A field test of point relascope sampling of down coarse woody material in managed stands in the Acadian Forest[1]

John C. Brissette[2,3]
Northeastern Research Station, USDA Forest Service, Durham, NH 03824

Mark J. Ducey
University of New Hampshire, Durham, NH 03824

Jeffrey H. Gove
Northeastern Research Station, USDA Forest Service, Durham, NH 03824

BRISSETTE, J. C. (USDA Forest Service, Northeastern Research Station, Durham, NH 03824), M. J. DUCEY (University of New Hampshire, Durham, NC 03824), AND J. H. GOVE (USDA Forest Service, Northeastern Research Station, Durham, NH 03824). A field test of point relascope sampling of down coarse woody material in managed stands in the Acadian Forest. J. Torrey Bot. Soc. 130: 79–88. 2003.—We field tested a new method for sampling down coarse woody material (CWM) using an angle gauge and compared it with the more traditional line intersect sampling (LIS) method. Permanent sample locations in stands managed with different silvicultural treatments within the Penobscot Experimental Forest (Maine, USA) were used as the sampling locations. Point relascope sampling (PRS) with three different angles spanning the practical range of angles for such stands was used along with 40 m of LIS sample per sample point. Compared to LIS, the three angles resulted in similar number of pieces and volume of CWM from stands with different histories of repeated partial harvests. In terms of sampling efficiency, PRS was up to 4 times more efficient than LIS. These results, while limited to only one forest type and a relatively small sample, are the first published results available on the field performance of PRS.

Key words: Angle gauge sampling, coarse woody debris, spruce-fir forests.

Dead wood on the forest floor, or down coarse woody material (CWM), is an important component of forest structure. It serves as wildlife habitat, as seedbed for many species, and has a role in nutrient cycling and soil formation (e.g., see: DeGraaf and Yamasaki 2000, Harmon et al. 1986, McGee 2001). Although the ecological importance of CWM is recognized, how much should be present and how should it be distributed in a stand to maintain ecosystem processes is largely unknown (Hagan and Grove 1999). This is especially true in regions like the Northeast where old growth forests, which can provide a benchmark, are rare. In managed forest ecosystems, CWM has become a premier conservation concern with respect to achieving balance between producing forest products and sustaining species that require dead wood (Hagan and Grove 1999). Consequently, sampling CWM is an important consideration for ecologists and managers alike.

One reason information about CWM is lacking is because traditional methods for measuring it, such as fixed area plots and line intersect sampling (LIS), are time consuming and laborious (Rubino and McCarthy 2000). Recently, point relascope sampling (PRS) for CWM has been introduced, which may provide an efficient alternative to traditional methods (Gove et al. 1999). A relascope is a simple angle gauge that can be fabricated with common materials (Gove et al. 2001). Using a relascope to assess whether a particular piece of CWM is "in", "out", or "borderline," PRS is analogous to inventorying standing trees in horizontal point sampling (HPS) with an angle gauge or prism (Grosenbaugh 1958).

While Gove et al. (1999) established the theoretical basis for PRS, they noted that field trials in different forest types were needed to determine the efficacy of the method. For example, in HPS using prisms, the appropriate prism factor varies depending on the range of diameter sizes and understory growth in the stands to be sampled (e.g. Wiant et al. 1984). Similarly, with

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[2] Author for correspondence.

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PRS, the most efficient relascope angle is likely to vary with forest conditions.

The purpose of this study was to assess the field performance of PRS using three different relascope angles in differing stand conditions as compared with traditional LIS. LIS was chosen as the standard for comparison rather than fixed area plots because both theoretical considerations (Kaiser 1983) and simulation studies (Pickford and Hazard 1978) have shown LIS is more efficient than fixed area plots. The study was conducted in three stands of mixed northern conifers on the Penobscot Experimental Forest (PEF) in east-central Maine. The stands are part of a long-term silvicultural experiment and have marked differences in horizontal and vertical structure because of different harvest histories. Our goal is to encourage measurement of CWM by offering an innovative yet simple method for sampling this ecologically important component of forest structure.

