Prism sweeps for coarse woody debris

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Abstract: A new method for sampling coarse woody debris (CWD) is presented, based on relascope sampling of CWD midpoint diameter. In this method, CWD is included in a sample if the angle subtended by the midpoint diameter viewed from plot center is greater than the critical relascope angle. The method is therefore referred to as diameter relascope sampling (DRS). Other methods for sampling CWD are reviewed and compared with DRS using sampling simulations and statistical power calculations. These are fixed area sampling, line intercept sampling, and point relascope sampling. DRS is shown to be have greater statistical power per unit sampling effort than other methods when CWD diameter and length are linearly or allometrically related, but results can vary with the diameter–length relationship employed. The relative benefits of different methods for sampling CWD are discussed.

Résumé : Une nouvelle méthode pour échantillonner les débris ligneux grossiers (DLG) est décrite. Elle est basée sur l'échantillonnage au relascope des diamètres médians des DLG. Un DLG est inclus dans l'échantillon lorsque l'angle sous-tendu par son diamètre médian et vu à partir du centre de la placette est plus grand que l'angle critique du relascope. La méthode est donc appelée échantillonnage au relascope par diamètre (ERD). D'autres méthodes pour échantillonner les DLG sont examinées et comparées à la méthode ERD en utilisant des échantillons simulés et les calculs de puissance statistique. Ces méthodes sont : l'échantillonnage à surface fixe, l'échantillonnage par ligne d'interception et l'échantillonnage au relascope par point. Lorsque le diamètre et la longueur des DLG sont reliés de façon linéaire ou allométrique, la méthode ERD possède la puissance statistique la plus élevée comparativement aux autres méthodes pour chaque unité d'échantillonnage déployée. Mais, les résultats peuvent varier selon la relation entre le diamètre et la longueur qui est utilisée. Les avantages relatifs des différentes méthodes pour échantillonner les DLG sont discutés.

[Traduit par la Rédaction]

Introduction

Coarse woody debris (CWD), composed of standing dead trees and fallen trees and branches, plays an important role in the ecology of forests (Harmon et al. 1986), nutrient cycling (Keenan et al. 1993), the provision of shelter, habitat, and food for wildlife (Bellhouse and Naylor 1996; Freedman et al. 1996; Hagan and Grove 1999), as a seedbed for regeneration (Takahashi et al. 2000), and as a carbon reservoir (Lugo and Brown 1992). Simple, precise, and statistically powerful methods for sampling CWD are thus of interest to a wide range of disciplines in forestry and forest science.

Methods for sampling CWD

Before introducing a new method for sampling CWD, existing methods will be briefly reviewed. Standing dead trees may be sampled using similar methods to live trees sampling, for example point relascope, or prism sweep (described in Philip 1994). Because they lie in the horizontal plane, fallen trees and branches must be sampled using other methods.

The target parameter in the majority of past studies has been volume or mass of CWD per unit area λ_y in forested region F of area A (examples in Harmon et al. 1986). The population of interest U is N pieces of CWD lying within F. The volume of the kth piece P_k is y_k, therefore $\lambda_y = A^{-1}\Sigma_{k\in U}\, y_k$. The total volume within F is $T_y = \Sigma_{k\in U}\, y_k$.

The methods described below rely on the design-based approach to make inferences about the population (Gregoire 1998). Using this approach, the population is viewed as fixed, and randomness is introduced only through the placement of sample points. M sample points are randomly placed within F, such that z_m is the location of the mth point. Let the random variable $I_{km} = 1$ if z_m falls within the inclusion area a_k of P_k, and $I_{km} = 0$ if z_m falls outside a_k. In other words, $I_{km} = 1$ if P_k is included in the mth sample. Let S be the subset of U for which $I_{km} = 1$, and n is the number of pieces within S.

The probability of z_m falling in a_k is the inclusion probability $p_k = a_k/A$. The inclusion area a_k may be a fixed quantity or be dependent on some property of P_k such as size, in which case the sampling methodology is known as probability proportional to size (PPS) sampling. If a_k overlaps the boundary of F, a_k will be smaller than expected, and a bias will be introduced unless a_k is measured. However, it is time consuming to measure a_k whenever boundary overlap occurs, and various other methods may be employed to eliminate this bias (e.g., Gregoire 1982; Schmid-Haas 1969).

