Assessment of the Line Transect Method: An Examination of the Spatial Patterns of Down and Standing Dead Wood[1]

Duncan C. Lutes[2]

Abstract
The line transect method, its underlying assumptions, and the spatial patterning of down and standing pieces of dead wood were examined at the Tenderfoot Creek Experimental Forest in central Montana. The accuracy of the line transect method was not determined due to conflicting results of t-tests and ordinary least squares regression. In most instances down pieces were randomly distributed along transect segments. Down pieces generally had a clumped distribution of their directional orientation. Standing pieces were usually found to be randomly distributed within belt transects. Consistent clumping scale of down or standing pieces was not found when studied using the paired quadrat variance method.

Introduction
Coarse woody debris (CWD), principally logs and snags, plays a key role in a wide range of ecological processes in conifer forests. It is important for wildlife, plant regeneration, nutrient cycling, water quality, fire fuels and more (Harmon and others 1986, Maser and others 1979, Maser and others 1988).

A number of researchers have used the line transect method (Brown 1974, Howard and Ward 1972, Van Wagner 1968, Warren and Olsen 1964) for quantifying the down component of CWD. Most studies have assumed the accuracy of the line transect method when quantifying down debris. In a literature search for this paper, studies were not found that compared volume measured on a fixed area to the volume estimated on that same area with the line transect method, in the natural setting. Few studies have tested two important assumptions of the line transect method for large debris: random piece orientation and spatially random piece distribution.

Correcting for nonrandom piece orientation requires additional measurement effort in the form of additional transect lines or a mathematical correction. Identifying a random distribution may reduce the number of line segments and thus the effort required to reach some desired level of precision. If pieces are spatially clumped at some consistent scale on the forest floor, the identification of that scale

[1] An abbreviated version of this paper was presented at the Symposium on the Ecology and Management of Dead Wood in Western Forests, November 2-4, 1999, Reno, Nevada.
[2] Consultant, Systems for Environmental Management, P.O. Box 17101, Missoula, MT 59808-7101 (e-mail: dlutes@fs.fed.us)

may be used to reduce or eliminate the bias introduced by nonrandom spatial distribution.

The objectives of this study were to 1) compare the volume of down debris (logs) measured on fixed-area plots against estimates of down debris made with the line transect method on the same area; 2) test two assumptions of the line transect method: pieces need to be distributed randomly in their orientation and at random, spatially, on the forest floor; 3) identify the spatial distribution of standing pieces (snags); and 4) examine for a consistent scale of clumping of down and standing pieces.

Methods

Study Site

This study was conducted at the Tenderfoot Creek Experimental Forest (TCEF) in central Montana *(fig. 1)*. The forest extends in elevation from approximately 1900 to 2400 m and covers an area just less than 3,700 ha. Lodgepole pine *(Pinus contorta)* is the predominant cover type with scattered patches of subalpine fir *(Abies lasiocarpa)* and Engelmann spruce *(Picea engelmannii)* dominating older stands. Whitebark pine *(Pinus albicaulis)* and limber pine *(Pinus flexilis)* are also found throughout the TCEF.

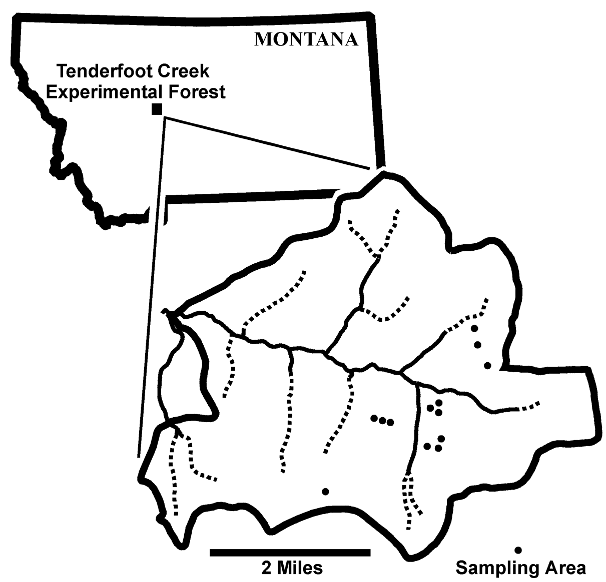

Figure 1—Study map of the Tenderfoot Creek Experimental Forest in central Montana, showing the locations of the13 sampling areas.