Materials and Methods. STUDY SITE. The PEF is in the towns of Bradley and Eddington, in Penobscot County, Maine. Much of Atlantic Canada and adjacent Maine, including the area around the PEF, are in the Acadian Forest Region (Braun 1950, Rowe 1972). The PEF is 1540 ha and located at 44° 52′ N, 68° 38′ W. It was established in 1950 for conducting ecology and management research in the northeastern mixed conifer forest type. It is dominated by a diversity of conifers, including eastern hemlock (*Tsuga canadensis* (L.) Carr.), balsam fir (*Abies balsamea* (L.) Mill.), red spruce (*Picea rubens* Sarg.), white spruce (*P. glauca* (Moench) Voss), eastern white pine (*Pinus strobus* L.), and northern white-cedar (*Thuja occidentalis* L.). Associated dominant hardwoods include red maple (*Acer rubrum* L.); paper birch (*Betula papyrifera* Marsh.); gray birch (*B. populifolia* Marsh.); and aspen, both quaking (*Populus tremuloides* Michx.) and bigtooth (*P. grandidentata* Michx.).

Three stands were used in this comparison in order to evaluate PRS in a variety of forest structures. The stands (experimental units, called compartments) are part of a replicated, long-term experiment designed to evaluate individual tree and stand responses to a range of silvicultural treatments. The treatments were devised to create and maintain an array of single- and multi-aged or cohort structures with varying control of tree species composition.

Compartments 4 and 15 are replicates of a diameter-limit cutting treatment. Diameter-limit cutting is considered exploitative and perhaps dysgenic (Nyland 1996). The treatment was included in the experiment as an example of poor forestry practice. We chose those compartments for this study because they have been treated the same except in one the most recent harvest was 5 years before we sampled while in the other it had been 22 years since it was last cut (Fig. 1). Compartment 16 is one of the replicates of selection management with a five-year cutting cycle. The goal of selection silviculture is to regenerate and maintain a multi-aged structure, and in this case, a defined species composition. Compartment 16 was chosen because, of all the treatments, it is the one most frequently entered for harvests (Fig. 1).

Detailed descriptions of these treatments are in Brissette (1996) and briefly summarized here:

In the diameter-limit treatment, harvests occur periodically when stand volume reaches roughly the average volume of the two replicates prior to the first harvests in the 1950s. The diameter at breast height (dbh) that determines whether a tree is cut depends on species; in general, more commercially valuable species have higher diameter limits than less valuable species. Compartment 4 has had three harvests: June 1952, May 1973, and January 1994 (Fig. 1). Compartment 15 has had two harvests: September 1956 and August 1977 (Fig. 1). The heavy cuts in these stands have created a range of opening sizes, resulting in prolific regeneration of woody and herbaceous vegetation.

Selection silviculture is practiced by cutting at regular intervals with a set of objectives to achieve a sustainable, multi-aged stand with desired structure and attributes. In the long-term experiment, there are objectives for residual stand basal area, maximum tree diameter, diameter distribution, species composition and tree quality. Every five years, trees of all sizes and species are selected for harvest to meet the stated objectives. Compartment 16 has had nine harvests since the start of the experiment: March 1957, June 1963, October 1966, April 1972, January 1977, September 1982, August 1987, September 1991, and March 1997 (Fig. 1). The series of light harvests has resulted in only small openings and maintained a nearly continuous overstory canopy.

Each compartment in the silvicultural experiment has a network of permanent, fixed radius plots located systematically after a random start from which stand inventory data are collected periodically. The center of each plot is monu-