Once sample points have been randomly placed, boundary overlap has been accounted for, and I_{km} calculated for all N pieces for all M sample points, the design-unbiased Horvitz–Thompson (Horvitz and Thompson 1952) estimator of λ_y from the sample at z_m is

$$\hat{\lambda}_{ym} = A^{-1}\sum_{K\in U}\frac{I_{km}y_k}{p_k} = \sum_{K\in U}\frac{I_{km}y_k}{a_k} = \sum_{K\in S}\frac{y_k}{a_k}$$

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The unbiased population estimator $\tilde{\lambda}_y = M^{-1}\Sigma_{m=1}^{M}\hat{\lambda}_{ym}$. A design-unbiased estimator of the variance of $\tilde{\lambda}_y$ is obtained as the observed variance among the M sample estimates (Gregoire 1998):

$$\hat{s}^2[\tilde{\lambda}_y] = \frac{1}{M(M-1)}\sum_{m=1}^{M}(\hat{\lambda}_{ym} - \tilde{\lambda}_y)^2$$

These estimators are applicable to all the methods described below. The methods differ in the calculation of a_k and may differ in the estimator of y_k. The methods assume that pieces of CWD are cylinders of length l_k, diameter d_k, and volume $\hat{y}_k = (\pi d_k^2 l_k)/4$. Since CWD may be tapered and is often irregular in shape, y_k is usually estimated using simple geometric solids of revolution, such as truncated cones or conoids (Philip 1994, p. 56). For example, Huber's formula treats pieces of CWD as frustra of quadratic paraboloids, i.e., $\hat{y}_k = (\pi d_{ck}^2 l_k)/4$ where d_{ck} is the midpoint diameter. This formula is often used, since it only requires two measurements to be made (e.g., Idol et al. 2001) and can give estimates of low bias and high precision (Figueiredo Filho et al. 2000). Mass may be estimated by multiplying y_k by an appropriate density constant (e.g., Idol et al. 2001).

Fixed-area sampling (FAS)

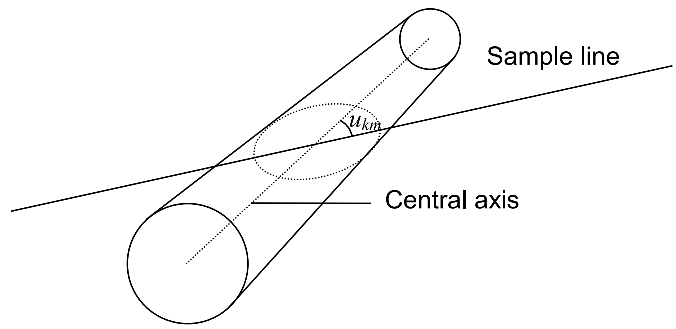
FAS is a commonly employed method (e.g., Pedlar et al. 2002) that involves enumerating all CWD within the boundary of a sample plot, with each plot having a constant area a. The shape of the plot used is irrelevant, but is often of fixed radius or a quadrat (e.g., Idol et al. 2001). For a fixed-radius plot, $I_{km} = 1$ if $r_{km} < R$, where r_{km} is the distance from the plot center z_m to the midpoint x_k of the central axis of P_k and R is the plot radius. In effect, this collapses each piece to a point and obviates the need for inclusion rules regarding pieces that fall across the plot boundary. Some other point on P_k, for example the center of the wide end, could be designated x_k, as long as this is consistent for $P_k \in U$. The inclusion probability is the fixed quantity $p = a/A$, where a is the area of the plot within A. The need to determine a for when boundary overlap occurs can be avoided by the use of the mirage method (Gregoire 1982), in which z_m is reflected across the boundary of F, and I_{km} is calculated again for the reflected point.

Line intersect sampling (LIS)

Another popular method is LIS (Van Wagner 1968), the term used in forestry literature for the general technique known as line intercept sampling. The method has been employed recently by Duvall and Grigal (1999). Sample lines of length L are scattered with random orientation and with their midpoints z_m within F. If the central axis of P_k is intersected by the sample line, then $I_{km} = 1$ (Fig. 1). The area of inclusion is $a_k = Ll_k \sin u_{km}$, where u_{km} is the acute angle between the sample line and the central axis of P_k (Kaiser 1983). LIS is an example of PPS sampling because $p_k \propto l_k$. Bias due to boundary overlap can be avoided by continuing in parallel a sample line that crosses the boundary of F back into F (Kaiser 1983) or by a modification of the reflection method (Gregoire and Monkevich 1994).