Sampling areas were established in five stands chosen from a fire history map of the TCEF (Barrett 1993). Four of the stands had last burned in 1873, 1845, 1765 and 1726, respectively. The fifth stand had burned in 1845 and again in 1873 (two-burn stand). None of the sampled stands showed any significant, identifiable sign of disturbance since the time of the last fire event. The 1873, 1845 and the two-burn stand were of the lodgepole pine cover type; the 1765 and 1726 stands were of the subalpine fir cover type. These stands were chosen because they were large enough to allow at least three sampling areas within each, had a wide variety of sizes and quantities of CWD, and were on sites with relatively little slope.

Field Sampling

Three sampling areas each were established in the 1873, 1845, 1765, and 1845 fire year stands. The two-burn stand had one sampling area. Each sampling area included ten 50-m line segments and ten 50 X 20-m belt transects. Line segments were oriented in the four cardinal directions. Belt transects were established by using the line segments as a centerline. Additionally, one 50 X 50-m (0.25 ha) fixed-area plot was established on five sampling areas *(fig. 2)*. The purpose of the fixed-area plots was to provide a "truth" to check the accuracy of line transect estimates of down debris.

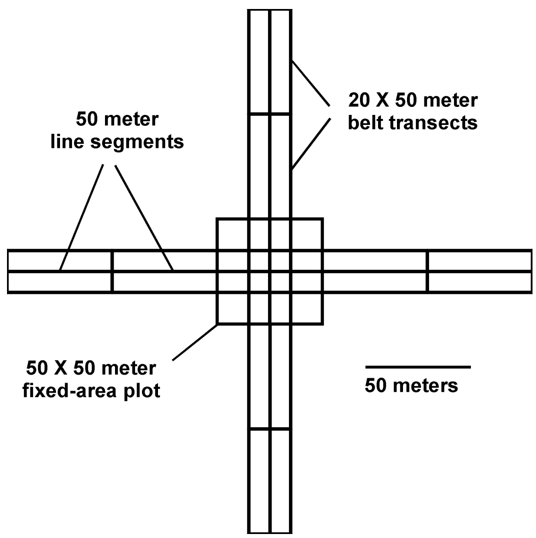

Figure 2—Sampling areas consisted of belt transects and 50-m line segments oriented perpendicularly. Five of the sampling areas had a 0.25-ha fixed-area plot that was positioned at the center of the sampling area.

Line-transect data in this study were used for three purposes: to provide a volume estimate for comparison with volume determined on a fixed area, to identify the log distribution pattern, and to examine clumping scale. Perpendicular lines were used to reduce or eliminate bias added by non-randomly-oriented pieces (Howard and Ward 1972). Estimated volumes were the mean of the 50-m north-south and east-west line segments.

Logs (down debris) in this study were defined as pieces leaning at an angle less than 45 degrees from the forest floor, ≥ 10 cm diameter—measured at the small end for pieces within the fixed-area plots or at the point of intersection for pieces measured with the line transect method—and at least 2 m long. Only pieces within 2 m of the forest floor were sampled. Diameter, directional orientation (large to small end), and distance from the start of the line segment were measured for all logs. Diameters of logs on the fixed-area plots were taken at three points: large end, mid-length, and small end. Diameters of logs recorded with the line transect method were measured at the point of intersection.

Some logs had decayed to the point where they were difficult to find, especially in areas of dense down debris, and therefore were extremely hard to quantify. For consistency, highly-decayed pieces were included in this study if they were above the plane of the ground surface, had no vegetation growing on them, and met the minimum log diameter and length criteria.

Measurements were collected for standing pieces (snags) if at least half of the area of the snag base fell within the 20 X 50-m belt. Snags were defined as pieces ≥ 10 cm diameter breast height (DBH), at least 2 m tall, and at an angle 45 degrees or greater from the forest floor. Distance from the start of the belt, measured perpendicular to the centerline of the belt, was recorded for each piece. Snags were the only component sampled using the belt transects.