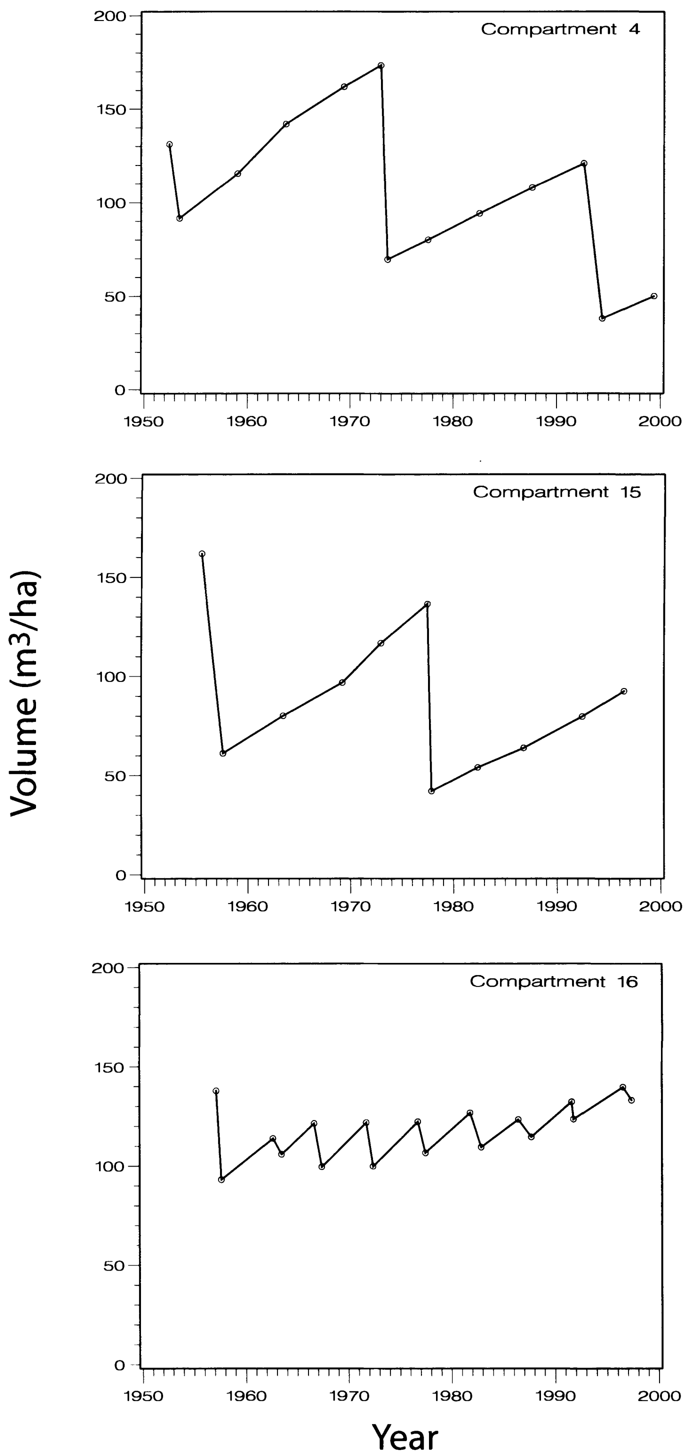

Fig. 1. Harvest histories of three compartments sampled for downed coarse woody material on the Penobscot Experimental Forest in Maine.

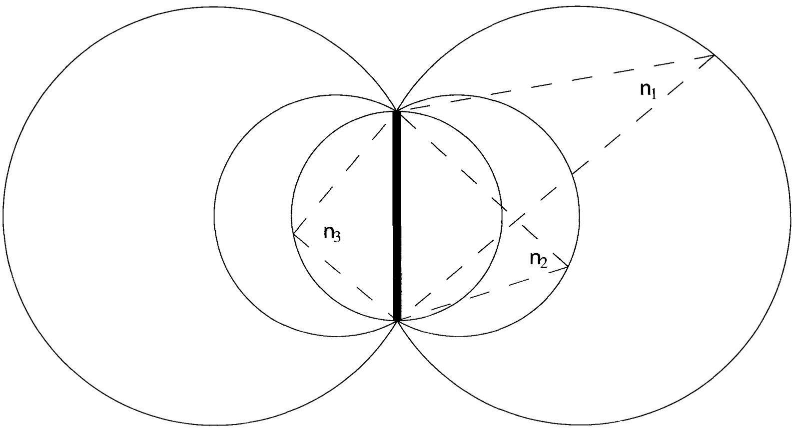

Fig. 2. Inclusion areas (partial circular regions) for point relascope sampling with three different angles (dashed lines) listed in Table 2 for a log (solid heavy line) of given length. If the sample point falls inside the inclusion area for a log, the log will be tallied with the relascope.

mented with a metal stake and the sampling design for CWM was superimposed over the permanent plot system. Compartment 4 has 13 permanent plots and Compartments 15 and 16 each have 12 plots.

CWM SAMPLING METHODS. Four methods were used for sampling the CWM component of the stands. First, a LIS scheme (Kaiser 1983, Warren and Olsen 1964) was used to provide a standard for comparison with the PRS. The LIS design consisted of four 10 m segments radiating from each sample point, oriented in the cardinal directions. Any piece of CWM, or "log," that was intersected by any of the four line sections was sampled. For all methods, minimum standards for a piece to qualify as CWM were a small-end diameter of 5 cm and a large-end diameter of 10 cm, regardless of length. If a log extended below the small-end cutoff, the portion less than 5 cm was ignored. Fragmented logs were treated as a single piece of CWM if the broken ends laid close to one another and had obviously been connected when part of the living tree. Such standards for determining what to measure are analogous to merchantability standards in typical forest inventories but, because there are no agreed upon standards for CWM, they are arbitrary. Nevertheless, the same standards were used for all sampling methods. The volume of each piece of CWM was calculated using Smalian's formula (Avery and Burkhart 1983).