The sample line may be thought of as a plane perpendicular to F (Van Wagner 1968). Where this plane intersects P_k, it forms an elliptical cross section with height d_k, length $d_k/\sin u_{km}$, and area $e_{km} = pd_k^2/4 \sin u_{km}$. Essentially, $\hat{\lambda}_{ym} = L^{-1}\Sigma_{k\in S}\, e_{km}$, i.e., the sum of the area of the ellipses over the length of the sample line. By integrating the product of e_{km} and the probability density of u_{km} with respect to u_{km}, Van Wagner (1968) shows that the expectation of e_{km} is independent of u_{km}, giving

Fig. 1. Geometry of line intersect sampling (LIS), perspective view. The sample line crosses the central axis of the piece (P_k) of coarse woody debris, forming an ellipse of height d_k and width $d_k/\sin u_{km}$. The sum of the area of these ellipses over the length L of the sample line gives $\hat{\lambda}_{ym}$.



$$\hat{\lambda}_{ym} = \frac{\pi^2}{8L}\sum_{k\in S} d_k^2$$

This estimator is design-unbiased, provided that sampling lines are randomly oriented with their midpoints located uniformly at random within region F, and boundary overlap is taken into account (Kaiser 1983).

Point relascope sampling (PRS)

A recently developed method samples CWD based on the angle v_{km} subtended by l_k from z_m (Gove et al. 1999). This method is based on horizontal point sampling, or relascope sampling, for standing trees (Bitterlich 1984; Grosenbaugh 1958) and is known as PRS. It may be argued that PRS could be renamed length relascope sampling to distiguish it from other methods based on relascope sampling, but here the precedent will be respected.

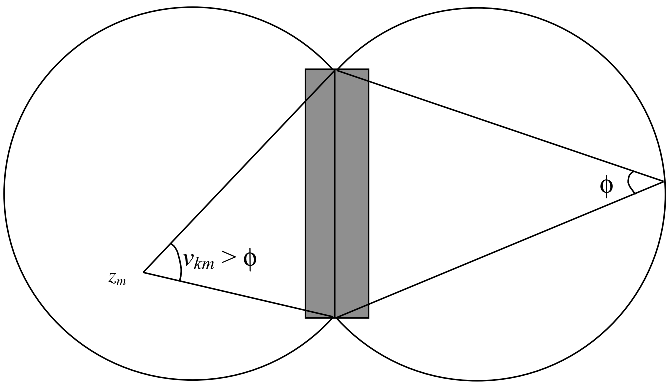
In PRS, $I_{km} = 1$ if $v_{km} > \phi$, where ϕ is constant and $0 < \phi \leq \pi/2$ (Fig. 2). The area of inclusion is

$$a_k = \frac{\pi - v + \sin\phi\cos\phi}{2\sin^2\phi} l_k^2$$

PRS is therefore an application of PPS sampling with $p_k \propto l_k^2$. Gove et al. (1999) describe methodology for eliminating bias due to boundary overlap. Bias incurred because of sloping terrain may be corrected using the methods of Ståhl et al. (2002). Each sampled piece represents a constant squared length per unit area; therefore, some estimator of y_k is required to estimate λ_y.

PRS is implemented by viewing pieces of CWD through an angle gauge consisting of two pegs inserted into a horizontally held bar, held at a distance from the eye such that the angle subtended by the pegs is equal to ϕ. If pieces are viewed from standing, sighting is not horizontal but at an angle of inclination γ_{km}. Sighting to poles held vertically over the ends of pieces can be used to reduce γ_{km} (Gove et al. 1999, 2001). The PRS methodology may also be conducted

Fig. 2. Geometry of point relascope sampling (PRS), plan view. The shaded bar is the piece (P_k) of coarse woody debris; the plot boundary the locus of points for which the angle subtended by the central axis of P_k is ϕ. The sample point z_m lies within the area of inclusion; therefore, $v_{km} > \phi$ and $I_{km} = 1$.



while walking along transects, in which case it is known as transect relascope sampling (Ståhl 1998).

A new method: diameter relascope sampling (DRS)

Here we present a new method for estimating λ_y, DRS, which is also based on horizontal point sampling (HPS) for standing trees. In HPS, the inclusion area is

$$a_k = \pi R_k^2 = \frac{\pi d_k^2}{4\sin^2(\theta/2)}$$

where $R_k = d_k/[2\sin(\theta/2)]$ is the radius of the inclusion area (Fig. 3). θ is constant and is the angle subtended by d_k from R_k. In the case of standing trees, d_k is the diameter at breast height (DBH). When θ is small, $\sin(\theta/2) \approx \theta/2$; therefore, $a_k \approx (\pi d_k^2)/\theta^2$. Inclusion may also be defined with reference to the limiting distance between x_k and z_m, i.e., $I_{km} = 1$ if $r_{km} < R_k$, where r_{km} is the distance from x_k to z_m.

In practice, $I_{km} = 1$ if $\alpha_{km} > \theta$, where α_{km} is the angle subtended by d_k from z_m. This is commonly achieved by viewing DBH horizontally through a prism, which refracts the image by θ (Philip 1994). If the image in the prism overlaps the unrefracted image, the tree is included in the sample. In cases where d_k is not completely visible from z_m or where $\alpha_{km} \approx \theta$, α_{km} must be determined by direct measures of d_k and R_k, from which $\alpha_{km} \approx d_k/R_k$ for small α_{km}.

