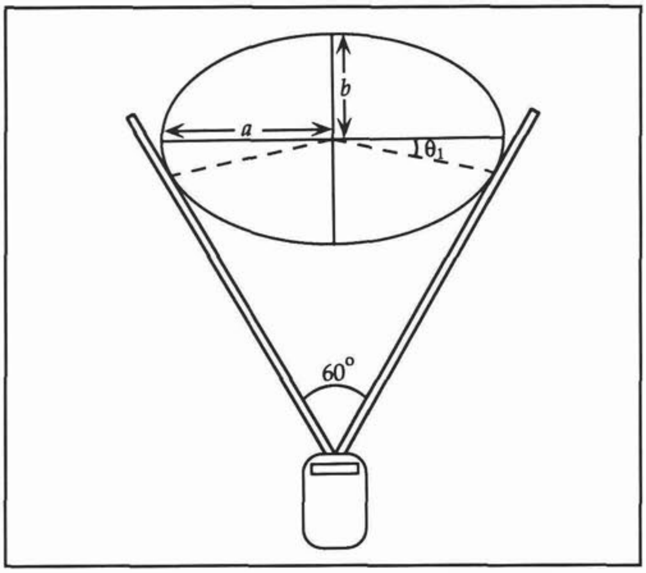

Figure 1. Measurement of the major axis of an elliptical cross section with the electronic tree measuring fork. (a: length of semi-major axis; b: length of semi-minor axis; θ_1: angle between the semi-major axis and the line between the peripheral point of contact of the ETMF and the center of the ellipse).

is equal to 30° for a circular cross section. Consequently, the measurement taken when the operator faces the largest axis of an ellipse is affected by both the major and the minor axis, and thus slightly underestimates the radius of the major axis. Conversely, the measurement taken when the operator faces the minor axis is overestimated. The simulated diameter for the ETMF (D_{ETMF}) can be mathematically expressed as:

$$D_{ETMF} = \left(\frac{\cos^2\theta_1}{a^2}+\frac{\sin^2\theta_1}{b^2}\right)^{-1/2}+\left(\frac{\cos^2\theta_2}{b^2}+\frac{\sin^2\theta_2}{a^2}\right)^{-1/2}$$

where $\theta_1 = \tan^{-1}\left(\frac{b^2}{a^2}\tan 30°\right)$; $\theta_2 = \tan^{-1}\left(\frac{a^2}{b^2}\tan 30°\right)$

These values were calculated for the caliper, the diameter tape and the ETMF and were compared to the best estimated DBH for an ellipse which corresponds to the geometric means of the axis (Pardé and Bouchon 1989) and is given by $\sqrt{4ab}$.

Another experiment was designed to compare the time required for different procedures of measuring and recording the DBH of trees in four permanent sample plots near Edmundston, New Brunswick. These 400 m^2 circular plots were mainly composed of balsam fir and white spruce and were selected because they had different number of stems ha^{-1}. This allowed us to compare the effect of stand density on the time required by each measurement method.

Five different procedures of measuring and recording tree DBHs were tested: (1) measuring with the ETMF which records the diameter automatically on computer memory (2) measuring with a caliper and recording the measurement on a tally sheet, (3) measuring with a caliper and recording the measurement on an electronic portable data collector, (4) measuring with a diameter tape and recording the DBH on a tally sheet and (5) measuring with a diameter tape and recording on an electronic portable data collector. DBH measurements were taken to the nearest mm. Two measurements $tree^{-1}$ at right angles were

Table 1. Mean DBH (±SE) of sampled trees as measured by different instruments

Species	Number of sampled trees	DBH[1]			
		ETMF	ETMF with reflector	Caliper	Diameter tape
White spruce	45	29.6±1.1*bc*	29.0±1.1*a*	29.4±1.1*ab*	29.8± 1.1*c*
Sugar maple	85	22.3±0.7*c*	21.5±0.6*a*	21.8±0.6*b*	22.2±0.6*bc*
White pine	56	19.5±0.4*c*	17.9±0.4*a*	18.2±0.4*a*	18.7±0.4*b*
American beech	81	16.7±0.5*a*	17.3±0.6*b*	17.6±0.6*c*	17.8±0.6*c*
Trembling aspen	73	14.7±0.5*a*	15.2±0.5*b*	15.0±0.5*b*	15.2±0.5*b*
Balsam fir	61	17.4±0.7*a*	17.8±0.6*ab*	17.8±0.6*ab*	18.0±0.6*b*

