FINAL REPORT FOR RESEARCH AGREEMENT
#INT-97083-RJVA
"Assessment of Coarse Woody Debris in Lodgepole Pine Forests of Tenderfoot Experimental Forest"
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Methods for the Quantification of Coarse Woody Debris and an Examination of its Spatial Patterning: A study from the Tenderfoot Creek Experimental Forest, MT

Completion Report
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ABSTRACT

Methods for the quantification of coarse woody debris volume and the description of spatial patterning were studied in the Tenderfoot Creek Experimental Forest, Montana. The line transect method was found to be an accurate, unbiased estimator of down debris volume (>10cm diameter) on 1/4 hectare fixed-area plots, when perpendicular lines were used. The Fischer Photo Guide (1981) for woody fuels did not quantify large down debris as precisely as the line transect method on 1/4 hectare plots. Chi-square tests found that down debris had a clumped spatial distribution in 23% of the tests. Pieces were found randomly distributed in the remaining 77% of the tests. Tests of log orientation showed evidence of clumping in 8 of 13 tests. The Paired Quadrat Variance method found no consistent scale of clumping in 24 plots of variance. Snags were found to have a clumped distribution in 37% of the tests, a random distribution in 62% of the tests and one test indicated a uniform distribution. The Variable Area Transect method accurately described snag density, however it was not successful at determining down piece density possibly because the transect width was too narrow.

INTRODUCTION

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

Its highly variable nature makes quantification difficult, so precise studies require intense effort. Through careful analysis of a number of characteristics it may be possible to identify a system which will allow precise CWD estimates in less time and in an unbiased manner.

A number of researchers have used the line intersect method for quantifying down debris (Brown 1974, Howard and Ward 1972, Van Wagner 1968, Warren and Olsen 1964). Most studies assume the accuracy of the line transect method when quantifying down debris. No studies were found that compared volume measured in a fixed area and 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: 1) random piece orientation and 2) random piece distribution, spatially.

Correcting for nonrandom piece orientation requires additional measurement effort in the form of additional lines or a mathematical correction. Discovering a random distribution may reduce the number of line segments, and thus the effort, required to reach some desired precision.

The Fischer Photo Guide consists of a series of photos which represent a number of fuel loadings. However, no studies were found that compared line transect and Fischer Photo Guide (1981) estimates of down debris in the natural environment. If the Guide allows accurate and precise estimates down debris volume then the Guide may lead to more efficient estimates of down debris.

If pieces are found to be spatially clumped at some consistent scale on the forest floor the identification of that scale can be used to reduce or eliminate the bias introduced by nonrandom spatial distribution.

The objectives of this study were to: 1) compare down debris volume on fixed-area plots against estimates of down debris made with the line transect method on the same area, 2) Compare the line transect method and Fischer Photo Guide (1981) for their ability to estimate large down debris, 3) compare line transect estimated volume at two scales - 100 meters of line representing down debris on a 0.25 hectare area and 500 meters of line estimating volume on a 6.25 hectare area, 4) test two assumptions of the line transect method - that pieces are distributed randomly in their orientation and spatially on the forest floor, 5) examine the scale of clumping of down and standing pieces and 6) explore the efficiency and reliability of a contagion independent plotless density estimator for estimating down and standing CWD.

METHODS

Study Site

This study was conducted in the Tenderfoot Creek Experimental Forest (TCEF) in central Montana (Figure 1). The forest extends from approximately 1900 to 2400 meters and covers an area just less than 3700 hectares. Precipitation averages 88.4 centimeters annually, 52% of that falls from October to March. Mean daily temperature is -7.5 degrees Celsius, October to March and 8.3 degrees April to September. Lodgepole pine (*Pinus contorta*) is the predominant cover type with scattered patches of subalpine fir (*Abies lasiocarpa*) predominating older stands.

Five stands were chosen from a fire history map of the TCEF (Barrett 1993). These stands had last burned in 1873, 1845, 1765 and 1726 and the fifth stand had burned in 1845 and 1873 (two-burn stand) (Table 1). 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, they had a wide variety of sizes and load of CWD and were on sites with relatively little slope.

Field Sampling

Three sampling areas were established in each stand, except in the two-burn stand which only had one sampling site - for a total of 13 sampling areas. Each sampling area included; 10, 50 meter line segments and 10, 50 X 20 meter belt transects (Figure 2). The line segments were oriented in the four cardinal directions and the belt transects were run in conjunction with the line segments. Additionally, 50 X 50 meter fixed-area plots were established on sampling areas 1, 2, 221, 248 and 280. The primary purpose of the fixed-area plots was to provide a "truth" to check the accuracy of line transect estimates of down debris.

In this study the line transect information was used for the comparison of fixed-area volume and line transect estimated volume, comparison of line transect and Fischer Photo Guide estimates of down debris, comparison of volume estimated with 100 meters and 500 meters of line and identifying the pattern of log distribution. Perpendicular lines were used to eliminate any bias added by non-randomly distributed pieces (Bailey 1969, Howard and Ward 1972). Estimated volumes are the mean of north-south and east-west oriented segments.

