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The Transect Relascope

- An Instrument for the Quantification of Coarse Woody Debris

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Abstract

A method for the quantification of coarse woody debris in terms of the total length of down logs of various types is presented. The method combines relascope and line intersect sampling theory. Estimation is based on a count of logs using a relascope instrument along a survey line. In cost-efficiency comparisons with line intersect and circular plot sampling, the proposed method showed promising results.
Key words: Coarse woody debris, forest inventory, relascope, sampling.

Introduction

During the last decades the scope of forest management has become wider. Goals such as the preservation of biodiversity nowadays occur alongside with goals for the timber production. Due to this, forest planning and inventory practices are currently refined.

The traditional methods of forest inventory were designed for the estimation of parameters related to timber production, e.g. the total timber volume within a forest area. Efficient sampling schemes recognize that trees are common and that there is some spatial autocorrelation present (Matérn 1960). The situation is slightly different when it comes to sampling elements of importance for biodiversity. Many of these elements are rare, and thus the standard methods of forest inventory tend to be inefficient.

As a consequence, new methods are emerging, old ones are redesigned, and methods from biological surveying are borrowed for application in forest management inventories. Interesting alternatives involve e.g. line transect sampling (Burnham et al. 1980), adaptive cluster sampling (Roesch 1993), line intersect sampling (Warren & Olsen 1964, De Vries 1986), strip survey (e.g. Lämås & Fries 1995), and field methods for estimating the area of habitats or species (Gregoire & Valentine 1995). Rather than using only one method, efficient schemes should utilize a combination of methods (Lämås & Fries 1995).

Although there are many probability sampling methods available, biodiversity oriented inventories often rely largely on subjective judgements (e.g. Nitare & Norén 1992). This may be appropriate since the ”biological value” of a forest area is complex to determine from the mere quantification of some of the parameters involved. On the other hand, there is a risk that quantitative analysis is completely dropped in favour of human intuition.

In this article, a method for the quantification of coarse woody debris in terms of the total length of down logs in a forest area is presented. Dead decaying wood have been identified to be important for many of the threatened species in the world (Samuelsson et al. 1994). Thus it is important to develop techniques that can be used for describing the habitat conditions for such species. The method combines the theory of line intersect sampling with the relascope theory. The total length of down logs of various types can be estimated by counting the logs that fill the gap of a ”transect relascope” while walking along a survey line.

In this article, the term ”down log” is used for all kinds of wood occurring on the ground, entire tree boles as well as parts thereof.

The method

The measurement instrument is very simple. Any construction that provides an appropriate sighting angle can be used. An example is given in Fig. 1, where it is also illustrated how the instrument is used.

Down logs that fill the gap of the transect relascope should be counted. Sightings should be made in all directions from the survey line. The count obtained should then be multiplied by an expansion factor to estimate the total length of down logs. The expansion factor depends on the construction of the instrument and the distance surveyed within a given area. By ocularly classifying each down log, the estimation can be differentiated on log types.

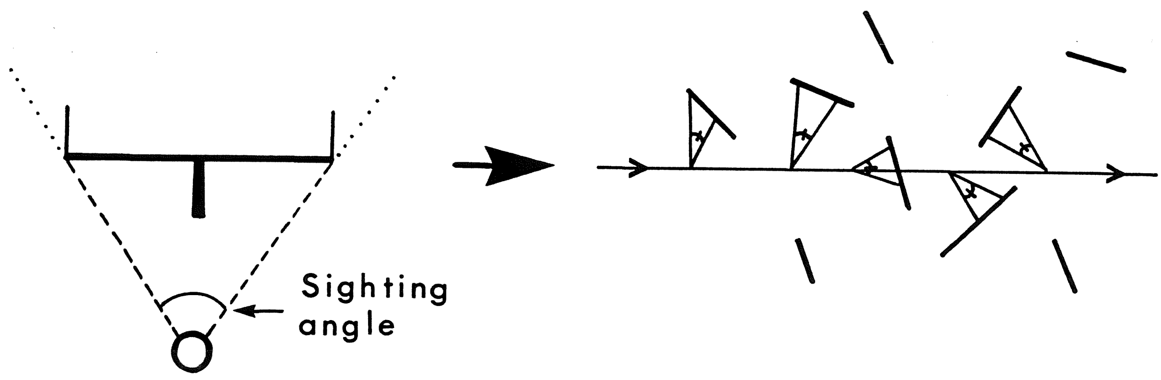


Figure 1 - The transect relascope (left) and its use along a survey line (right).