*a–c*Values in the same row followed by different letters differ (P < 0,05), according to Tukey's multiple comparison test.

taken with the caliper and the ETMF, while only one measurement was necessary for the diameter tape.

Within each plot, the five procedures were executed successively and the order at which they were applied was determined randomly. Care was taken to follow the same measurement sequence from tree to tree in order to avoid bias due to procedural changes. For each procedure, the time required to measure and record all trees within each plot was recorded to the nearest second. Since only one operator was needed when the ETMF was used, while the caliper and the diameter tape necessitated two operators, the time requirement recorded for each procedure was converted to person-seconds. The time required for the manual data entry of the measured DBH of each plot from the tally sheets was also recorded to give a general idea of the data collection time requirement.

Results and Discussion

For all the tested species, significant differences in mean DBH occurred among instruments (Table 1). When compared with the other instruments, the data taken with the ETMF generally showed the largest difference between instruments but the addition of a reflector at the surface of the bark greatly reduced these differences (Table 1). The measurements made with the diameter tape were generally slightly larger than those made with the caliper. Even though differences among instruments were statistically significant, they were generally less than one cm for five of the six tested species.

For white pine, however, the use of the ETMF without reflector resulted in an important overestimation of the DBH as compared to the caliper, the diameter tape or the ETMF with a reflector (Table 1). This can be attributable to the typical cracked bark observed on the measured white pines. When the ETMF is used in such an irregular bark, a part or all of the ultrasonic waves can reach the bottom of a crack. This would lead to a longer average travel time for the ultrasonic waves to come back to the ultrasonic receiver and would be perceived by the ETMF as a larger diameter. The use of the ETMF could also induce errors if lichens or small twigs interfered with the ultrasonic waves, or if the bark was wet (Guinaudeau and Peragallo 1991). Consequently, to avoid any of these potential errors, the ETMF should always be used with a reflector.

The differences in mean DBH between instruments could be partly explained by the occurrence of elliptical cross sections of measured trees. Because the circle is the geometric form with the shortest perimeter for a given area, the use of the diameter tape overestimates the "true" diameter of an ellipse, and the percentage of error increases with increasing eccentricity of the ellipse (Fig. 2). This could partly explain the slightly higher values of DBH for the diameter tape as compared to the caliper.

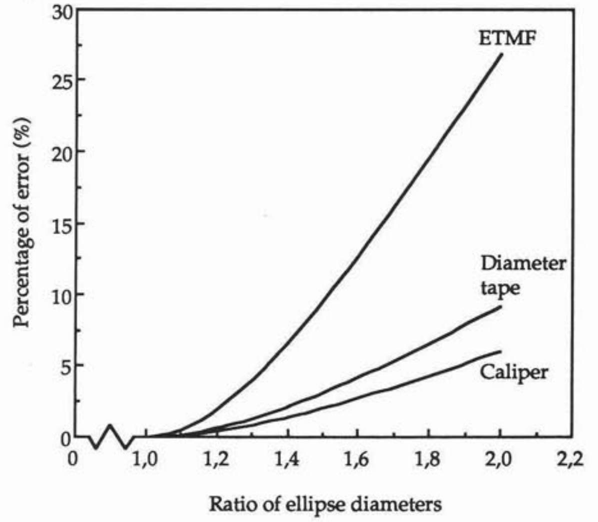

Figure 2. Percentage of error in diameter associated with three instruments as a function of the ratio of the major to the minor axis of an ellipse.