Logs in this study were defined as pieces leaning at an angle less than 45 degrees from the forest floor, 10 centimeters and larger in diameter, measured at the small end for pieces in the fixed-area plots or at the point of intersection for pieces measured with the line transect method, and at least 2 meters long. Pieces crossing the line greater than 2 meters above the floor were not included. Diameter, directional orientation (large to small end) and distance from the start of the line segment were measured for all logs in this study. Diameters of logs on the fixed-area plots were taken at three points, large end, mid-length and small end. Diameter of logs recorded with the line transect method were measured at the point of line crossing or the mid-length point of the log. Mid-length measurement reduces variation in estimated volume on lightly loaded sites but adds time as one has to locate the mid-point of each piece (Van Wagner and Wilson 1976).

Well decayed logs were extremely hard to quantify. They had decayed to that point where they were difficult to find, especially in areas of dense down debris. When pieces were found one was almost guessing at piece length and diameter. For consistency I included well decayed pieces in this study if they were above the general level of the adjacent ground and had no vegetation growing on them. Measurements were made on the portions of the log that met this and minimum log diameter and length criteria.

Snag measurements were collected for those pieces where at least half of the area of the snag base fell within the 20 X 50 meter plot. Pieces 10 centimeters and greater diameter breast height (DBH), at least 2 meters tall and at an angle 45 degrees or greater from the forest floor, were defined as snags. Distance from the start of the belt, measured perpendicular to the center line of the belt, was recorded for each piece.

Analysis

Logs and snags within the ¼ hectare fixed-area plot were mapped and measured. The volume of logs on each plot was calculated with Newton's formula and the volume converted to a per hectare basis. This volume was compared with the volume estimated by two, perpendicular 50 meter line segments run through the center of the fixed-area plot. Comparison of the fixed-area and line transect volumes was made with one sample t-tests. T-tests were used to identify significant differences in the mean volume estimated with the Fischer Photo Guide and the 2, 50 meter line segments, and for identifying significant differences in volume estimated by the 2, 50 meter and the 10, 50 meter line segments. The second set of tests constitutes a comparison of estimated down debris on a 0.25 hectare (50 X 50 meter) site vs. a 6.25 hectare (250 X 250 meter) site. Insignificant differences may indicate the adequacy of estimating down debris on a large area with less total line transect data.

Because there was no volume measured with the 2, 50 meter lines on sampling area 221 no t-tests were included that required the 2, 50 meter line estimate of volume.

The volume of down woody debris on each 50 meter line is estimated with the equation proposed by Van Wagner (1964):

[1] $$V = \pi^2 \sum_{i=1}^{n} d^2 / 8\, l$$

where d is diameter, perpendicular to the length of the log, in centimeters,

n is the number of individuals encountered,

l is the length of line in meters and

V is the log volume (m^3/ha).

Two popular tests were investigated to describe the pattern of piece distribution on the forest floor and the orientational distribution of logs. When using the first test, which I will call the Distribution Test, one compares the pooled frequency distribution against the Poisson and Negative Binomial distributions. The second test uses the variance:mean ratio (V/M Test) as an indicator of pattern.

Random piece distribution is an assumption of the line transect system and was tested here with the V/M Test. Each 250 meter east-west and north-south line was divided into 10 meter, 25 meter and 50 meter segments which resulted in a total of six tests per sampling area (2 lines, 3 tests each). Three segment lengths were chosen because clumps appear at different scales so the discovery of a clumped distribution is related to the size of the area tested. Snag distribution was also studied with the V/M test at the same three scales.

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

[2] $$s^2 = \left(\sum_{x=0}^{k} (x^2\,Fx) - \overline{x}\,n\right) / N - 1$$

Where k is the 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,

N is the number of sampling units.

If a pattern is random then the variance and mean are equal. The chi-square test is used to check for significant differences of the variance:mean ratio from one - less than one suggesting uniform distribution, more than one suggesting clumped distribution. The snag data for sampling areas 2, 248 and 280 were dropped from this analysis due to missing measurements. (The chi-square test of fit was used extensively in this study. For a thorough review of testing with the chi-square statistic see Ludwig and Reynolds 1988, Pielou 1977 or Kershaw 1973.)

The Distribution Test was used to check for random log directional orientation. Logs were assigned to 1 of 36 groups by 10 degree class 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 should not be less than three. Then the frequency distribution of the pooled data was tested against the Poisson and Negative Binomial distribution of expected counts with the chi-square test of fit. On sampling areas 1 and 192, 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 sampling area 221 was not analyzed in this test due to degrees of freedom limitations.

Two hypothesis were tested when using the Distribution Test. First, that the frequency distribution follows the Poisson distribution (random distribution). Second, that the frequency distribution follows the Negative Binomial distribution (clumped distribution). Rejecting the first hypothesis and failing to reject the second implies a clumped pattern.

If the distribution of individuals is clumped, spatial pattern analysis may be of assistance in describing the scale of the clumping. The Paired Quadrat Variance (PQV) technique (Ludwig and Reynolds 1988) was used to examine clumping scale in this study. To accomplish this I chose a 5 meter line segment to serve as a "quadrat". Then using the variance equation:

$$var(x_s)=[1/N-S]\{[0.5(x_1-x_{1+s})^2]+[0.5(x_{1+s}-x_{(1+s)+s})^2]+\ldots+[0.5(x_{N-s}-x_N)^2]\} \quad [3]$$

where S is the spacing between quadrats, in meters,

s is the quadrat sequence number,

N is the number of quadrats and

x is the piece count in the quadrat,

the variance up to N/2 block spacing was calculated for each north-south and each east-west line in the study. A peak in the graph of variance vs. quadrat spacing may indicate clumps occurring at about twice the quadrat spacing distance.