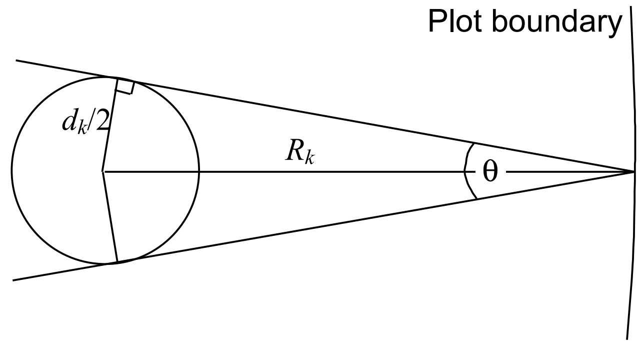
The basal area of sampled trees is a constant proportion g of a_k, such that

$$g = \frac{(\pi d_k^2)/4}{\pi R_k^2} = \frac{(\pi d_k^2)/4}{(\pi d_k^2)/[4\sin^2(\theta/2)]} \approx \frac{\theta^2}{4}$$

When expressed in $m^2 \cdot ha^{-1}$, g is known as the basal area factor (BAF) of the prism or relascope. The estimated basal area per unit land area obtained from the trees selected at z_m is therefore $g\Sigma_{k\in U} I_{km} = gn$.

In DRS, HPS is modified to sample CWD by designating α_{km} as the angle subtended by the midpoint diameter d_{ck} from z_m. By employing Huber's formula, the measurement of l_k of included pieces gives

Fig. 3. The relationship between the diameter d_k and plot radius R_k for horizontal point sampling.



$$\hat{\lambda}_{ym} = \sum_{k\in S} \frac{\hat{y}_k}{a_k} = \sum_{k\in S} \frac{(\pi d_{ck}^2 l_k)/4}{\theta^2/(\pi d_{ck}^2)} = \frac{\theta^2}{4}\sum_{k\in S} l_k = g\sum_{k\in S} l_k$$

because each sampled piece represents g cross-sectional area per unit area. As for trees, diameter distributions and number of pieces of CWD can be calculated if the diameter is measured (Philip 1994). The number of pieces per unit area $\lambda_n = N/A$. This can be estimated using the Horvitz–Thompson estimator where each piece contributes unity to the total:

$$\hat{\lambda}_{nm} = A^{-1}\sum_{k\in U} \frac{I_{km}}{p_k} = A^{-1}\sum_{k\in S} \frac{A}{a_k} = \sum_{k\in S} a_k^{-1}$$

$$= \frac{\theta^2}{\pi}\sum_{k\in S} d_k^{-2} = \frac{4g}{\pi}\sum_{k\in S} d_k^{-2}$$

A practical issue concerns the sighting of d_{ck} from z_m. When sampling standing trees, the line of sight is in the plane of the DBH, and the BAF prism is held vertically so that the image is refracted horizontally. The area of inclusion is a circle of radius R_k around the tree at breast height. In DRS, d_{ck} is viewed by orienting the relascope so that it is perpendicular to the line of sight, and the image is refracted perpendicular to the length (Fig. 4). This is equivalent to sighting some point above or below breast height in a standing tree. The area of inclusion, a_k, is a horizontal circle of radius R_k centered on the midpoint of P_k at a height of $d_{ck}/2$ above the ground (Fig. 5). The acute angle β_{km} from the central axis to the line of sight has no influence on the ability to view d_{ck} when $\beta_{km} > 0$. In other words, d_{ck} can be seen from any point in the plane of the central axis, other than directly end-on.

Often, pieces of CWD will be viewed from a position z'_m vertically above z_m (e.g., from a standing position) that will allow d_{ck} to be viewed from any point, even end-on (Fig. 5). The angle of elevation γ_{km} above the plane decreases α_{km} by a factor of cos γ_{km}, and so could lead to the unwarranted exclusion of P_k from a sample. In practice, γ_{km} will only have a significant influence for small pieces of CWD with small R_k. For such pieces, γ_{km} can be minimized by viewing d_{ck} close to the ground or eliminated by direct measurements of d_{ck} and R_{km}. Similar steps are taken with standing trees when they are obscured from view, for example by moving around the x_k at a distance r_{km}. As with point sampling for standing trees, when sampling CWD on a slope of angle σ, $\hat{\lambda}_{ym}$ will be underestimated by a factor of cos σ because of the in-

Fig. 4. Perspective view of orientation of basal area factor (BAF) prism so that the image is refracted perpendicular to the length. CWD, coarse woody debris.