Table 1. Relascope angles, reach-to-width ratios, and squared length factors for three PRS designs.

PRS design	Relascope angle (degrees)	Reach : width	Squared length factor ($m^2 \cdot ha^{-1}$)
ν_1	28.07	4:1	1444.17
ν_2	53.13	2:1	4750.77
ν_3	90.00	1:1	12732.40

Because of the novelty of the PRS technique, we describe the sampling process in more detail. With PRS, an angle of fixed width is projected using the relascope from a sample point. The relascope angle can be determined in degrees ($0 < \nu \leq 90$) or as a reach-to-width ratio, which facilitates relascope construction (Gove et al. 2001). The surveyor swings a complete circle about the sample point, viewing all candidate logs through the gauge. If a log's length appears larger than the projected angle when viewed through the relascope, the log is sampled. In this way, logs are sampled with probability proportional to their length squared (Gove et al. 1999). This means that, for a given relascope angle, longer logs can be further away from the point center than shorter logs and still be sampled. Furthermore, a smaller relascope angle "reaches out" farther than a larger angle, so for logs of equal length, the smaller the angle the further the log can be away from the sample point and still be "in" (Fig. 2).

Figure 2 illustrates three pairs of truncated circular areas, one on either side of a log, that comprise the so-called inclusion areas for that log (Gove et al. 1999). These three sets of inclusion areas correspond to the angles and reach-to-width ratios given in Table 1 and illustrate the relationship between angle size and distance for a log of fixed length. For a given relascope an-

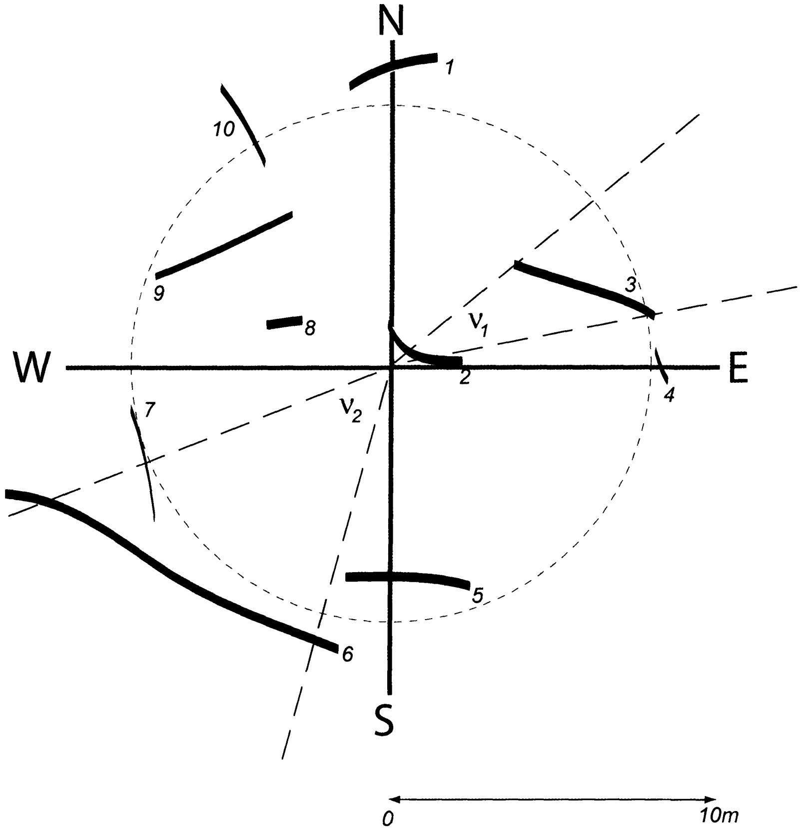

Fig. 3. Sample design for the Penobscot Experimental Forest survey with arbitrary pieces of downed coarse woody material (numbered). Line intersect sampling (LIS) design is oriented in the cardinal directions with 10m lines; two projections of relascope angles υ_1 and υ_2 are also shown. Projection of υ_3 corresponds to any two perpendicular legs of the LIS sample lines in those given directions, though in practice, a continuous 360 degree swing about the point is done for each angle.

gle, any sample point falling inside a log's inclusion area would select that log into the tally record for that point. Because the surveyor must be able to view the length of a log through the angle gauge, it should be observed that as one views the log more end-on instead of broadside, the likelihood of sampling the log vanishes. As mentioned earlier, this procedure is completely analogous to the circular inclusion areas formed by a wedge prism or angle gauge in HPS for standing trees and snags.