Theoretical background

The theory of the transect relascope is most easily explained if the Horwitz-Thompson (HT) theory of sampling (e.g. Cochran 1977) is used. The HT-estimator, $\hat{Y}$, of some population total can be expressed as:

$$\hat{Y} = \sum \frac{y_i}{\pi_i}$$

This formula can be used whenever it is possible to derive the different sampling units' probabilities of inclusion, π_i. The variable y_i refers to the value of the variable of interest on the i:th unit sampled. The key to understanding the theory of the transect relascope lies in the determination of the probability of inclusion of a given down log. This will now be described in steps.

Firstly, the shape of the inclusion area around a down log should be determined. Using the transect relascope, this area turns out to be the union of two intersecting circles of equal size; the log extending between the two points of intersection (Fig. 2). This follows from the fact that, in a circle, all angles at the circumference between two rays emerging from the same two points on the circumference are equal (e.g. Coxeter 1989). Therefore, since the sighting angle of the transect relascope is fixed, the area of inclusion will have the shape depicted in Fig. 2 (for acute relascope angles).

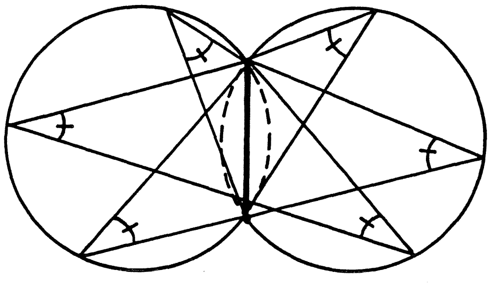


Figure 2 - The shape of the area of inclusion around a down log.

The next step in deriving the probability of inclusion of a log is to study the situation when a survey line is to traverse the forest at some random location along the side of "width" L of a forest area (Fig. 3, left part). The line is to be laid out perpendicularly to the side.

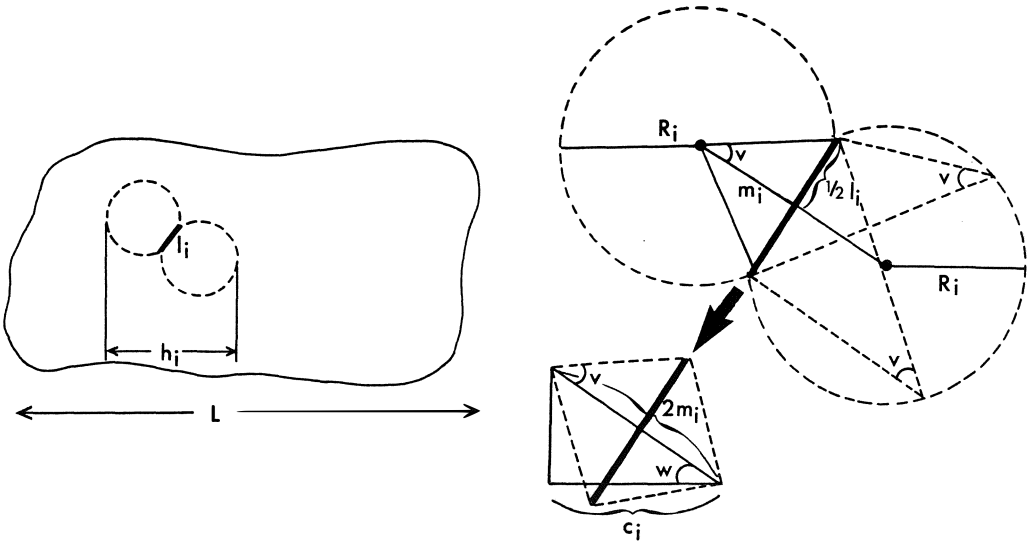


Figure 3 - The situation before a survey line is laid out (left part). Details of the determination of the vertical projection h_i of the area of inclusion (right part).