Analysis

Logs and snags within the 0.25-ha fixed-area plot were mapped and measured. The volume of logs on each plot was calculated using Newton's formula (Avery and Burkhart 1983) and converted to a per-ha basis. Fixed-area volume was compared against the volume estimated by two perpendicular 50-m line segments run through the center of the fixed-area plot. Comparison of the measured, fixed-area volume and estimated, line-transect volume was made with t-tests and ordinary least squares (OLS) regression.

The volume of down woody debris on each 50-m line was estimated with the equation proposed by Van Wagner (1968):

$$v = \frac{\pi^2 \sum_{i=1}^{n} d_i^2}{8L} \qquad (1)$$

in which d is diameter in cm, measured perpendicular to the length of the log, n is the number of individuals encountered, L is the length of line in meters, and v is the volume of down debris (m^3/ha).

Ordinary least squares analysis of fixed-area volume and line transect volume was accomplished by simultaneously testing that the intercept was equal to zero and the slope of the relationship was equal to one (Draper and Smith 1981). To test this hypothesis the Q-statistic was computed using:

$$Q = (\beta - b)'\, x'\, x(\beta - b) \qquad (2)$$

in which β_0 and β_1 are the hypothesized population parameters (vector), b_1 and b_2 are the regression parameters (vector), and x′x is the matrix term of the independent variable (in this case the line-transect estimated volumes). The null hypothesis was rejected if the test statistic was greater than the critical value calculated with:

$$ps^2 F(p, v, 1-\alpha) \qquad (3)$$

in which p equals the regression degrees of freedom, s^2 is the variance, and the F-value is from the appropriate F-statistic table.

Two popular tests were used to describe the pattern of piece distribution on the forest floor and the orientational distribution of logs. The first test used the variance:mean ratio (V/M test) as an indicator of spatial pattern. The second test, which will be referred to as the distribution test, compared the pooled frequency distribution against the frequency that would be expected given the Poisson and negative binomial distributions. The distribution test was used to identify orientational clumping.

Random piece distribution is an assumption of the line-transect method and was tested here with the V/M test. Each 250-m east-west and north-south line was divided into 10-m, 25-m, and 50-m segments, which resulted in a total of six tests per sampling area (two lines, three tests each). Snag distribution was also studied with the V/M test at the same three scales, within the belt transects. Tests were conducted at three segment lengths because clumps may appear at different scales. The segment lengths were chosen to be as long as possible while still allowing a sufficient sample size.

To test the spatial distribution of down pieces and snags with the V/M test (Ludwig and Reynolds 1988), the variance was calculated with the formula:

$$s^2 = \frac{\left(\sum_{x=0}^{k} \left(x^2 Fx \right) - \bar{x}n \right)}{N-1} \tag{4}$$

in which k is the greatest frequency per sampling unit, x is the frequency class, Fx is the count in the x frequency class, n is the number of individuals, and N is the number of sampling units.

The chi-square test was used to check if the variance:mean ratio was significantly different from 1, where a value < 1 suggests uniform distribution and a value > 1 suggests clumped distribution. A random pattern is assumed when the variance:mean ratio is equal to 1. The snag data for three of the sampling areas were dropped from this analysis due to incomplete data.

It is important to note that the tests of log distribution using the line transect data were actually identifying the pattern of log crossings in one dimension, not in two dimensions on the forest floor. It is unclear whether the pattern identified by the V/M Test is indicative of the pattern of log distribution on the forest floor.

The distribution test was used to check for random directional orientation of logs. Logs were assigned to 1 of 36 classes by 10-degree increments and pooled by frequency. Pooling followed the recommendation of Ludwig and Reynolds (1988): when the number of frequency classes is less than five, the expected number in each class is not to be less than five; if the number of classes is five or greater, then the expected number is not to be less than three. Then the frequency distribution of the pooled data was tested against the Poisson and negative binomial distributions of expected counts using the chi-square test. On two of the sampling areas, counts within each frequency class were pooled to three individuals per class instead of the five per class recommended by Ludwig and Reynolds (1988) because of the low number of down pieces. The data for one sampling area were not analyzed for orientation due to degrees of freedom limitations.

Two hypotheses were tested with the distribution test: the frequency distribution followed the Poisson distribution (random distribution); the frequency distribution followed the negative binomial distribution (clumped distribution). Rejecting the first hypothesis and failing to reject the second implied a clumped pattern.