Ludwig and Reynolds (1988) suggest using N/10 as the maximum quadrat spacing however in this study I used N/2 to extend the analysis to a larger area. This may have resulted in some unreliable variance estimates at the larger quadrat spacings.

Accurately estimating the density of clumped pieces can be difficult and time consuming. The Variable Area Transect (VAT) method (Parker 1979) has been shown in Monte Carlo tests to be an unbiased estimator of density regardless of the pattern of the individuals being assessed (Engeman, et al. 1994). It was investigated here to identify its performance in natural conditions. Logs were studied on three sampling areas with 50 X 2 meter belts, snags on 12 sampling areas, with 50 X 20 meter belts. Density is calculated with the formula:

[4] $$\hat{\lambda} = (3n - 1) / w \sum_{i=1}^{n} l_i$$

where w is the width of the transect in meters,

n is the number of third individuals encountered,

l is the distance measured to the third individual, in meters.

Variance of the VAT density measurements is:

[5] $$\text{var}\,\hat{\lambda} = \hat{\lambda}^2 / (3n - 2)$$

where n is the number of third individuals measured.

By convention an error level of p=0.05 was used throughout this study otherwise noted.

RESULTS AND DISCUSSION

Fixed-Area / Fischer Photo Guide / Line Transect Volume Comparison

The accuracy of the line transect method was tested with t-tests and ordinary least squares (OLS) regression, on the ¼ hectare fixed-area plots. T-test results are listed in Table 2 and the OLS results in Figure 3. No significant differences were found between the mean volume estimated by 2, 50 meter line segments and the volume measured on the fixed-area plots with Newton's formula. Regression of 2, 50 meter line segment and fixed-area volumes resulted in a significant relationship (F=368.76 P(368.76)=0.0003). The coefficient on the independent variable was equal to one and the intercept coefficient was insignificant. These two tests indicated that the line transect method was an accurate, unbiased estimator of down debris on ¼ hectare plots.

Comparison of volumes estimated with the Fischer Photo Guide and 2, 50 meter line segments were made with t-tests (Table 3). Four of 13 tests found significant differences in the estimated mean volume. In 12 of 13 instances the standard deviation was higher when using the Fischer Photo Guide. There was evidence that the Fischer Photo Guide estimates of large down debris were not as precise as those made with 2, 50 meter line segments and in four cases the estimates were not accurate.

A perceived benefit of the Photo Guide was the opportunity to make quicker estimates of down debris. However in some cases the time required by field assistants to choose the appropriate photo from the guide would have allowed actually measuring down debris on 2, 50 meter line segments. This was especially true on lightly to moderately loaded sites. Field assistants were also frustrated with the photo guide on some sites because they had difficulty finding the "right" photo, either having too many choices or too few. The photo guide is designed for estimation of a number fuels sizes and other, fire related, site characteristics so finding that it did not work well in this study is not necessarily a failure of the guide but possibly an indication of its improper application in this study.

No significant differences in volume were noted between the 2, 50 meter and 10, 50 meter line segments (Table 4). This was strong evidence that down debris volume on an area of 6.25 hectares may be reliably estimated with 100 total meters of line. Since the volume estimated with each length of line - 100 and 500 meters - was equal then it suggested that down pieces were not clumped at those scales, or that any bias introduced by clumping was minimal. However no tests for clumping at this scale were done in this study.

Log Distribution

The V/M Test was used to identify the distribution of logs on the forest floor (Table 5). Of 78 tests performed on the log line transect data, 18 (23%) tested as having a clumped distribution. The remainder, 60 (77%), tested as having a random distribution. No lines were found to have a uniform distribution of logs.

In some cases the log distribution pattern changed with scale of the tested data. Six of the 13 sites tested had at least one test indicating a clumped distribution. The greatest was sampling area 370, which had five of the six tests indicate a clumped distribution. Every site had at least one test which indicated a random pattern. Sampling areas 1, 192, 221, 5, 247 and 398 did not test for a clumped pattern at any scale. No identifiable relationship was found between the number of individuals, whole line or per segment, and clumped pattern. No relationship was 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.

Random Log Orientation

There was an obvious eastward directional bias of down pieces (Figure 4) and most of the study sites had a clumped orientational distribution. Only five sampling areas had pieces that followed the Poisson distribution. Log distribution followed the Negative Binomial distribution on all 12 of the sampling areas. This indicates that in eight of 12 instances there is evidence of clumped log orientation (Table 6).

Effects of Scale on CWD Estimates

The PQV model revealed little evidence of a scale effect on CWD estimates (Figure 5). 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 in unclear. The results of the V/M Test only confound any analysis. There was no systematic pattern to the graphs of variance for any of the 13 sampling areas in this study. These four a presented for the reader's examination.

Snag Distribution

Like logs, snags showed little evidence of clumped distribution (Table 7). Of 60 tests, 37, or 62% were judged as having randomly distributed. Twenty-two, or 37% had a clumped distribution of snags and one was found to be uniform. 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 least one scale and nine belts tested had a random distribution at every scale. Only sampling area 5 tested for a clumped distribution on both lines at every scale. There was no relationship found between the number of individuals and the distribution suggested by the V/M Test. No identifiable relationship was found between scale and distribution.

Variable Area Transect Density Estimates

The VAT method was used to calculate a pattern independent density for each 50 X 20 meter belt segment in the study. Comparisons of the VAT and belt transect snag densities imply that the VAT method works well as a density estimator regardless of pattern (Table 8).