In case only one transect line is to be laid out, the probability of inclusion of the down log is h_i/L, h_i being the vertical projection of the inclusion area. Using the right part of Fig. 3 as an illustration, h_i can be determined in the following way:

$$h_i = 2R_i + c_i$$

Here, R_i is the radius in each of the two circles, and c_i is the vertical projection of the line connecting the centers of the circles. Given the transect relascope angle, R_i depends solely on the length, l_i, of the down log, while c_i depends both on the length of the log and its orientation.

Since, in a circle, the angle at the center is twice as large as the angle at the circumference when the rays forming the angles meet the circumference in the same two points (e.g. Coxeter 1989), R_i can be determined as:

$$R_i = \frac{l_i}{2\sin v}$$

Here, v is the angle formed by the relascope. Moreover, if the angle w_i in Fig. 3 is used for describing the orientation of the down log, the distance c_i can be determined as:

$$c_i = 2m_i \cos w_i = l_i \cot v \cos w_i$$

Thus, the following formula is obtained for the vertical projection h_i of the inclusion area:

$$h_i = l_i \cdot (\frac{1}{\sin v} + \cot v \cos w_i)$$

The probability of inclusion of a given down log is then obtained by division with L. Consequently, the HT-estimator is:

$$\hat{Y} = L \cdot \sum \frac{y_i}{l_i (1/\sin v + \cot v \cos w_i)}$$

This estimator can be used for any population parameter that can be derived from measurements on down logs. An interesting situation occurs when the parameter of interest is the total length of down logs. In this case there will be an l_i-term in both the numerator and the denominator. Since the two terms cancel there is no need to measure the length of logs. Still, the angle w_i must be measured.

The estimator can, however, be elaborated further by letting the orientation of the survey line be random. In this case the angle w_i is a random variable. Assuming w_i to be uniformly distributed, $E(h_i)$ can be determined as:

$$E(h_i) = \int_0^{\pi/2} \frac{l_i}{\sin v} \cdot (1 + \cos w_i \cos v) \frac{1}{\pi/2} dw_i = l_i \cdot (\frac{1}{\sin v} + \frac{2}{\pi} \cot v)$$

In this case, the HT-estimator of the total length of down logs is:

$$\hat{Y} = \frac{L_p}{\frac{1}{\sin v} + \frac{2}{\pi} \cot v} \cdot n$$

Here, n is the number of logs counted and L_p is the "width" of the forest area perpendicularly to the survey line. The quotient preceding n is an expansion factor, similar to the basal area factor in traditional point sampling (Bitterlich 1984).

The estimator is unbiased, but due to the fact that most forest areas are not rectangular it may have large variance. Also, it should in many cases be difficult to determine the width, L_p, of a forest area. Both these complications can be solved if a ratio estimator of log length per area unit is developed. By multiplying such an estimator with 10000 (1 hectare) we arrive at an estimator, $\hat{Y}_R$, of log length per hectare: $\hat{Y}_R = 10000 \cdot \hat{Y}/\hat{A}$. Here, we obviously need an estimator of the forest area A. If the forest is seen as divided into a multitude of very small area units, which are assumed to be sampled, the HT-estimator will be:

$$\hat{A} = \sum \frac{a_i}{\theta_i} = \frac{D \cdot ds}{ds/L_p} = L_p \cdot D$$

Here, a_i is the size of the small area units which are assumed to be squares of size ds times ds, D is the length of the transect line, θ_i is the probability of inclusion of an area unit, and L_p is the width of the forest area perpendicularly to the transect line. To grasp the intuition behind this, imagine the survey line to be ds units wide. Using this estimator of A, we arrive at a final estimator of the length of down logs per hectare. The estimator is:

(1)
$$\hat{Y}_R = \frac{10000}{D \cdot (\frac{1}{\sin v} + \frac{2}{\pi} \cdot \cot v)} \cdot n$$

Three variables remain: the angle of the relascope, the length of the survey line, and the number of down logs counted. The two former variables together decide the expansion factor by which the number of logs should be multiplied. In Table 1, some examples of expansion factors are given.

Table 1 - Expansion factors at different relascope angles and transect lengths.

Transect length (D) (meter)	Sighting angle (v) (degrees)	Expansion factor (meter)
100	9.4	10
100	28.0	30
100	55.0	60
200	9.4	5
200	28.0	15
200	55.0	30

Efficiency evaluation

In theory, the method outlined provides unbiased estimates of the total length of down logs. This, however, does not necessarily mean that the method is useful. Important aspects that remain to be studied are the design-variance of the estimator, the accuracy of field measurements, and the cost of using the method. In the following, these issues will be addressed.