The sampling design used in this study is illustrated in Figure 3. The four 10 m LIS segments are shown centered on the permanent sample point. The dashed-line circle represents the smaller of two fixed-area plots used on the PEF (0.02 ha or 8 m radius). Ten pieces of downed CWM are arbitrarily scattered about. Also shown are two positions where the 360° swing of the relascope about the point center would have encountered logs in the sampling procedure for two different angles ν_1 and ν_2 (Table 1). The third relascope angle, $\nu_3 = 90°$, can also be imagined as being coincident with any two of the LIS line segments connecting at right angles (e.g., the north and east sections). It is clear from the illustration that logs 1, 2, 4 and 5 would be sampled once each on the LIS inventory phase. In addition, log 2 is longer than the width of the projected angle from ν_1 and therefore is clearly "in", while log 3 is "borderline;" in which case, measurements from the point center to the ends of the log would be required to ascertain whether it is indeed in the sample (Gove et al. 1999, 2001). Similarly, log 6 is clearly a sample log for ν_2 and therefore would also be sampled with ν_1. There are other logs, such as log 5, that could also be tallied with one or more of these three relascope angles; however, log 10 would be clearly be "out" for any chosen angle on this sample point since the combination of its orientation and distance make it impossible to be sampled (refer to Fig. 2). In addition, there may be other logs that are longer than those illustrated that could be significantly farther from the point center, falling outside the area shown, and still be sampled with PRS; this is especially true for the smaller angle.

A relascope is simple to construct using common materials (Gove et al. 2001). There are three pairs of pins on top of the wooden support, one pair for each of the three angles or ratios in Table 1. The strapping attached to the relascope, which, in conjunction with the pairs of pins, defines the angles, is held next to the surveyor's eye and directly over the sample point location. The gage is always held in the horizontal plane when used and should never be tilted towards the log or along the slope. An easy way to ensure accuracy, especially for "borderline" logs, is for other crew members to hold poles vertically at each end of the log being sampled, allowing the surveyor to look horizontally. On sloping ground, simple conversions detailed in Ståhl et al. (2002) may be applicable. In addition, both LIS and PRS require corrections when sampling close to the forest edge. The reflection or "mirage" method may be applied to both LIS and PRS to provide the requisite corrections. Gregoire and Monkevich (1994) discuss the application of the reflection correction method to LIS, while Gove et al. (1999) detail its use with PRS.

The expansion of sample quantities to per unit area means and totals in PRS is straightforward. For each relascope angle there is a corresponding squared length factor, L, that plays the same role as the basal area factor in HPS. With PRS, however, L connotes the amount of squared length (e.g., m^2/ha) represented by each sampled log and is a constant for a given relascope angle (Table 1). Therefore, for any variable, y_i, (e.g., volume) associated with the ith log, the estimate for a given sample point is determined as:

$$\hat{Y} = L \sum_{i=1}^{m} \frac{y_i}{l_i^2}$$

where m is the number of logs tallied about the point and l_i is the length of the ith log. PRS would typically be applied using multiple sample points in the area being inventoried. In this case, each sample point provides a value of $\hat{Y}$. The usual mean and variance formulas can be applied to the individual point estimates for the construction of confidence intervals, exactly as is done when estimates are taken from multiple point samples of overstory or multiple fixed-area plots (Gove et al. 1999, 2001).

It should be noted that while LIS was chosen as a convenient method for comparison against the field test of PRS, it only provides an estimate and does not represent the "truth." Therefore, we used a measure of relative efficiency that incorporates the sampling error in all methods for comparison rather than some measure of absolute accuracy. The same considerations would apply if fixed-area plots had been used as the basis for comparison. Short of conducting detailed simulations on the efficiency of PRS, this is perhaps the best approach available for field studies.