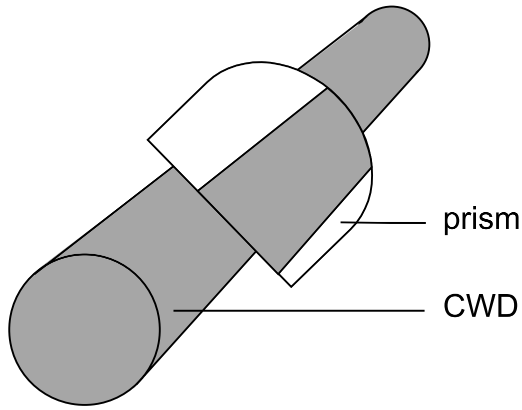
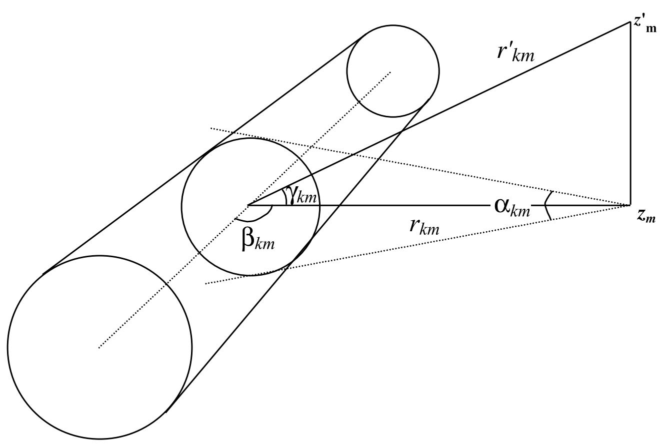


Fig. 5. Perspective view of the piece (P_k) of coarse woody debris showing α_{km} from sample point z_m. The acute angle β_{km} from the central axis of P_k to the line of sight from z_m has no influence on the ability to view the midpoint diameter, d_{ck}, when $\beta_{km} > 0$. The angle of elevation γ_{km} from z_m to z'_m enables viewing of d_{ck} from any point, but decreases α_{km} by a factor of cos γ_{km}.



crease in r_{km}. Final volume estimates must therefore be divided by cos σ to correct for slope angle (Philip 1994).

Direct measures of r_{km} and d_{ck} are required for CWD that is borderline for inclusion or difficult to view from z_m. Direct measures are also required where a log is highly decayed and has collapsed to an oval cross section. In such a case, calculation of mean midpoint diameter from height and width at the center are required. In a field test of DRS in Ontario, Canada, horizontal distances for borderline pieces were automatically calculated using highly accurate Forest Pro handheld laser units and reflectors (Laser Technology Inc., Englewood, Colo., U.S.A.). Problems due to large γ_{km}, large σ, $\beta_{km} \approx 0$, and $\alpha_{km} \approx \theta$ are eliminated when such instruments are available. Measurement tapes held horizontally can achieve similar, if less accurate, results.

Boundary overlap can be dealt with using the method of Gregoire (1982), i.e., by counting pieces again that are sampled in mirage points reflected across the stand boundary, though in real forests accurately locating the stand boundary can be very difficult.

Table 1. Parameters ± SE for diameter–length relationships in the sampling simulation, where L is length and D is diameter.

	Parameter	
Relationship	*a*	*b*
Linear: $L = a+bD$	3.27±0.75	22.7±2.4
Power: $L = aD^b$	18.0±0.5	0.5±0.02
Sigmoidal: $L = \exp(a - b/D)$	3.50±0.03	0.30±0.02