Firstly, a field study concerning the accuracy of measurements is presented. Secondly, cost-precision relationships are derived using Monte-Carlo sampling simulation. In this context, the transect relascope method is compared with line intersect sampling and circular plot sampling.

Field study

Although an inventory method can be shown to be efficient in theory, it will be of limited use unless it can be handled in the field the way theory prescribes. For the transect relascope method, it is crucial that surveyors really can detect and classify down logs properly. Bad visibility and surveyor misjudgements may cause problems. Sighting angles must, however, be chosen with care since small angles lead to theoretical inclusions far away from the survey line.

A minor study was carried out in order to evaluate the performance of the transect relascope in the field. Eight 50 m transects were laid out in an old-growth forest in northern Sweden. In this forest, the maximum length of down logs was approximately 25 m. Each transect was surveyed independently by two surveyors, previously inexperienced in the method. The sighting angle of the instrument was 28 degrees. Down logs having a diameter larger than 10 cm in their thickest end were to be counted. In Table 2, the results from the study are presented. The reference value is the count considered to be the true one, obtained from a more thorough search for down logs around each transect.

Table 2 - Transect relascope field measurements. Counts of down logs and average time consumption from surveys of 50 m transects using a 28.0 degrees sighting angle.

Transect #	Surveyor 1 (logs counted)	Surveyor 2 (logs counted)	Reference value (number of logs)	Average time (sec)
1	5	6	6	90
2	8	8	8	200
3	11	11	11	135
4	14	14	14	150
5	10	9	10	90
6	4	5	5	80
7	5	5	5	65
8	5	5	5	75

The study is very limited. The results from it, however, give some indication that the transect relascope might be used with appropriate accuracy in the field.

Monte-Carlo sampling simulation

To study cost-precision relationships, the transect relascope method was implemented in a sampling simulator developed by Ståhl & Lämås (1995). In this Monte-Carlo simulator, line intersect sampling and circular plot inventory were already implemented.

The three methods were compared with respect to their efficiency for estimating the total length of down logs in two 20 ha (500 by 400 m) large forests. Down log locations in the forests were simulated according to a Poisson process. The lengths of logs were specified to follow a normal distribution with mean 15 and standard deviation 5 m. Upper and lower limits were 30 and 0 m respectively. The orientations of logs were simulated according to a uniform distribution (between 0 and 360 degrees). In forest A, the intensity of down logs was 5 units ha^{-1}. In forest B, the intensity was 20 units ha^{-1}. This corresponds to "low normal" and "high normal" occurence of logs in northern Sweden according to Lämås & Fries (1995).

Standard estimators were used for the line intersect method and the circular plot method (see Ståhl & Lämås 1995). In circular plot sampling, logs were classified as belonging to the sample once their thicker end was located on a plot. The plots were laid out entirely at random; the numbers ranging from 4 to 200. In all cases, a plot radius of 15 m was used. As to line intersect sampling, the estimator used assumed log orientations to be random, implying that the total length of logs can be estimated from a mere count of the number of logs intersected, (see De Vries 1986). Regarding the transect relascope method, estimation was carried out according to formula (1). The survey lines used for line intersect sampling and transect relascope sampling were located entirely randomly, but were always laid out in a north to south direction. Each line traversed the forest. The line numbers varied between 2 and 60.

The accuracy of a sampling strategy is easily derived using Monte-Carlo sampling simulation. Potential bias shows as a deviation between the known true value and the average estimated value. The design-variance is obtained as the variance among simulated parameter estimates.

The costs of the methods studied depend largely on the time required for field measurements. If the time consumption for walking and different measurement activities is known, the total time is obtained by summation (followed by an averaging over simulated outcomes). The figures for time consumption used in the study are given in Table 3. They are derived from results in Lindgren (1984), Lämås & Fries (1995), and the limited study presented in Table 2.

