

PRACTICAL ASPECTS OF THE LINE INTERSECT METHOD

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PRACTICAL ASPECTS OF THE LINE INTERSECT METHOD

Abstract

This report provides information and comment on a number of practical aspects of the line intersect method, including specific equations for volume and weight for various sets of units; problems of orientation bias and sample layout; diameter-class limits and centres; use of the method to determine total length of pieces or networks and piece-length distribution; sample size, length of line, and precision; and others. The report is not a complete review of line intersect literature, nor does it present new theory. It does bring together in one place ideas on the practical application of the method that are presently scattered throughout the literature.

Résumé

Ce rapport présente des informations et des commentaires sur de multiples aspects pratiques de la méthode d'échantillonnage linéaire, comme les équations spécifiques du volume et du poids pour diverses séries d'unités, les problèmes relatifs aux écarts d'orientation et au relevé des échantillons, les limites et les centres des classes de diamètre, l'application de la méthode à la détermination de la longueur totale des parties ou des réseaux et la répartition de la longueur des parties, la taille des échantillons, la longueur de la ligne, la précision et bien d'autres encore. Ce document ne constitue pas une revue exhaustive de la documentation sur la méthode d'échantillonnage linéaire ni n'introduit une nouvelle théorie. Il est plutôt une compilation des idées qui se trouvent éparpillées dans les divers documents existants sur l'application pratique de cette méthode.

Introduction

Since its original description by Warren and Olsen (1964), the line intersect method has been extensively used for measuring the quantity of wood lying on or near the ground. The original application was for the estimation of logging residue, further developed by Bailey (1970). Van Wagner (1968) and Brown (1971) described the method's use for measuring forest fuels. De Vries (1973) investigated its mathematical basis in depth, and Pickford and Hazard (1978) carried out a series of simulation studies. Also, many more specific uses

have been reported in the literature. Although the essence of the method's theory is simple, many questions arise in its use. The aim of this report is to provide a quick reference to a number of practical aspects of the line intersect method. It is not a conventional review of literature, nor does it introduce new theory. Instead, it is intended to fill the gap between theory and handbook and to promote the best possible understanding of the method. Detailed instructions for field procedure are listed by Brown (1974) and McRae et al. (1979) and are not reproduced here.

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I. Nature of the line intersect method

The line intersect sample is best pictured as a strip sample of infinitesimal width. The data collected are the diameters of the wood pieces at their points of intersection with a sample line. The sample line is really a vertical plane, and the tally in effect collects a series of circular cross-sectional areas from the intersected wood pieces. Of course the actual cross-sectional areas are really ellipses of various shapes (except when the intersection is exactly at right angles), but, for convenience, a factor derived from probability theory allows the areas to be summed as circles. The sum of cross-sectional areas is then divided by the length of the sample line; at this point the result is in terms of cross-sectional area per unit length of sample line. Multiplying both numerator and denominator by width converts the line sample into a strip sample (Van Wagner and Wilson 1976), and the result can then be quoted as volume per unit of ground area. Volume can in turn be readily converted to weight. The basic equation (Van Wagner 1968) is

$$V = (\pi^2/8L) \Sigma d^2 \quad (1)$$

where V is volume per unit area,
 d is piece diameter at intersection,
 L is length of sample line.

The quantity $\pi^2/8$ is the product of two terms: $\pi/2$, the probability factor mentioned above, and $\pi/4$, the factor needed to convert d^2 into a circular area. This equation embodies three assumptions—that the pieces are randomly oriented, circular in cross section, and horizontal. These assumptions are dealt with again later.

Multiplying by the wood density converts volume to weight. The basic equation becomes

$$W = (S \pi^2 / 8L) \Sigma d^2 \quad (2)$$

where W is weight per unit ground area, and S is density in units of weight per unit volume.

One consequence of the strip sample concept is that the length of the pieces is seen to be irrelevant; furthermore, each intersection is an event to be tallied, regardless of any connection in the space on either side of the sample line.