Simulation study

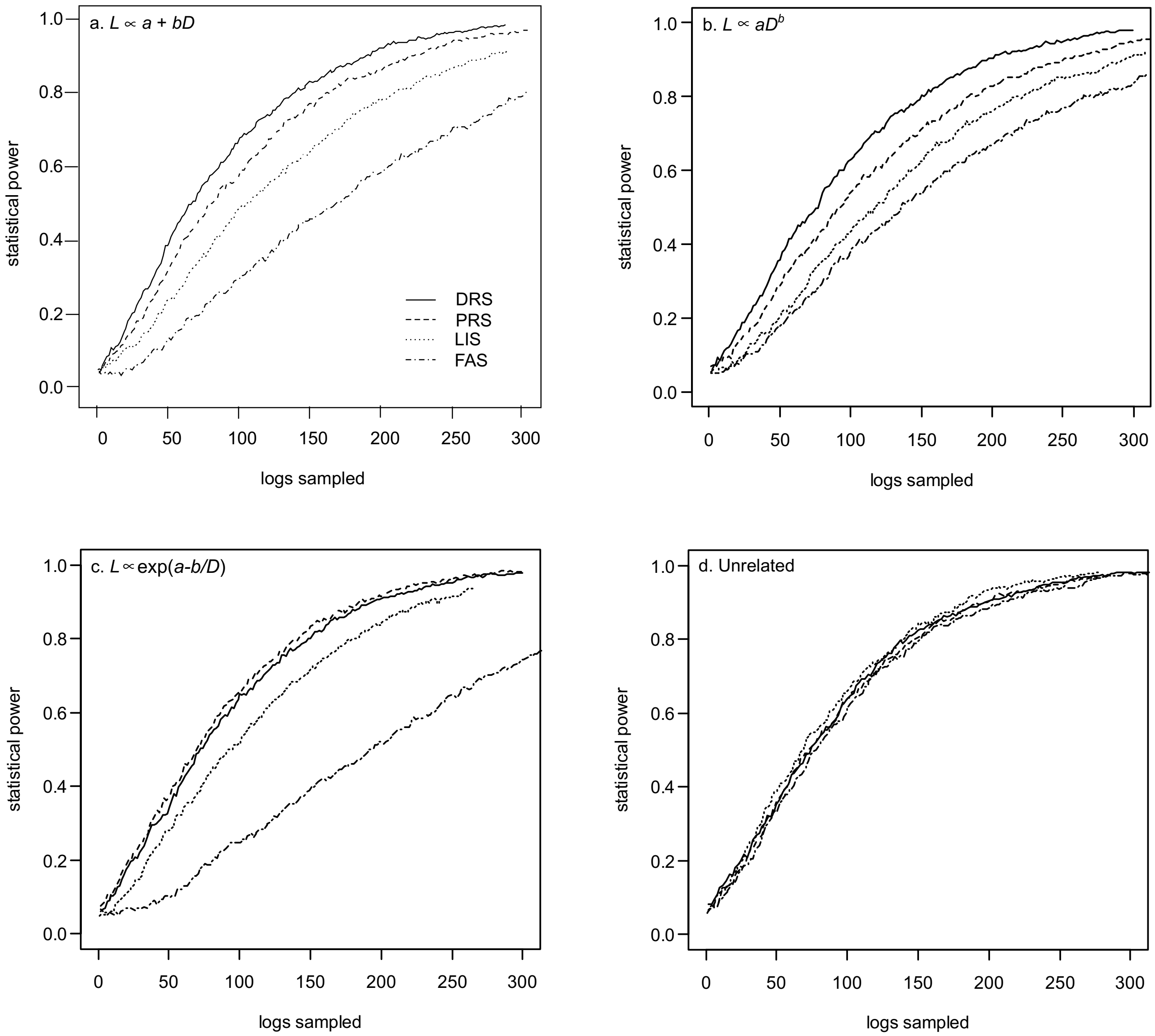
Modelling simulations of the prism method were carried using R statistical software (Ihaka and Gentleman 1996, see http://cran.r-project.org/) to compare its performance with FAS, LIS, and PRS.

In the model simulation, 10^4 pieces of CWD were scattered with random orientation over a 1 km × 1 km (100 ha) stand using a spatially aggregated distribution. The diameters of CWD pieces were modelled using a two-parameter Weibull distribution derived from natural origin CWD samples from Ontario, Canada (D. Bebber and S. Thomas, unpublished data). Four diameter–length relationships were modelled using parameters derived from unpublished measurements of CWD and trees (Table 1). Each parameter was assigned a normally distributed random error. The first model was based on the diameter–length relationship for CWD from Ontario ($r^2 = 0.19$, $p < 0.001$) in which length was a linear function of the diameter with a normally distributed error ($L = a + bD$). The second and third models were based on DBH–height relationships from standing white pine (*Pinus strobus* L.) in Ontario. The second model was a power, or allometric, relationship ($r^2 = 0.28$, $p < 0.001$) in which length was related to the square root of diameter ($L = aD^{0.5}$). The third was a sigmoid model for standing white pine ($r^2 = 0.30$, $p < 0.001$) in which length reached an asymptote ($L = \exp(a - b/D)$). In the fourth, length was modelled using a two-parameter Weibull derived from the Ontario CWD data, but was independent of diameter. Logs were modelled as cylinders with volume $V = \pi D^2 L$. In each of the simulations, λ_y was set at around 30 m^3·ha^{-1}.