The VAT method was used to estimate log density with a 50 X 2 meter belt, on the five sampling areas that included fixed-area plots on the site. The belt width was considered too narrow to allow an adequate number of logs to be tallied and, thus, gave inaccurate results (Table 9). It is probable that wider belts would improve the density estimates of logs. Estimating log density was time consuming because the mid-length point had to be identified and then judged whether that point was inside the belt transect. Wide transects only compound this problem requiring more measurements. Judging from the results in this study, log density may best be measured on fixed-area plots.

CONCLUSION

When the possibility of a clumped distribution is taken into account, the line transect method was found to be an unbiased estimator of down debris on ¼ hectare plots.

The Fischer Photo Guide allows estimates of a wide range of debris sizes. In this study it was found to estimate down debris volume with less precision than the line transect method with only a small improvement in field efficiency. This should not necessarily be considered a shortcoming of the Guide in general but of its use for estimating large down debris.

No tests found significant differences in the volume of down debris estimated by 100 meters of line transect (2, 50 meter lines) and the amount estimated with 500 meters of line (10, 50 meter segments). This is strong evidence that 100 meters of line transect is not an acceptable estimator of down debris over a larger area.

Both the distribution and orientation tests indicate some element of non-randomness. Careful choice of line length can reduce any bias introduced by clumped distribution. Because there was no significant relationship found between the line lengths tested in this study and the indicated pattern it is assumed that there was little bias introduced by clumped pieces. Any bias introduced by clumped log orientation can be substantially reduced by designing a sampling scheme that takes this characteristic into account (e.g. perpendicular lines).

Most tests of log and snag distribution indicated a random pattern. Tree regeneration and mortality are generally assumed to occur in aggregated pattern (Harmon et al. 1986, Franklin et al. 1987, Maser et al. 1988, Lundquist 1994) so the results from this study are somewhat surprising. Lodgepole pine tends to regenerate in a relatively uniform manner (Fischer and Bradley 1987) with mortality and log accumulation assumed to follow that pattern. Since most plots were in predominantly lodgepole pine stands this may explain generally finding random patterns. Also, the scale of study may have had an effect on the results because the sizes tested for distribution were quite small.

The eastward bias of down pieces is interesting. Because the sampling areas had no or little slope (less than 15 percent) pieces probably are not moving to new orientations after they fall. Wind is likely the major factor effecting directional orientation. Most snags are broken or uprooted when the wind is from the west.

The usefulness of the PQV method was not well represented here, theoretically due to the relatively small quadrat distance tested. It would be interesting to use the method to examine variance and block size relationships over a larger area, for example 1 km. Doing so may lead to confounding results, however, if the line crosses through areas were exogenous factors may cause changes in patterns of down debris e.g. ridgetops, differing stand ages, steep slopes and changing aspects.

The VAT method worked well for snag density estimations. Though poor results were reported in this study, it may be useful when used to describe the density of down pieces if belt widths are substantially greater than the 2 meter width used here.

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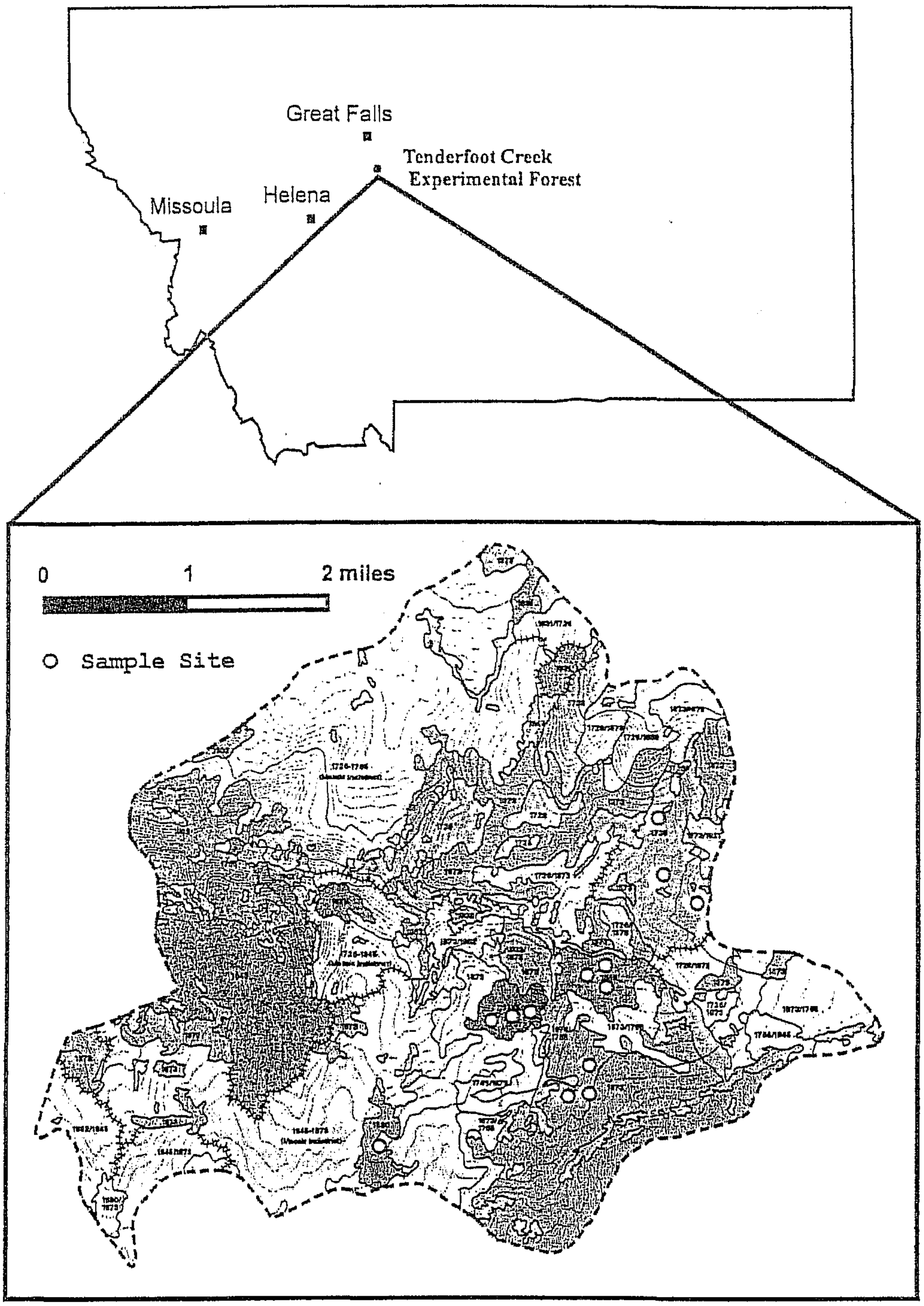