II. Specific equations for volume and weight

The basic equations can be used directly only if all quantities are in compatible units. Generally this will not be so in practical use. Each specific equation will then have its own constant embodying $\pi^2/8$ plus conversion factors.

The basic equation for weight depends on the simple fact that volume times density equals weight. However, in practical application it is more convenient to use specific gravity in place of density. The equation constant must therefore include the density of water in the pertinent units of weight and volume. General forms for the practical equations are

$$V = (k/L) \Sigma d^2 \quad (3)$$

for volume per unit area, and

$$W = (G k/L) \Sigma d^2 \quad (4)$$

for weight per unit area,

where G is specific gravity, and k is equation constant.

Table 1 lists k for some practical unit combinations.

III. Piece orientation and sample layout

The basic equation assumes that the pieces to be sampled are oriented at random, all angles being equally represented. In such an ideal population, one sample line in any direction will give an unbiased result. Orientation bias, in which the pieces are lined up more in one direction than in others, can result from windfall and some kinds of logging. It may be obvious or it may not. However, since orientation bias can be easily neutralized, it makes sense to design the sample layout to insure against it. This is done by running sample lines in more than one direction and averaging the results.

Brown's (1974) method is to choose

Table 1. Equation constant k for some length, volume, and weight units in line intersect sampling

d	Unit Combinations			k
	L	V	W	
cm	m	m^3/m^2		0.0001234
cm	m	m^3/ha		1.234
cm	m		kg/m^2	0.1234
cm	m		t/ha	1.234
in	ft	ft^3/ft^2		0.008567
in	ft	ft^3/ac		373.3
in	ft		lb/ft^2	0.5348
in	ft		T/ac	11.65

Note: Meaning of symbols as in text.

at random one of six directions at 30-degree intervals at each line's starting point—a quite satisfactory approach. An alternative is to calculate the maximum possible bias that could result for various combinations of sample line directions, then to adopt a standard layout that reduces the maximum possible error below some reasonable limit.

It can be shown (Van Wagner 1968) that the maximum possible error due to orientation bias is 21 percent for two sample lines at right angles but only 9 percent for three lines at 60-degree angular intervals. These maximum errors are of course possible only when all pieces are aligned in the same direction, and even then only when the sample line pattern is oriented in one particular, least-favourable way—a most unlikely situation. Therefore, it appears that adequate insurance against orientation bias can be obtained with the three-direction pattern, which is just as easy to install as a two-direction pattern and does not require a specific choice each time a sample line is started. The most convenient field layout is an equilateral triangle.

Field efficiency in line intersect surveys requires that three things be minimized:

- The amount of walking apart from actual sampling
- The amount of measured distance in addition to the actual sample lines
- The number of starting points to be located

Equilateral triangles have the following points in their favour:

- They can be of any size and number.
- Any single one will give a level of insurance against orientation bias that is obtainable only from a considerable number of randomly oriented sample lines.
- The starting points may be located without accurate surveying; i.e., the only measured distances necessary will be the sample lines themselves.
- The initial direction can be chosen at random or deliberately oriented to minimize an obvious orientation bias. See Figure 2 in Van Wagner (1968).

5. The triangle need not be closed exactly as long as the lengths of the sides are accurately measured.

For field application the most convenient unbiased layout is a mechanical grid imposed on the map. Starting points can then be located on the ground by pacing or from identifiable landmarks. Orientation of lines or triangles can be set beforehand or determined by some reasonable method on the spot.

IV. Piece tilt and ground slope

The basic equation assumes horizontal pieces. If a piece is tilted, its probability of being intersected by the sample line is obviously lessened. If many pieces are tilted, there will be fewer intersections for a given volume of wood. The error will always be negative and amounts to $1 - \cos h$, where h is the angle of tilt from horizontal. The correction factor is therefore $1/\cos h$, or $\sec h$. This error is very small at low angles, being only 0.4 percent at 5 degrees and still less than 10 percent at 25 degrees. It is most common where smaller pieces are attached to larger ones, as in fresh logging slash.