Much of the time spent on a sampling method is taken up with measurement of individual tallied pieces. This impacts the efficiency of different sampling methods. For example, a method with high variability between points may still be more efficient than one with low variability, if the method with high variability requires tallying and measuring fewer pieces per point. We calculated efficiency of a method (the three relascope angles in this case), relative to LIS, as:

$$E = 100\frac{s^2_{LIS}\bar{m}_{LIS}}{s^2\bar{m}}$$

where $\bar{m}$ is the average number of pieces tallied on a point, and s^2 is the sample variance between points. An efficiency of 200% for an angle indicates that to obtain equal confidence limits, twice as many logs would have to be tallied using LIS as using the angle in question. The relative efficiency measure E can be derived in a straightforward manner by setting the confidence limits to be obtained under LIS and an alternative method equal, and solving for the number of sample points needed under each method. Measuring the total inventory cost for a given method as some constant times the number of points required, times the mean number of pieces tallied at each point, the relative efficiency measure is simply the ratio of the costs for the two methods.

An assumption of the efficiency measure used here is that number of pieces tallied per point is a reasonable proxy for time required per point, and that the time cost per piece is similar for LIS and PRS. This assumption may not hold when volume is the only variable of interest as LIS requires only one measurement (diameter at

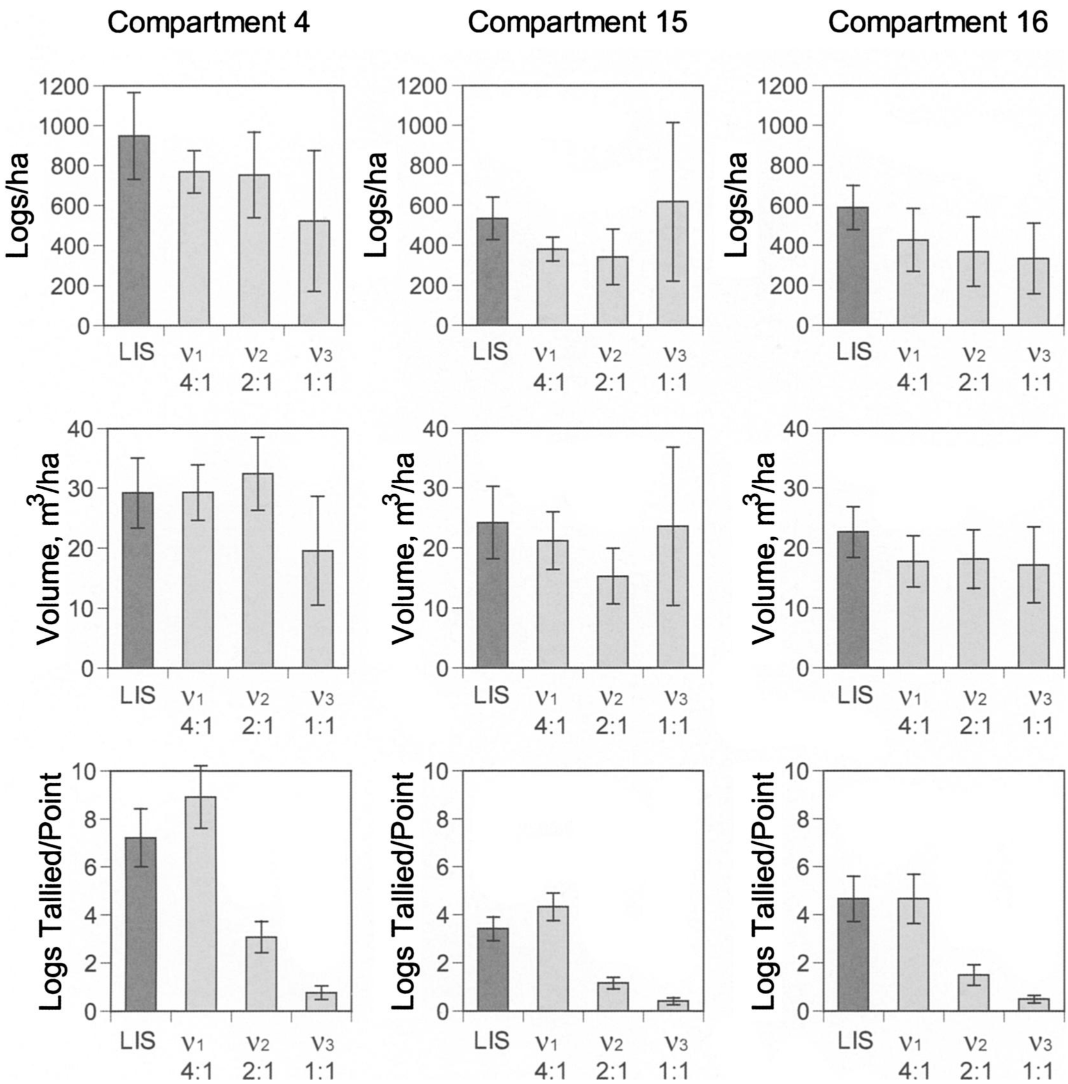

Fig. 4. Comparison of line intersect sampling (LIS) and point relascope sampling inclusion angles (υ_1, υ_2, υ_3) for all compartments with number of logs and volume/ha; in addition average number of logs tallied per point for each technique is given. Confidence intervals at the 95% level are shown about the histogram bars.