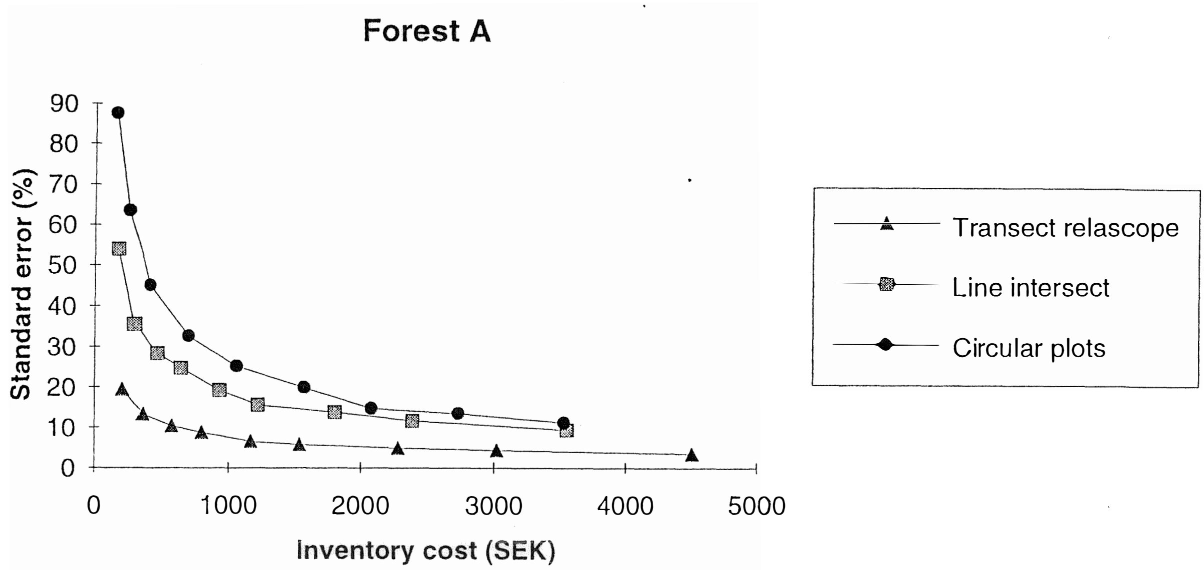
Table 3 - Time consumption for the different methods.

Method	Walking between plots/transects (sec 100 m^{-1})	Walking along transects (sec 100 m^{-1})	Establishment of one plot/transect (sec)	Measurement of one down log (sec)
Circular plots	200	-	240	40
Line intersect	200	200	240	5
Transect relascope	200	250	240	10

The time specified for walking along a transect with the transect relascope does not correspond to the results in Table 2. Instead a higher figure, being more consistent with the figures for the other methods, was used. With regard to measurements of logs, the circular plot method requires more time than the other methods since the logs in this case must be measured, whereas they only need to be counted in the other cases. The figure 10 sec log^{-1} for the transect relascope is derived from the field study presented in Table 2. All other figures are derived from the literature.

To compute the cost of a method, the time consumption was multiplied by 200 SEK h^{-1}. Consequently, it is the variable cost for field measurements rather than the total cost of a method that is estimated.

The results are presented in terms of cost-precision relationships in Figure 4. Given a specific number of plots or survey lines, each method was simulated 300 times to establish the cost and standard error. No substantial bias was found for any of the methods.