Whether the error is worth correcting for is a matter of judgement for any individual survey. An objective correction would require a subsample of piece-tilt angles. Brown and Roussopoulos (1974) have provided experimental average correction factors (i.e., secants) for logging slash of 10 conifer and 1 hardwood species. According to them, tilt errors are indeed significant, averaging about 20 percent in fresh logging slash (all sizes up to 7.6 cm) and 15 percent after one or more years. Their correction factors can be used directly for the species covered or they can be extrapolated with judgement to other similar species.

With respect to sloping ground, there are obviously two bases for quoting the result of the line intersect survey, the choice depending on the ultimate use of the result: (1) actual ground area for, say, fire behaviour estimation, or (2) horizontal map area for, say, residue inventories. In any event, the sample line is most conveniently measured on the actual ground surface, a

record being kept of slope angle. Then, if volume or weight per unit of horizontal area is desired, the result is multiplied, as it is for tilt, by the secant of the slope angle. Brown (1974) gives the formula in terms of ground slope:

$$\text{Correction factor} = \sqrt{1 + \left(\frac{\text{percent slope}}{100}\right)^2} \quad (5)$$

V. Piece taper and cross-sectional shape

Because the line intersect method simply collects an unbiased sample of circular cross sections from the wood pieces lying on the ground, as if the sample line were a strip sample of infinitesimal width, one can intuitively judge that taper in the pieces will introduce no error (Van Wagner 1968). This conclusion was well confirmed by Pickford and Hazard (1978) in their simulation studies. It can be stated safely that the line intersect result is unaffected by any kind of variation in diameter throughout the length of the pieces.

It is obvious, however, that noncircular cross section could introduce error if only one dimension were measured at each intersection. The simplest way to handle occasional obvious noncircular cross section is to estimate one representative diameter from the average of two measurements. If the departure is serious, e.g., a rectangular rather than a circular cross section, the equation itself can be modified as per Brown (1971). The degree to which noncircular cross section need be accounted for is very much a matter of judgement.

VI. Diameter-class limits and centres

Normally it is quite impractical and unnecessary to tally the exact diameter of every piece crossed, especially when there is much small material. Intersections are therefore tallied by diameter classes. The number and spacing of classes depends on the purpose of the survey. If the interest is mainly in the amounts of small material, then the larger material can be measured approximately or ignored. However, if a confident estimate of total volume or weight is desired, then the

large material must have special attention. For example, a 1-cm error in measuring a 10-cm piece is the equivalent of 20 1-cm pieces. This means that diameter classes should not be widened as diameter increases, but rather they should be kept at constant width. Above some point, class tallying can be replaced by individual piece measurement.

The fire research group of the Canadian Forestry Service has adopted the following diameter-class framework: 0-1, 1-3, 3-5, 5-7, and 7+ cm. It is understood that this set of classes can be further subdivided if desired. If fine material is to be emphasized, then the lowest class can be split in two; if a very good total weight or volume is required, then the entire 0-7 range can be sampled in 1-cm classes. Pieces over 7 cm in diameter are commonly measured individually to the nearest 0.1 centimetre.

When the pieces are tallied in classes, some appropriate single diameter must be chosen to represent each class. The term $\sum d^2$ in Equation 1 becomes $\sum (n_i D_i^2)$, where n_i is the number of intersections in diameter-class i , and D_i is the representative class diameter. Theoretically, since d^2 is the property being summed, the class value must be the quadratic mean diameter (the square root of the average squared diameter) rather than the simple arithmetic class centre or average diameter.

There are two approaches to selecting a quadratic mean diameter (QMD). One is by objective field sampling that reflects the natural diameter distribution within each class for the population in question (Brown and Roussopoulos 1974; Bevins 1978; Sackett 1980). This is a sensible and valid approach but does have two conditions: (1) field work must be done for each different tree species or kind of wood complex, and (2) the published QMDs apply to one set of diameter classes only and cannot be recalculated to fit another set (except perhaps from the original raw data).