The four sampling methods were simulated 1000 times for 200 randomly placed sample points. The expected sample size for each method can be estimated by $\Sigma_{k\in U}\, p_k$. Prism sampling was simulated for a BAF 2 prism with plot center at the sample point, and the parameters for the other methods were adjusted so that the number of logs sampled was similar for each (around 1.5 logs per sample). FAS was simulated with a circular plot of radius 7.5 m centered on the sample point. PRS was simulated using a $\pi/4$ (45°) angle gauge with plot centre at the sample point. LIS was simulated using a randomly oriented, 35 m long line centered on the sample point. The statistical power of each method was calculated as the probability of detecting a significant difference (t test, $p = 0.05$) between the mean sample volume and an arbitrary value (67% of λ_y).

All methods gave estimates of λ_y within <1% of the true value when the results of all runs were combined. No bias was evident because CWD was modelled as a cylinder, and estimates were not dependent on the volume estimator. The

Fig. 6. Relationship between number of logs sampled and statistical power for simulations of four sampling methods on four diameter–length relationships. Sampling methods are diameter relascope sampling (DRS, —), fixed-area sampling (FAS, -·-·), line intersect sampling (LIS, ····), and point relascope sampling (PRS, - - -). Diameter–length relationships are (*a*) Linear: $L \propto a + bD$, (*b*) Power: $L \propto aD^b$, (*c*) Asymptotic: $L \propto \exp(a\text{-}b/D)$, and (*d*) Unrelated. Power was calculated as the probability of detecting a difference between the mean sample volume and an arbitrary value (67%) of the total.

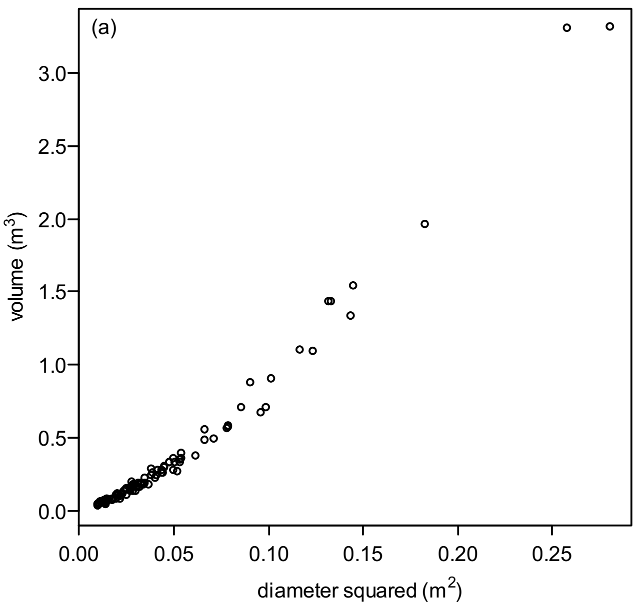


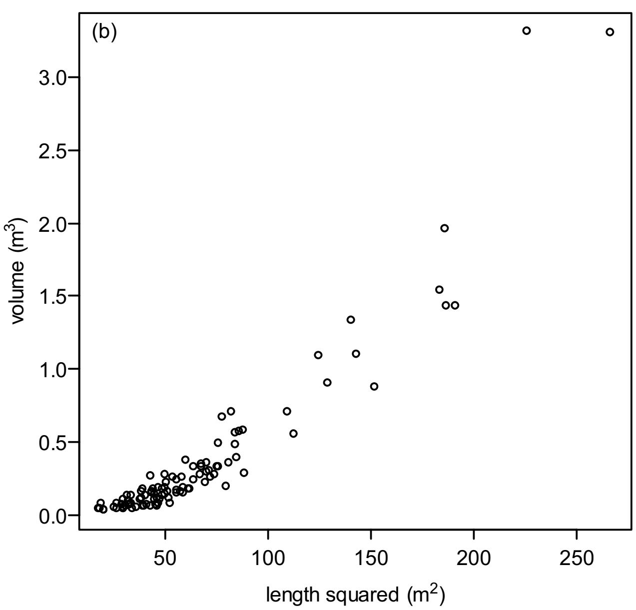
relative statistical power of the methods varied with the CWD diameter–length relationship (Figs. 6*a*–6*d*). When diameter was linearly related to length, DRS was found to be more powerful than the other methods (Fig. 6*a*), since diameter is a stronger (quadratic) predictor of volume than is length (Figs. 7*a*, 7*b*). A similar result was found with the power relationship (Fig. 6*b*). With an asymptotic relationship, the power of PRS increased because PRS was more likely to sample longer pieces, and where length reaches an asymptote, a small increase in length gives a disproportionately greater increase in diameter and, thus, volume (Fig. 6*c*). LIS performed poorly in comparison with DRS and PRS because the probability of inclusion is linearly, rather than quadratically, related to size. LIS, therefore, samples a greater number of smaller pieces, and the simplicity of searching in only one dimension is balanced by a lack of power. Where diameter was unrelated to length, all methods had similar power, since the advantage of PPS methods in preferentially sampling larger pieces was lost (Fig. 6*d*). In summary, it appeared that the power of different methods in estimating volume was dependent upon their ability to preferentially sample larger, rarer pieces of CWD.