the intersection with the sample line to obtain unbiased estimates of volume per unit area). However, LIS requires set-up time to lay out a line, or to follow carefully a line that has not been laid out. Furthermore, when variables other than volume, such as number of logs, are of interest, LIS requires measurement of length for each log, so that time spent measuring each log becomes virtually identical. An alternative interpretation of the efficiency measure views the number of pieces tallied as similar but varies the relative measurement time. If PRS with a certain angle has a relative efficiency of 200%, then it will be more efficient than LIS unless measurement time per piece is more than twice as long.

Results and Discussion. In the Acadian Forest, PRS compared favorably with LIS for measuring CWM. Each of the relascope angles gave results comparable to LIS for the number of pieces of CWM, or "logs", per unit area and for volume of CWM per unit area (Fig. 4). However, in this forest the average number of logs tallied per sample point using angle ν_1 was the most comparable to LIS.

When using LIS, it is commonly assumed that

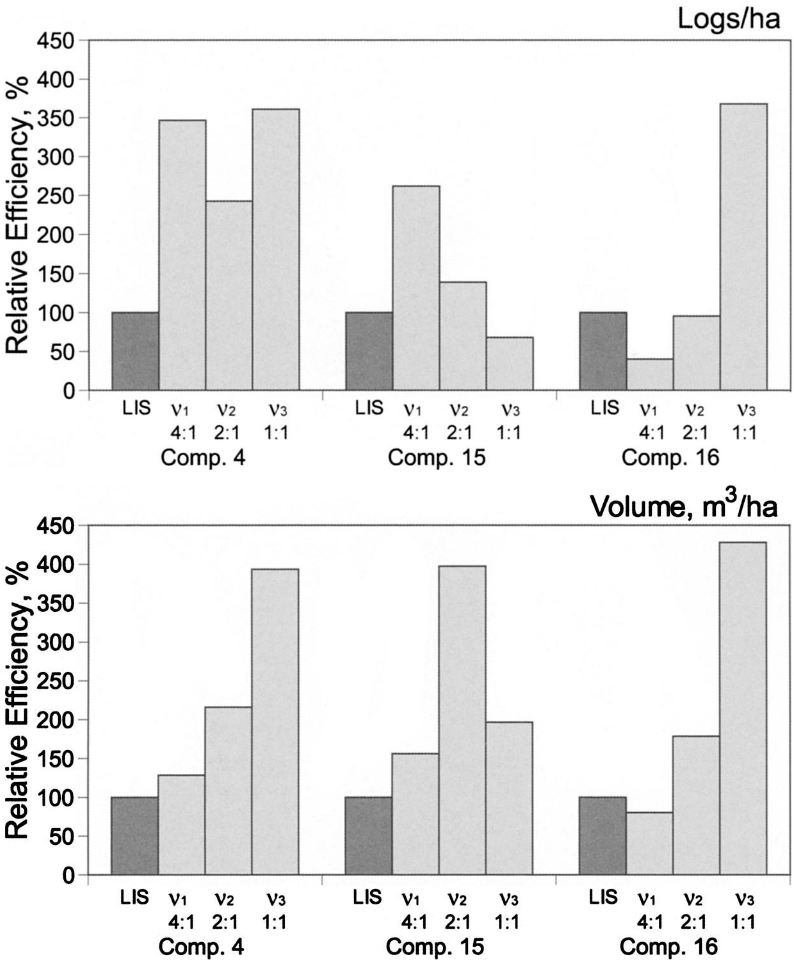

Fig. 5. Relative efficiencies of point relascope sampling inclusion angles (υ_1, υ_2, υ_3) compared to line intersect sampling (LIS) for density and volume of coarse woody material.

no logs should be missed; however, Ringvall and Ståhl (1999) have documented that surveyors do miss logs, either intentionally or unintentionally, especially in stands with dense amounts of CWM, leading to an underestimation bias with LIS. The fixed diameter limit stands (compartments 4 and 15) had dense understory vegetation resulting in poor visibility and mobility. Consequently, we were concerned that PRS, especially with ν_1, might not work as well as LIS in those stands. This challenge was largely alleviated by using range poles placed at the ends of candidate logs for determining their sample status with the angle gauge (Gove et al. 1999, 2001). The results suggest that no logs were missed. Because the understory in Compartment 16 was quite open, finding all the CWM associated with a plot was not difficult with any of the PRS angles.