Another approach is to compute QMDs from the diameter frequency distribution in the line intersect tally itself,*

* Van Wagner, C.E., journal note in preparation.

based on the assumption that the frequencies follow a simple power law:

$$y = ax^b \quad (6)$$

where y is number of intersections per unit length of sample line for a diameter class of one unit width,
 x is diameter,
 a and b are constants.

The procedure then consists of plotting adjusted diameter frequencies over diameter on double-log paper to determine the value of the exponent b , and applying the formula

$$(\text{QMD})^2 = \frac{(b+1)(x_2^{b+3} - x_1^{b+3})}{(b+3)(x_2^{b+1} - x_1^{b+1})} \quad (7)$$

where x_2 and x_1 are the upper and lower limits of each diameter class. An arbitrary lower limit (say 0.1 or 0.2 cm) must be applied in place of zero to make the equation work for the lowest class.

To determine the exponent b for a given line intersect survey, proceed as follows:

1. If sample lines of different length were used for different diameter classes, divide each frequency by its line length and multiply by a common length.
2. Further divide each frequency by its class width (i.e., $x_2 - x_1$).
3. Plot each adjusted frequency over the midpoint of its class on double-log paper.
4. Fit a straight line and estimate the logarithmic slope, b (always a negative value). Note that the constant a in Equation 6 is not required.
5. If a single straight line is not possible, break the graph into any number of straight sections and determine b for each.

Equation 7 has a pair of further limitations: it cannot be solved when b is exactly -1 or -3. Special formulas could easily be written for these cases, but it is probably more convenient to keep one

general formula and avoid exact values of -1 or -3 . For example, values of either -2.99 or -3.01 will give satisfactory results when $b = -3$, and similarly for $b = -1$.

This approach has the following advantages: (a) no extra field work is required, (b) QMDs are tailored to the given line intersect survey, and (c) the method may be applied to any desired set of diameter classes.

As for accuracy, these calculated QMDs should always give better results than plain arithmetic class centres, and they may match the experimental QMDs fairly well. In any event, if accuracy in a line intersect survey is a serious consideration, it makes more sense to tally in more and smaller diameter classes than to spend time on finer determination of quadratic mean diameters.

VII. Length of a network or total piece length

The line intersect theory can be readily adapted to measurement of the total length of a network or of unconnected elements within any defined area. Some examples are the length of a road or street system, the length of streams and rivers in a watershed, and the length of wood pieces per unit ground area. Matern (1964) provides the first example of this application, and Hildebrandt (1973) a later one. Length estimation is in fact simpler than volume estimation, but the basic principle is the same. Matern (1964) provides the equation:

$$Y = (\pi/2) (n/L) \quad (8)$$

where Y is network or element length per unit of sampled area,

n is number of intersections with sample line or lines,

L is length of sample line.

This formula gives total length per unit of area equal to the squared unit used to measure the sample line length, L . A conversion factor may be required. For example, when L is measured in metres and length per hectare is desired, the right side of Equation 8 must be multiplied by 10 000. Multiplying Y by the area sampled then gives the total network or element length

on the whole area. It is immaterial whether the intersected elements are straight or curved.

The possibility of nonrandom element orientation must be accounted for, as in wood volume estimation. The simplest way is, as before, to run sample lines in at least three directions at equiangular intervals. Also, sloped ground should be accounted for (see section IV). Otherwise there are no sources of error in this application. If the elements are visible from the air, the work can obviously be done from photographs.

VIII. Piece-length distribution

The standard line intersect result (Equations 1, 2, 3) is obtained without reference to the lengths of the pieces intersected and gives no information about piece length or its distribution. The simple formula (Equation 8) in the previous section yields total piece length per unit area, but again nothing about number of pieces or their lengths. If the distribution of piece lengths is desired as part of the result, then the lengths of the intersected pieces (or a subsample of them) must be measured. The survey tally can then be used to derive a length distribution.