The paired quadrat variance (PQV) technique (Ludwig and Reynolds 1988) was used to identify any consistent clumping scale. A peak in the graph of variance vs. quadrat spacing indicated clumps occurring at about twice the quadrat spacing (block) distance. To accomplish the test, a 5-m line segment was chosen to serve as a "quadrat" and the variance was calculated using the equation:

(5)

$$\operatorname{var}(x_s) = [\frac{1}{N-S}]\{[0.5(x_1 - x_{1+s})^2] + [0.5(x_{1+s} - x_{(1+s)+s})^2] + \ldots + [0.5(x_{N-s} - x_N)^2]\}$$

in which S is the spacing (in m) between quadrats, s is the quadrat sequence number, N is the number of quadrats, and x is the piece count in the quadrat. The variance was calculated to a block spacing of N/2 for each north-south and each east-west line in the study. Ludwig and Reynolds (1988) suggest using N/10 as the maximum quadrat spacing; however, N/2 was used to extend the analysis to a larger area. This may have resulted in some unreliable variance estimates at the larger quadrat spacings. By convention, an error level of $p = 0.05$ was used throughout this study.

Results and Discussion

Fixed-Area/Line Transect Volume Comparison

The accuracy of the line-transect method was tested with t-tests and OLS regression on the 0.25-ha fixed-area plots. T-tests indicated that there was no significant difference between the mean volume estimated by two 50-m line segments and the volume measured on the fixed-area plots using Newton's formula, except on sampling area 221 *(table 1).* Down pieces were not measured with the line-transect method on sampling area 221; thus, the result may be an indication of the estimating power of the line-transect method on lightly loaded areas. Brown (1974) and Pickford and Hazard (1978) note that coefficient of variation decreases as sample size increases, and they suggest counting at least 25 pieces for dependable results.

Table 1—*T-test results of total fixed-area volume compared against the mean volume estimated with two perpendicular 50-m lines found no significant differences, except on sampling area 221 where no pieces were measured using the line transect method.*

Plot	F/A[1] vol.	L/T[1] vol.	L/T std. dev.	t	p(t)
	-----------------------	m^3/ha	-------------------		
001	14.91	33.23	4.26	6.08	0.10
002	134.52	139.83	77.78	0.09	0.94
221	7.74	0.0	0.0	-	-
248	277.47	294.18	11.71	2.01	0.29
280	33.08	24.88	3.19	3.63	0.17

[1] F/A = fixed-area; L/T = line transect

Ordinary least squares regression of two, 50-m line segments and fixed-area volumes resulted in a significant (F = 368.76; p = (368.76) = 0.0003) and highly correlated (r^2 = 0.99) relationship *(fig. 3)*. However, the Q-statistic was greater than the critical value (62895.66 > 1093.12), which indicated that β_0 was significantly different from 0 and/or β_1 was significantly different than 1. Because of the small sample size, inconsistent t-test and Q-test results, and inconsistent tests of the underlying assumptions of the line transect method, the ability of the line-transect method to estimate down volume was not determined.

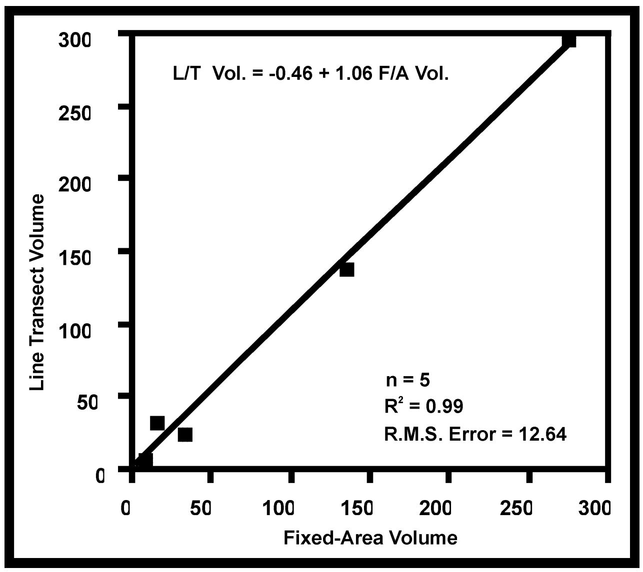

Figure 3—Ordinary least squares regression results of volume estimated with two perpendicular 50-m line segments vs. the actual volume measured on a 0.25-ha fixed-area plot.