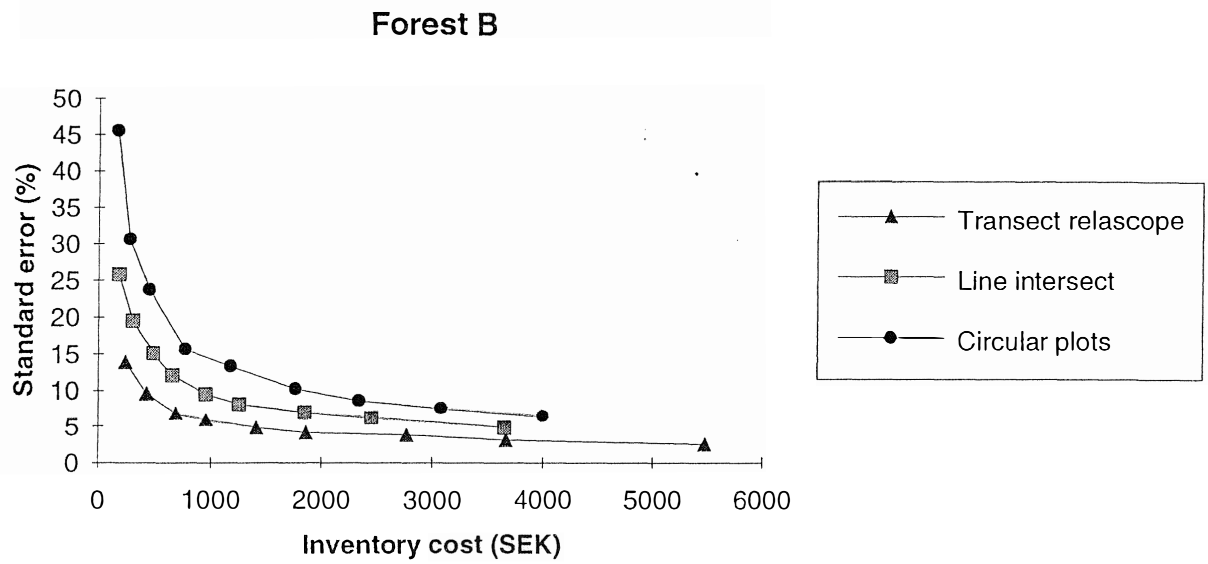


Figure 4 - Results from the Monte-Carlo sampling simulations in terms of cost-precision relationships for the different methods. The standard error is given in percent of the true value.

The transect relascope method turned out to be the most efficient alternative in both forests. Its relative superiority was larger in forest A where the intensity of down logs was low.

DISCUSSION

With regard to the studies made, the transect relascope method seems to be an interesting alternative for the quantification of coarse woody debris. Its properties in the field must, however, be studied more thoroughly before it can be finally concluded that the method is useful.

It is important that a sighting angle that corresponds to the visibility in the forest is chosen. Small angles lead to inclusions at long distances. On the other hand, the logs must be very large to be included if they are located far from the survey line and large logs are often easy to detect (unless they are very decomposed). The transect line must also be properly followed during the inventory. Deviations from it may cause bias, especially if the deviations are related to the occurrence of down logs.

When using the transect relascope, measurements of logs within a specific area should start a few meters before the surveyor enters the area and continue a few meters after the surveyor leaves the area. This is due to the shape of the area of inclusion around down logs. Also, sightings should be made in all directions, even backwards to the sides of the survey line.

Hilly terrain may cause problems. In theory, the transect relascope should always be operated horisontally and the down logs should extend in the horisontal plane. Small deviations from this situation cause only very limited bias. In case of large deviations, the surveyor should try to imagine the horisontal image of the inventory situation and count logs that fill the relascope gap in this case. It should, however, be possible to construct the instrument in such a way that it automatically corrects for sighting angles deviating from the horisontal plane, similar to how the Spiegel Relaskop (Bitterlich 1984) corrects for this in basal area estimation.

The precision of the method, using formula (1), depends on the randomness of down log orientations. In the simulation study, the logs were assumed to be entirely randomly oriented. This may not be the case in practise. The performance of the method can, however, probably be enhanced if the transects are made L-shaped or if they are laid out in some random zigzag manner.

The method is less sensitive to down log orientations than is the line intersect method (in comparing estimators where log orientations are not included). An interesting special case occurs if a transect relascope with a 90 degrees sighting angle is used. In this case, the areas of inclusion around logs are circular and thus the properties of the estimator will not depend on the orientation of logs.

The purpose of using the transect relascope should primarily be the description of habitat conditions for wood-inhabiting species. Such habitat conditions are often given in terms of volumes rather than lengths of down logs. It can, however, be questioned if the volume describes a habitat better than does the total length of logs, at least if a classification of logs into different dimension and perhaps decomposition classes is made. Such a classification can be made ocularly when the transect relascope is used. Still, if volumes rather than lengths are required, the method can be extended to include measurements of diameters on subsampled logs (e.g. on the logs intersected). If this is made, it is possible to estimate also the total volume of down logs.

Another extension would be to include dead standing trees. If a relascope instrument with a vertical sighting angle is used along a transect, the probability of inclusion will be proportional to the trees' heights. Thus, the total length of standing trees of interest can be obtained by counting the trees that fill the vertical relascope gap. This method is mentioned by Strand (1957) in connection with the estimation of stand volume.

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