Discussion

Researchers and foresters now have a number of methods available to measure CWD. All the methods presented here are theoretically capable of giving unbiased estimates for CWD. Selection of a method will therefore depend on factors such as efficiency, ease of application, the variable to be estimated, and field conditions. While FAS and LIS have been widely applied in the field, PRS and DRS are new and

Fig. 7. The relationship between (*a*) diameter squared and volume and (*b*) length squared and volume for a subset of 100 pieces of coarse woody debris (CWD) simulated using a linear diameter–length relationship. Volume was computed as $V = \pi D^2 L/4$, where D is diameter and L is length. The relationship between diameter squared and volume is stronger ($r^2 = 0.99$) than that between length squared and volume ($r^2 = 0.94$).





have yet to undergo extensive field testing. Familiarity may therefore disincline workers from switching to methods based on horizontal point sampling. However, we believe that the greater sampling efficiency of such methods, at least for volume estimation, make them competitive alternatives to traditional methods.

Power analysis is an elegant, though underused, method of evaluating the sensitivity of statistical tests (Thomas and Juanes 1996). We believe that power analysis allows more rigorous comparisons between methods than, for example, plotting standard errors (Ståhl and Lämås 1998). The simulation study showed that DRS performed well under a range of realistic diameter–length relationships. LIS, and particularly FAS, were less efficient than the relascope methods for estimating volume. It is likely that FAS would be more efficient for estimating CWD frequencies. DRS was slightly more powerful than PRS in two of the simulations and of virtually equal power in the other two simulations. Our unpublished data suggest that a linear relationship between length and diameter is the most appropriate, though this is likely to vary depending on the population in question. Diameter–height relationships for standing trees are likely to differ from those for CWD, for example when dead trees break into pieces rather than falling over intact or when forestry operations lead to short pieces of large-diameter “cull” timber left in situ.

The ability to calculate volume per unit area by multiplying the length of sampled pieces by the relascope BAF is an elegant outcome of using Huber’s formula to estimate volume. Though the DRS estimator is unbiased, the use of Huber’s formula could introduce a bias, depending on the relationship between midpoint diameter and volume in the population of interest. Several estimators for log volume using various diameter measures have been developed, e.g., Smalian’s formula (using end diameters), Newton’s formula (end and midpoint diameters), cubic spline interpolation (Goulding 1979), and the centroid method that employs the diameter at the centre of volume (Wood et al. 1990). Figueiredo Filho et al. (2000) compare several methods with volumes obtained by water displacement of *Pinus elliottii* Engelm. logs. Huber gave the most accurate estimates, followed by centroid and Newton, cubic spline, Bailey, and Smalian. Huber also had the advantage of stable percent error with increasing log length and required the fewest measurements. Martin (1984) also found that Huber gave the least biased volume estimates with the second smallest standard error in a test of several different methods for nine species of hardwoods measured using water displacement. Smalian consistently gives very poor estimates and should not be employed (Figueiredo Filho et al. 2000; Patterson et al. 1993*a*; Wiant et al. 1992, 1996). The centroid method has given estimates of low bias and high precision for certain species, particularly when butt logs are considered (Patterson et al. 1993*a*, 1993*b*; Wiant et al. 1992; Wood and Wiant 1990). The centroid is usually found at around 0.3–0.4 of the log length from the large end of a log (Wood et al. 1990). DRS might therefore be modified to sight to the approximate centroid rather than the midpoint diameter. Alternatively, a scaling factor could be used to adjust estimates from sightings to the midpoint. However, we would not recommend this change unless it were warranted by accurate measures of CWD diameter–volume relationships in the system in question.

Implementation of DRS will be most expedient within a sampling strategy already using relascopes to estimate tree basal area. Though there will be fewer pieces of CWD in most forests than there are standing trees, the diameter distributions are likely to be similar (except in highly disturbed forests), i.e., many small and few large pieces and trees. Use of the same prism for standing trees and CWD seems a reasonable and convenient practice. In a field test in Ontario, the main difficulty encountered was finding logs obscured by trees, undergrowth, and litter. Diligent searching is therefore required where visibility is reduced. Where visibility is very poor, LIS is perhaps a better option than DRS (or PRS), since searching is in only one dimension and for a finite distance. Fortunately, location of CWD in DRS is facilitated by the fact that the smaller and less visible a piece of CWD, the smaller its area of inclusion.

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