Figure 1. The Tenderfoot Creek Experimental Forest (3693ha) is located in the Little Belt Mountains of Montana. Elevation ranges from approximately 1900m to 2400m. Cover type is primarily lodgepole pine however small pockets of subalpine fir and Engelmann spruce are scattered throughout. The enlargement of the TCEF fire history map shows the locations of the 13 sample plots.

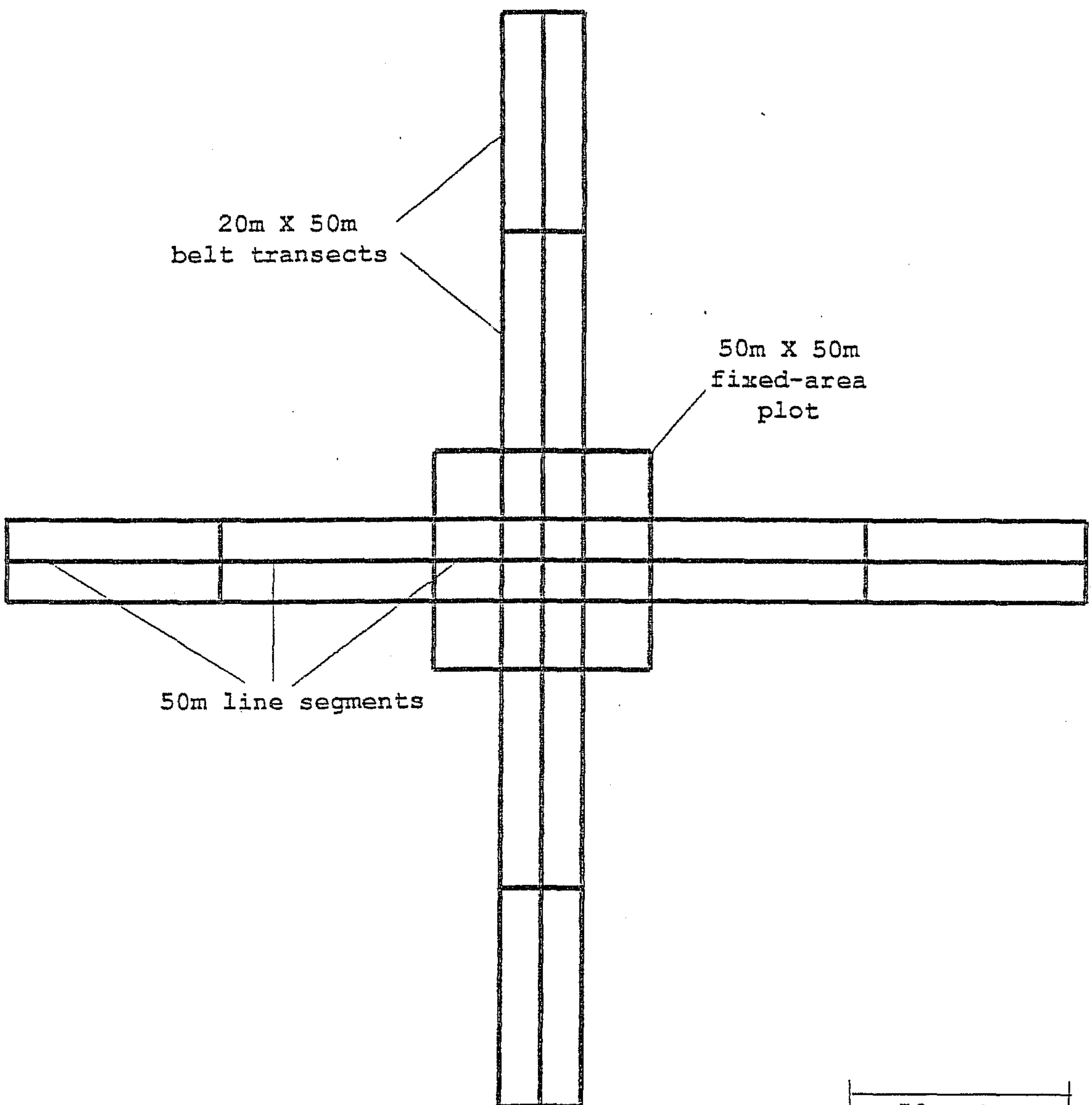
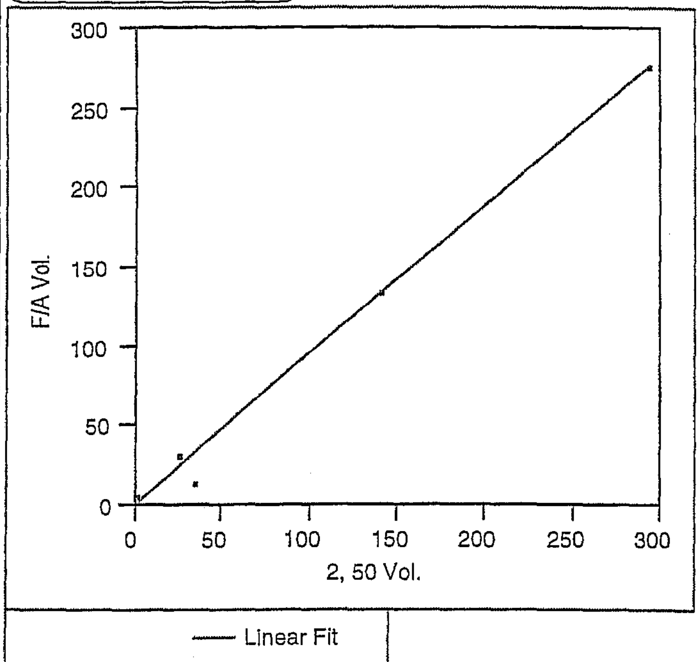