A set of piece-length classes should first be chosen. A piece-length distribution will then presumably be expressed as the number of pieces by length class per unit of sampled area. A problem of adjustment of the tallied length frequencies arises, because the probability that any piece will be crossed is obviously proportional to its length; longer pieces will therefore appear disproportionately in the tally. This problem was described and dealt with by Bailey and Lefebvre (1971), who supply the answer: "The distortion of (length) class frequencies is removed by using piece length as an (inverse) weighting factor." (When referring to this Bailey and Lefebvre publication, note that the bodies of Figures 1 and 2 were switched; the captions remain in place.)

The number of pieces per unit area in length class i can be calculated from the total piece length, Y (see Equation 8), as follows:

$$N_i = (Y/l_i) (n_i/n) \quad (9)$$

where N_i is number of pieces per unit area in length class i ,
 n_i is number of tallied intersections in length class i ,
 l_i is midpoint or average length of length class i ,
 n is (as before) total number of intersections.

This equation can be simplified by substituting for Y according to Equation 8:

$$N_i = (\pi n_i) / (2L l_i) \quad (10)$$

where L is (as before) length of sample line. The inverse weighting factor mentioned above appears as l_i in both the above equations. As in section VII, a conversion factor for the chosen unit area may be required. The total number of pieces per unit area (N) is then simply $\sum N_i$.

Complete information may require stratification by diameter as well as length class. The above procedure can then be repeated for each diameter class.

IX. Size and precision of sample

The validity of the line intersect result, in the sense of accuracy, is essentially guaranteed by the basic theory, only subject to proper neutralization of the potential biases that can affect it, namely (1) nonrandom piece orientation, (2) piece tilt, (3) noncircular cross section, and (4) skewed distribution within diameter classes. These have been dealt with in previous sections.

The precision of the result, on the other hand, as in all sampling procedures, depends upon the size of the sample and the variability of the material. For credibility, the line intersect result must be accompanied by a measure of its precision. Probably the most practical and significant measure is the standard error, that is, the standard deviation of possible volume estimates about the true value. It can be quoted either quantitatively or as a percent of the result, depending on the end use of the information.

The concept of standard error in the line intersect method is, however, not quite obvious. This is because the method measures an areal attribute rather than

some property of a population of discrete units, for example, a set of tree diameters. In the line intersect method, the total sample is clearly the total length of line tallied, but there is no identifiable discrete unit. The individual piece intersection does not qualify, since there is no identifiable ground area associated with it. As it happens, this difficulty, although a little obscure, is easily overcome by dividing the whole sample into sections and computing the standard error of their average result. The question is how best to do this.

De Vries (1973) analysed the mathematics of the line intersect method in depth, including the estimation of precision, and Pickford and Hazard (1978) reported extensive simulation studies leading to several conclusions about precision. Drawing on these references plus other experience, one may list the following principles:

1. For any given situation, the level of precision depends primarily on the total size of the sample.
2. Theoretically, the size of the area to be sampled is irrelevant; it is the variability of the material being sampled that counts.
3. It follows that for a given total line length the number of sections is, within limits, immaterial. For example, 10 sections of 100 m each should provide the same standard error as 100 of 10 m each.
4. The sections may be either physically separate or parts of a longer continuous line.
5. Precision is also related to concentration, that is, to the number of intersections per unit length of sample line. Thus, the smaller the diameter class, the more numerous the pieces, and the shorter the sample line needed to achieve a given precision. Both Brown (1974) and McCrae et al. (1979) specify that for best efficiency, only the largest diameter class be tallied on the whole of each sample line or triangle leg; the proportion of line used for each class decreases with diameter.