Log Distribution

The V/M test was used to identify the spatial distribution of logs on the forest floor *(table 2)*. Of 78 tests performed on the line-transect data, 18 (23 percent) tested as having a clumped log distribution. The remaining 60 (77 percent) tested as having a random distribution. No lines were found to have a uniform distribution of logs.

Table 2—*Log distribution indicated by the V/M Test indicated a generally random pattern at the three scales tested.*

	Scale		
Pattern	**10 m**	**25 m**	**50 m**
	---------------------Number of sampling areas-------		
Uniform	0	0	0
Random	20	22	18
Clumped	6	4	8

In some cases the log distribution pattern changed with the scale of the test data. Six of the 13 sampling areas had at least one test indicating a clumped distribution. One sampling area had five of the six tests indicate a clumped distribution. Every sampling area had at least one test that indicated a random pattern. Six sampling areas did not test for a clumped pattern at any scale. An identifiable relationship was not found between the number of individuals, whole line or per segment, and clumped pattern. A relationship was not found between segment length (scale) and clumped pattern.

On sampling areas in the youngest stand (1873), the low number of logs may have led to unreliable estimates of the variance: mean ratio and thus the indicated pattern. For the remainder of the sites, however, the V/M method seemed to be appropriate.

Log Orientation

There was an obvious eastward directional bias when down pieces from all sampling areas were graphed together *(fig. 4)*. Log orientation data were tested separately for each sampling area. Only five sampling areas had pieces that followed the Poisson distribution. Log orientation followed the negative binomial distribution on 12 of the sampling areas (The low number of down pieces on one sampling area did not allow testing against the negative binomial distribution.) This indicated that in eight of 12 instances there was evidence of clumped log orientation.

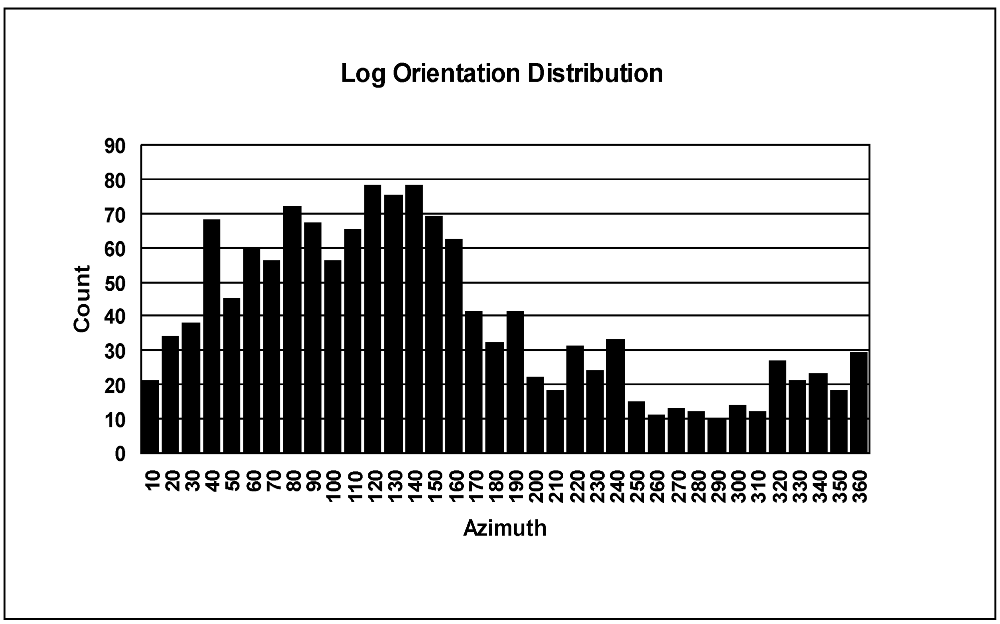

Figure 4—Log orientation of all sample pieces showed an obvious eastward bias.