Figure 2. Each sampling area included 10, 50m line segments and 10, 20m X 50m belt transects. Five, 50m X 50m fixed-area plots were also included in the study to test the estimating ability of the line transect method.

F/A Vol. By 2, 50 Vol.



Linear Fit

F/A Vol. = 1.18885 + 0.93834 2, 50 Vol.

Summary of Fit

RSquare	0.99193
RSquare Adj	0.98924
Root Mean Square Error	11.9073
Mean of Response	93.544
Observations (or Sum Wgts)	5

H_0: $\beta=1$
H_1: Not H_0

t=1.26
P(1.26)<.20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	52283.982	52284.0	368.7582
Error	3	425.352	141.8	Prob>F
C Total	4	52709.334		0.0003

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.1888514	7.175447	0.17	0.8789
2, 50 Vol.	0.9383397	0.048864	19.20	0.0003

Figure 3. The volume estimated with 2, 50 meter line segments was regressed against the actual volume on each ¼ hectare fixed-area plot, with OLS. The relationship was significant and the coefficient of the independent variable was equal to one. The intercept coefficient was not significant. OLS results indicated that the line transect method accurately estimated large down debris on ¼ hectare plots.

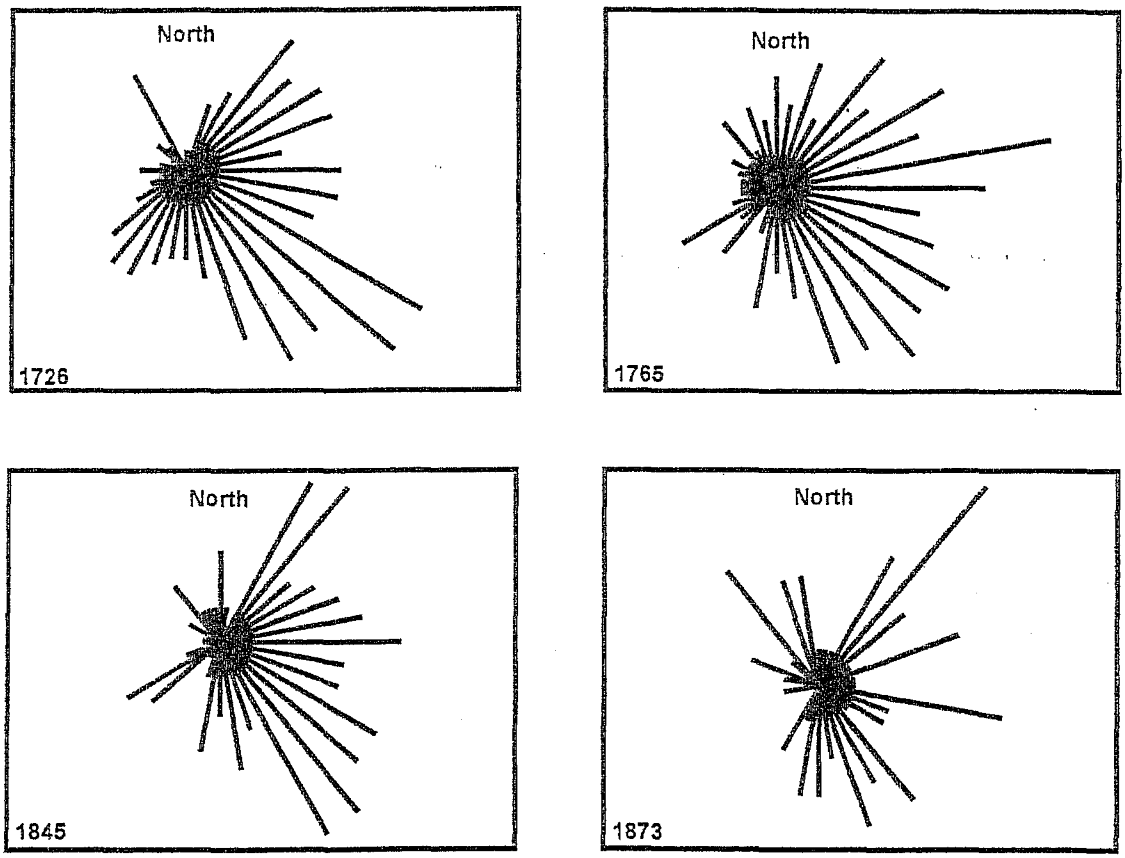


Figure 4. Windrose diagrams of the log orientation data indicate an obvious eastward bias. The Distribution Test was used to identify whether the pieces were randomly orientated or had a clumped distribution.

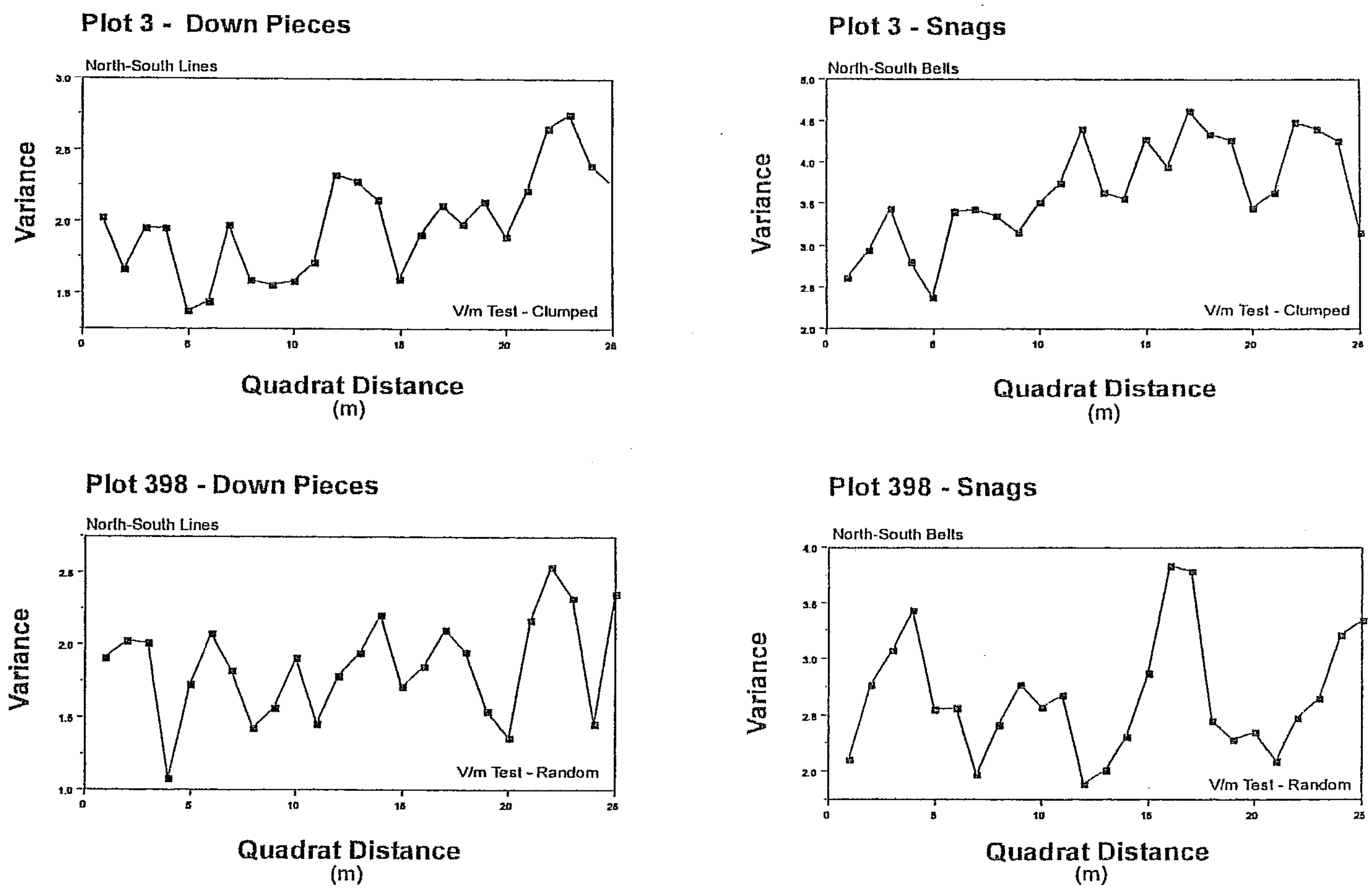


Figure 5. The PQV method was used to examine the distribution of down debris and snags. A comparison of PQV results within stand ages did not identify a common pattern of down debris. The method did not seem to support or contradict the results of the V/M test in a consistent way.

Table 1. Plot, stand age and elevation relationships of the 13 sampling areas.