These principles require a few practical comments. While the total sample size (point 2) is not theoretically dependent on the area to be sampled, it may nevertheless seem unrealistic to scatter the sample units too thinly over a large area. Thus, for general credibility, McCrae et al. (1979) recommend at least one equilateral triangle of 30-m sides for every 20 ha of sampled area.

With respect to the minimum number of sections for a given total sample (point 3), the literature is not quite clear on the pertinent theory. Some empirical simulations at this institute suggest that the number of sections should not be reduced below a certain minimum. If they are, instability in the standard error may result; in other words, the chance of getting a standard error close to the true standard error may decrease. Until someone settles this question, it seems reasonable to suggest that the standard error be based on not less than 10, and preferably 20, sections. These may be individual lines or sections of a line or legs of equilateral triangles. To reiterate for clarity, this consideration applies only to the minimum number of sections within a given total sample; that is, if the number of sections is halved, the implication is that their individual length is doubled. Apart from this possible limitation on minimum number, to quote Pickford and Hazard (1978), "the product of number of lines times line length is approximately constant for specified levels of precision". (See their Table 12 and Figure 1.)

A practical aspect of variability (points 3 and 4) is scale. At its smallest scale, variability is absorbed into the individual sections of the total sample. However, when abnormal piece densities appear in large enough patches, they may dominate individual sample sections or even affect two or more adjacent sections. When this happens, an important principle of random sampling is violated—that each sample unit should be independent of every other one. As the scale of patchiness increases further, complete stratification into separate estimates may be indicated. This problem is one of judgement according to end use. Good estimates of fire behav-

our may require a stratification of area according to density, whereas an estimate of useable logging residue may not.

The various points affecting the size and number of individual line sections suggest the need for some flexibility. Thus, if a standard layout produces an obvious lack of independence between sections, these can be lengthened or placed farther apart. If the separate legs of equilateral triangles do not seem independent enough, the triangle can be enlarged, or else the whole triangle considered for statistical purposes as one unit.

The starting point for choice of total sample length is the specified degree of precision. Then, if the variability of the material is not roughly known, a preliminary uniformity trial may be necessary to establish a tentative estimate of it. The choice of degree of precision is critical, because the square of sample size is inversely proportional to the allowable error, a universal sampling principle well illustrated for the line intersect method by Pickford and Hazard (1978, Table 12). Thus, to double the precision (that is, halve the allowable standard error) would require four times the sample.

The choice of degree of precision should be made only after an objective look at the value of the volume estimate, because unnecessary precision is costly. It is also worth noting that when individual sample lines or triangles are laid out on a grid system, the degree of precision is generally considered somewhat better (to an indeterminate degree) than an equivalent sample taken by random location. A standard error of ± 10 percent of the estimate would probably suffice for any end use, and ± 20 percent for many. (Quantitative quotation of standard error may be preferable.)

The standard error of the line intersect volume estimate may be computed as follows (drawing on any standard statistics text):

$$\frac{s}{\bar{x}} = s/\sqrt{n} \quad (11)$$

where $\frac{s}{\bar{x}}$ is standard error in units of volume/unit area,

n is number of sections in the total sample, and

s is standard deviation, given by

$$s = \left[\frac{\sum X^2 - (\sum X)^2/n}{n-1} \right]^{1/2} \quad (12)$$

where X is individual section volume. The correction for small populations is not needed here, the potential number of line samples on any area being presumably infinite. The probability is then 67 percent that the true average volume per unit area falls within the range $\bar{X} \pm s_{\bar{x}}$, where \bar{X} is the mean of the individual X s. The 95 percent confidence limits, as used by Pickford and Hazard (1978), comprise a range of about $\bar{X} \pm 2 s_{\bar{x}}$.

X. Name of method

The name used here is "line intersect method," following the original paper of Warren and Olsen (1964) on measurement of logging residue, and this name has been adopted by all authors working in that application. Van Wagner (1968) used the same name with respect to forest fuel measurement. It is, of course, understood that the line intersect sample line is really a vertical plane extending as high above ground as necessary to include all material in direct or indirect contact with the ground. Brown (1971) developed a variation of this concept in which sample planes could be oriented if desired at angles other than vertical; he called it the "planar intersect method." He subsequently included this method in his Handbook for Inventorying Downed Woody Material (Brown 1974), which has been used widely in forest fuel measurement, especially in the United States. A question arises as to the difference, if any, between the line and planar methods.