Effects of Scale on CWD Estimates

The PQV model revealed little evidence of a consistent scale effect on CWD estimates. The graphs of variance vs. quadrat spacing for sampling areas 3 and 398 indicate peaks of variation at some block sizes, but whether these indicate clumps or simply the random distribution of logs is unclear *(fig. 5).* Results of the V/M test only confounded any analysis. There was no systematic pattern to the graphs of variance for any of the 13 sampling areas in this study.

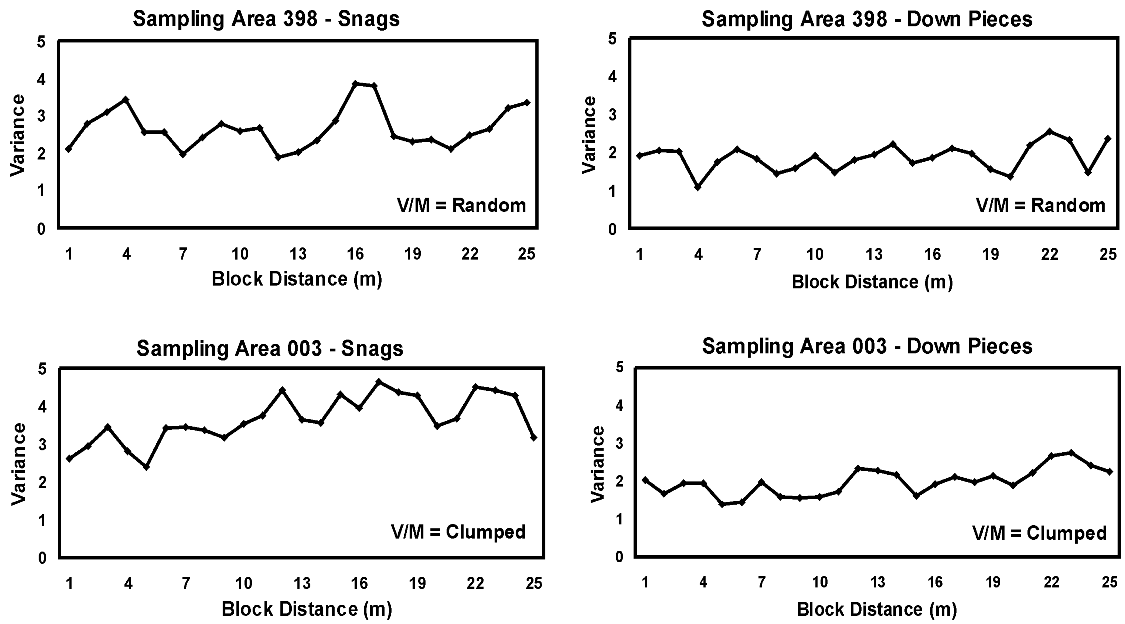

Figure 5—A consistent pattern of down or standing piece distribution was not identified using the paired quadrat variance method. Four examples of the original 46 graphs are presented here for the reader's examination.

Snag Distribution

Like logs, snags showed only moderate evidence of clumped distribution *(table 3).* Of 60 tests, 37 (62 percent) indicated snags were randomly distributed. Twenty-two (37 percent) indicated a clumped distribution of snags and one test indicated a uniform distribution. Six of the 20 belts were found to have a clumped distribution of snags at each of the three scales. Half of the belts were found to have clumped snags at at least one scale, and nine tests indicated snags were distributed randomly at every scale. Only one sampling area tested as having a clumped distribution on both lines at every scale. A relationship was not found between the number of individuals and the distribution suggested by the V/M test. An identifiable relationship was not found between scale and distribution.

Table 3—*Snag distribution indicated by the V/M test indicated a generally random pattern at the three scales tested.*

	Scale		
Pattern	**10 m**	**25 m**	**50 m**
	------------Number of sampling areas-------		
Uniform	0	1	0
Random	12	12	13
Clumped	8	7	7

Conclusion

The accuracy of the line transect method could not be determined in this study for two reasons: inconsistent test results indicated that two important assumptions of the line transect method, random spatial and orientational distribution, could not be guaranteed; and the sample size was quite small (n = 5).

The bias introduced by not meeting the assumptions of the line transect method was probably small, however. First, the sampling scheme used in this study (perpendicular lines) should have substantially reduced any bias introduced by clumped log orientation (Howard and Ward 1972). Secondly, because log distribution was found to be generally random at the scales tested in this study (10-m, 25-m and 50-m) there was likely little bias introduced by clumped pieces.