Plot	Stand Age	Elevation (m)
1	1873	2284
2	1845 / 1873	2280
3	1726	2241
4	1845	2248
5	1765	2237
192	1873	2285
221	1873	2284
247	1765	2242
248	1765	2231
280	1845	2241
309	1845	2195
370	1726	2289
398	1726	2257

Table 2. T-tests of fixed-area down debris volume (m^3/ha) and the volume measured with 2, 50 meter line transects identified no significant differences in measured and estimated volume. This indicated that the line transect method was an accurate, unbiased estimator of down debris

Plot	F/A Vol.	2, 50 Vol.	2, 50 S.D.	t	P(t)
1	14.91	33.23	4.26	6.08	.10
2	134.52	139.83	77.78	.09	.94
221	7.74	0	0	-	-
248	277.47	294.18	11.71	2.01	.29
280	33.08	24.88	3.19	-3.63	.17

Table 3. T-tests of down debris volume estimated with 2, 50 meter line segments and four Fischer Photo Guide estimates found significant differences in volume on sampling areas 4, 221, 247 and 248. The standard deviation for the Fischer volume estimates was great than the line transect method in 12 of 13 instances. The Fischer Photo Guide was not as precise or accurate at estimating of down debris, when compared to the line transect method.

Plot	2, 50 Vol.	2, 50 S.D.	Fischer Vol.	Fischer S.D.	t	P(t)
1	33.23	4.26	20.49	13.57	1.23	.285
2	139.83	77.78	147.31	82.33	.107	.890
3	140.32	72.72	153.97	123.97	.139	.896
4	26.15	.07	109.08	16.10	6.87	.002
5	328.42	25.59	186.57	79.50	-2.94	.079
192	7.59	.61	18.94	18.58	.815	.461
221	0	0	14.52	3.62	5.36	.006
247	408.82	112.70	88.78	4.44	-6.54	.002
248	294.18	11.71	139.27	49.45	-4.14	.015
280	24.88	3.19	87.22	52.32	1.59	.188
309	19.70	12.47	18.52	18.85	.078	.941
370	45.03	20.87	135.31	108.15	1.11	.331
398	114.39	29.07	121.99	49.13	.727	.508

Table 4. No significant differences were found in t-tests of the volume (m^3/ha) estimated with 2, 50 line segments and 10, 50 meter line segments. This suggests that volume on the 6.25 hectare sites (250 X 250 meter area) may have been successfully estimated with 2, 50 meter segments.

Plot	2, 50 Vol.	2, 50 S.D.	10, 50 Vol.	10, 50 S.D.	t	P(t)
1	33.23	14.35	25.38	6.42	-.50	.63
2	139.83	77.78	125.99	46.39	-.56	.59
3	140.32	48.49	124.55	21.69	-.30	.77
4	26.15	9.67	29.68	4.33	.33	.75
5	328.42	43.58	317.62	19.49	-.23	.83
192	7.59	6.21	9.45	2.78	.28	.79
221	0	0	4.95	4.47	1.51	.16
247	408.82	69.67	383.10	31.16	-.34	.74
248	294.10	48.48	251.51	21.68	-.80	.44
280	24.88	13.97	26.91	6.25	.13	.90
309	19.71	14.64	26.33	6.55	.41	.69
370	45.03	35.82	87.91	16.02	1.09	.30
398	114.39	33.35	125.01	14.91	.29	.78

Table 5. The results of 78 V/M tests of log distribution indicate most plots had logs distributed in a random manner. Each line was tested at three scales; 10 meter, 25 meter and 50 meter line lengths.

	Scale		
Pattern	10m	25m	50m
Uniform	0	0	0
Random	20	22	18
Clumped	6	4	8

Table 6. The Distribution test was used to check for the existance of clumped log orientation. Log azimuth was divided into 36 classes and the frequency distribution was tested against the Poisson and Negative Binomial distributions. Rejecting hypothesis 1 and failing to reject hypothesis 2 indicates a clumped pattern of orientation exists.

Hypothesis 1

H_0 : Frequency distribution follows the Poisson Distribution.

H_1 : Not H_0

Hypothesis 2

H_0 : Frequency distribution follows the Negative Binomial Distribution.

H_1 : Not H_0

Line Transect

Plot	n	Hypo. 1	Hypo. 2
1	32	F	F[2]
2	112	R	F
3	122	R	F
4	82	F	F
5	256	F	F
192	30	F	F[2]
221	11	R	[1]
247	293	R	F
248	225	R	F
280	42	F	F
309	48	R	F
370	103	R	F
398	146	R	F

[1] Not enough df.
[2] Modified Pooling to allow enough df.
Note: F=Fail to Reject. R=Reject

Table 7. Results of 60 V/M tests of snag distribution indicate most plots had snags distribtued in a random manner. Each line was tested at three scales; 10m X 20m, 25m X 20m and 50m X 20m belt sizes.

	Scale		
Pattern	10m	25m	50m
Uniform	0	1	0
Random	12	12	13
Clumped	8	7	7

Table 8. The comparison of snag density (snags/ha) calculated with the VAT method and the 10, 20m X 50m belt transects (quadrats) found the VAT method to be an unbiased estimator of density.

Stand Age	VAT		Quadrat	
	$\bar{x}$	s^2	$\bar{x}$	s^2
1873	68	33	66	32
1845	179	80	162	70
1765	243	68	224	56
1726	221	28	223	26

Table 9. Comparison of log density (logs/ha) calculated with the VAT method and counted within the fixed-area plots. Narrow transect width limited the number of counted logs which caused large standard deviations. No logs were within the 2 meter wide belt transect on plots 192, 221 and 280. Wider transects may have allowed more reliable estimates.

Plot	VAT		Fixed-Area
	$\bar{x}$	s^2	
002	518	38332	112
248	520	39628	708

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