The relative sampling efficiency of PRS in each stand is shown in Figure 5. The results for log density are highly variable. There is always at least one relascope angle that is substantially more efficient than LIS. However, this angle varies among stands. Relascope angle ν_2 is always at least competitive with LIS. The results for volume are more consistent across methods. PRS was more efficient than LIS across all stands and using all angles, except for ν_1 in Compartment 16. Even there, however, the efficiencies of PRS and LIS are similar. Wider angles were also generally more efficient. Given the clumped distribution of downed CWM in these stands, it makes more sense to tally a few pieces on average at many sample locations, than to tally many pieces on a few sample locations; the estimate is strongly influenced by how many points land in clumps or between clumps. Although the ability to move through the forest may influence sampling design (e.g., following a severe wind throw disturbance), in general sampling at more locations is a more efficient way of improving estimates, than sampling intensively at fewer locations in stands like those we studied.

The agreement between the average number of logs sampled per point with ν_l and LIS is purely serendipitous. The choice of four, 10m LIS line segments per point, was completely arbitrary and was not determined with any forethought to "matching" the tally of a given PRS angle tally. In fact, this would be a difficult task even with prior knowledge of CWM size and spatial distributions.

In all cases, while not recorded, PRS took no more time to conduct on a sample point than LIS, even at the smallest angle (ν_l). Indeed, using the medium and large angles (ν_2 and ν_3) was much faster than LIS. If we assume that the time it takes to measure any given log is proportional to its length because of travel time between ends, then the above conclusion can be logically defended, especially for ν_2 and ν_3, since the average number of logs tallied per point is low (Fig. 4) and the effective search radius for these logs is small (Fig. 2). For ν_l, larger logs can be some distance from the sample point; but these occur infrequently. Because there is no setup time with PRS as there is laying out lines in LIS, the only extra time associated with this technique beyond the actual measurement time is the time spent locating candidate logs and determining whether "borderline" logs are "in" or "out".

Conclusions. For even the most basic ecological investigations, field effort is often a limiting factor. In the Acadian Forest, PRS has potential to provide an accurate, relatively fast method of measuring downed CWM, making it easier to include this important structural element in ecological assessments. Compared to LIS, PRS provides similar estimates of CWM density and volume, but with greater sampling efficiency and without the need to layout sample transects or other plot boundaries. The results shown in Figures 4 and 5 suggest that for all-around use in stands similar to the PEF, whether managed or unmanaged, a relascope angle between ν_l and ν_2 may be most appropriate. The smallest angle was more efficient for sampling volume, but was not always efficient for determining log density. Obtaining reliable estimates with ν_3 also requires sampling at a large number of points. The efficiency calculations presented here do not consider the fixed costs of setting up a new sample location. Operationally, ν_2 presents some practical advantages as well. Using that angle, a log cannot be tallied unless it is at least as close to the sample point as it is long (and may not be tallied even then depending on its orientation). If the downed CWM in a forest comes predominantly from trees of the current dominant cohort, using the ν_2 angle gauge sets an effective maximum search radius of approximately one dominant tree height. From a practical standpoint, this allows field crews to avoid excess search time in areas far from the point, while at the same time helping crews to understand how far from the point they should travel in order to ensure no downed logs are missed.

It should be remembered that the results of this study are dependent on the specifications for the minimum dimensions of CWM to be sampled. That is, it must be expected that results, even within the same stands, would vary from those found in this study if, for example, the smallest log sampled was required to have a small-end diameter of 10 cm and minimum of 2 m in total length. Guidelines for defining and measuring CWM have been presented by Harmon and Sexton (1996). Inventory specifications for CWM are analogous to merchantability standards in typical forest inventories but, in the absence of a specific rationale such as the habitat requirements of a particular species of wildlife, are more arbitrary. Nevertheless, it remains an important point for consideration when designing inventories for down CWM and subsequent comparison with other studies.

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