Most tests of log and snag distribution indicated a random pattern. Because tree regeneration and mortality are generally assumed to occur in aggregated patterns (Franklin and others 1987, Harmon and others 1986, Lundquist 1995, Maser and others 1988), the results from this study were somewhat surprising. However, lodgepole pine tends to regenerate in a relatively uniform manner (Fischer and Bradley 1987) with tree mortality and log accumulation possibly following that pattern. Lodgepole pine comprised some or all of the tree cover on the sampling areas in this study, which may explain finding mostly random patterns. Also, the scale of sampling may have had an effect on the results because the line segment and quadrat sizes tested for log and snag distributions were quite small.

The eastward bias of down pieces was likely not due to logs moving to new orientations after they fell, since the sampling areas had no or little slope (less than 15 percent). Also, pieces were probably not greatly affected by wind events exacerbated by local geography (ridge-tops, canyons, etc.) but simply fell away from the prevailing westerly winds.

The usefulness of the PQV method was not demonstrated here theoretically due to the relatively small quadrat distance tested. The method may prove useful for variance and block size relationships over a larger area—1 or 2 ha for example. However, the potential effects of disturbance, ridge-tops, differing stand ages, steep slopes, and changing aspects on the pattern of piece distribution must be considered.

Acknowledgments

This project was funded by the USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana. I would like to thank Colin Hardy, Elizabeth Reinhardt, Carl Fiedler, John Chmelik, and Bill Laudenslayer for numerous useful review comments.

References

Avery, E. A.; Burkhart, H. E. 1983. **Forest measurements**. New York: McGraw-Hill; 331 p.

Barrett, S. W. 1993. **Fire history of the Tenderfoot Creek Experimental Forest, Lewis and Clark National Forest.** RJVA INT-92679 on file with RM-RWU-4151, Bozeman, MT; 19 p.

Brown, J. K. 1974. **Handbook for inventorying downed woody material**. Gen. Tech. Rep. INT-16. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 24 p.

Draper, N. R.; Smith, H. 1981. **Applied regression analysis,** 2d edition. New York: J. Wiley and Sons; 709 p.

Fischer, W. C.; Bradley, A. F. 1987. **Fire ecology of western Montana forest habitat types.** Gen. Tech. Rep. INT-223 Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 95 p.

Franklin, J. F.; Shugart, H. H.; Harmon, M. E. 1987. **Tree death as an ecological process.** BioScience 37: 550-556.

Harmon, M. E.; Franklin, J. F.; Swanson, F. J.; Sollins, P.; Gregory, S. V.; Lattin, J. D.; Anderson, N. H.; Cline, S. P.; Aumen, N. G.; Sedell, J. R.; Lienkaemper, G.W.; Cromack, K.; Cummins, K. W. 1986. **Ecology of coarse woody debris in temperate ecosystems.** Advances in Ecological Research 15: 133-302.

Howard, J. O.; Ward, F. R. 1972. **Measurement of logging residue—alternative applications of the line transect method.** Res. Note PNW- 183. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 8 p.

Ludwig, J.; Reynolds, J. F. 1988. **Statistical ecology**: **primer on methods**. New York: J. Wiley and Sons; 406 p.

Lundquist, J. E. 1995. **Pest interactions and canopy gaps in ponderosa pine stands in the Black Hills, South Dakota, USA.** Forest Ecology and Management 74: 37-48.

Maser, C.; Anderson, R. G.; Cromack, K.; Williams, J. T.; Martin, R. E. 1979 **Dead and down woody material.** In: Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture; 78-95.

Maser, C.; Tarrant, R. F.; Trappe, J. M.; Franklin, J. F. 1988. **From the forest to the sea: a story of fallen trees.** Gen. Tech. Rep. PNW-GTR-229. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 153 p.

Pickford, S. G.; Hazard, J. W. 1978. **Simulation studies on line intersect sampling of forest residue.** Forest Science 24: 469-483.

Van Wagner, C. E. 1968. **The line intersect method in forest fuel sampling**. Forest Science 14: 20-26.

Warren, W. G.: Olsen, P. F. 1964. **A line intersect technique for assessing logging waste.** Forest Science 10: 267-276.