The essential criteria for distinguishing field survey methods should presumably be (a) the basic theory and equation, (b) the information collected, and (c) the tallying rules. Appeal to these criteria shows that the two methods are indeed one and the same whenever the planar method deals with vertical planes only. In Brown's (1974) handbook, the sampling is in fact carried

out with vertical planes. Without any suggestion that anyone should change the name by which he calls the method, it would help if users appreciated that, for purposes of measuring wood volume on the ground, the so-called line and planar intersect methods are identical.

The field layout itself is simply a matter of choosing the length and number of lines and their arrangement on the ground, all of which can be varied endlessly according to judgement and experience.

XI. Choice of diameter

The line intersect sample can be looked on as a strip sample of infinitesimal width (see section I) in which piece diameter is measured at the point of intersection. Alternately, it can be used as a device for selecting pieces whose diameter will be measured either at midpoint or at both ends. Piece volume would then be computed by the Huber or Smalian formulas. Several authors (e.g., Bailey 1970, Ménard and Dionne 1972) have used the Smalian formula with both-end diameters to convert their logging residue estimates to standard log scale volumes. De Vries (1973) based part of his analysis on midpoint diameters and the Huber volume formula. The primary point to be made here is that both the Huber and Smalian formulas are unbiased only if the pieces are cylinders or paraboloids. It follows that the measurement of diameter at the point of intersection gives the only estimate of volume per unit area that is free of possible bias if the pieces do not match these shapes (Van Wagner and Wilson, 1976). It follows further that a line intersect survey based on intersection diameters, and designed so as to be free of other potential biases listed earlier, constitutes the primary standard for total-volume methods in which the material is left in place. A better primary standard would be possible only by using a plot method in which all piece volumes were determined by immersion in a calibrated water tank. Furthermore, not only is the volume determined from intersection diameters free from any shape bias, all experience shows that intersection diameters are by far the fastest to

obtain (Bailey 1970, Howard and Ward 1972, Ménard and Dionne 1972, Van Wagner and Wilson 1976); this means that a much larger sample can be obtained for the same effort. For special purposes, such as estimation of length distribution or butt rot, it may be necessary to visit the ends of some tallied pieces.

Conclusion

The theoretical essence of the line intersect method is simple (see Equation 1), but many practical questions arise in its use. Some of these refer to potential sources of bias or error, others to the efficiency of field layout and the precision of the result. Potential sources of error are as follows:

1. Nonrandom piece orientation (section III)
2. Piece tilt from horizontal (section IV)
3. Noncircular cross section (section V)
4. Where diameters are tallied in classes, nonuniform distribution of diameters within classes (section VI)

Provided these error sources are neutralized or accounted for, the line intersect method yields a valid result that can be used as a primary standard for methods of measuring wood quantity on the ground.

Other practical questions include what to do about the following:

1. Field layout (section III)
2. Ground slope (section IV)
3. Diameter-class limits (section VI)
4. Sample size and precision (section IX)

The precision of the final result depends mainly on the total length of sample line run, but also on the diameter-class structure used in the tally. When total volume is desired, large pieces should be measured accurately or in narrow classes.

The line intersect method, simply by the counting of intersections, can be used to determine the total length of pieces or networks within the sampled area (section VII). Or it may also be used, by tallying the lengths of the intersected pieces (or a subsample of them), to find the piece-length distribution as the number of pieces by length and diameter classes per unit of

sampled area (section VIII).

Finally, all things considered, it is apparent that a well-designed line intersect survey provides, for any chosen level of precision, the fastest and most reliable method of measuring wood quantity on the ground.

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