On the other hand, for a given ratio of the major to the minor axis of an ellipse, the use of the ETMF theoretically results in the highest overestimation in diameter. However, even if the ETMF seems to induce very large errors with increasing eccentricity (Fig. 2), our field data shows that this error was never higher than 2% since the maximum ratio of the minor to the major axis of the sampled trees was 1:1.2.

In regard to the eccentricity of an ellipse, the use of a caliper results in the smallest overestimation in DBH. Furthermore, the percentage of error related to the use of the caliper could be decreased to zero for any level of eccentricity if the geometric mean rather than the arithmetic mean was calculated. However, tree cross sections rarely correspond to a perfect circle or ellipse, and the arithmetic average of the two diameters is generally calculated (Hush *et al.* 1982).

When the time requirement for measuring and recording DBH of trees is converted into person-seconds, the use of the ETMF is clearly advantageous in comparison to either the diameter tape or the caliper (Table 2). Since the utilization of the ETMF needs only one operator, the time saved by its use could be utilized by the other crew member to execute other inventory work. The time required by the use of the caliper is generally slightly longer than what is needed for the diameter tape because during this experiment, two measures were taken with the caliper while, for the diameter tape, only one measure was needed.

Table 2. Time requirement for measuring and recording DBH of trees in four plots of 400 m^2 according to five different procedures

Plot number	Number of stems per plot	person-seconds ETMF	Diameter tape + data collector	Diameter tape + tally sheet	Caliper+ data collector	Caliper+ tally sheet
1	19	304	606	682	638	750
2	32	410	766	668	828	720
3	36	542	744	848	850	1004
4	51	766	984	1108	1190	1194
Average	34	506	775	826	876	917

As expected, the time requirement for measuring DBH of trees increases with increasing stand density (Table 2). However, the slope of the relationship between the time needed for data collection and the number of stems $plot^{-1}$ is less than one. This could be explained by the shorter time needed for travel from tree to tree in the higher stand density.

The use of an electronic data collector instead of a tally sheet for recording the DBH of both the diameter tape and the caliper did not result in appreciable differences of time in the field (Table 2). Nonetheless, the time for data entry, an important but time-consuming step of forest inventory, was very low when the electronic data collector was used. In this study, the time needed for DBH data entry was directly proportional to the number of trees in the plot. It took 84 seconds to enter the DBH (two measures) for the plot with 19 trees recorded on a tally sheet, while 210 seconds were required for the plot with 51 trees. When the data were recorded by the ETMF, the time requirement for the data transfer was constant (45 s) for all the stand densities encountered in the present study.

Finally, note that the time necessary to learn how to use the ETMF and transfer the information on a personal computer system should not exceed half a day. Moreover, by using the available menu, the ETMF does not present any difficulty.

Conclusions

Because of the automatic data recording, the ETMF can save time and money[1] in the data collection stage of forest inventory. In order to replace the traditional instruments measuring tree diameter, however, measurements made with the ETMF should be similar to those taken with other instruments. From the results of the present study, it seems that the differences between the values derived from the ETMF, the diameter tape and the caliper are generally less than one cm. Larger errors can be observed with the ETMF if the bark characteristics of the trees interfere with the ultrasonic waves, but these errors are reduced when a reflector is placed on the surface of the bark. Since the use of this reflector does not lengthen the measurement time, it should always be used with the ETMF.

Even if the ETMF is more sensitive to the eccentricity of stem cross sections than the caliper, the overestimation would be generally less than 2%. Consequently, the ETMF seems to be a valuable instrument for replacement of the caliper since it can measure tree diameters without loss of accuracy but with a noticeable time-saving.

For increment studies, tree remeasurement of permanent sample plots is generally done with the diameter tape. In this case, the diameter tape is preferred to the caliper since diameter measures are more consistent from year to year; the circumference of the tree at a given height is measured instead of only two diameters. For the same reason, an ETMF could not give better results than a caliper, and the diameter tape should thus continue to be preferred for remeasurements of permanent plots.

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[1]The purchase cost of the different instruments is, approximately, $2,000.00 for the ETMF, $80.00 for the caliper and $25.00 for the diameter tape (taxes not included).