Draft Report

Decomposition Rates of Red and White Fir in the Klamath Ranger District, Winema National Forest, Oregon

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Summary

In this report we describe the decomposition rates of the two dominant species of true firs (*Abies concolor* (Gord. & Glend.) Lindl. and *Abies magnifica shastensis Lemm.*) occurring on the Winema National Forest. We employed the chronosequence method, dating fallen trees from fall scars, from living stumps, and known ages of logging and thinning slash. The decomposition of the two species true firs differed by 20%, with white fir and Shasta red fir having decomposition rate constants of 0.035 and 0.043 year^{-1}, respectively. These results are hypothesized to be caused by excessive drying at the lower elevations where white fir was most abundant. Regression of decomposition rate constants for individual sites versus elevatio indicated a very minor change with elevation, however, this trend was not statisitically significant. As the decay resistance of the two species of fir are quite similar, the differences between them are hypothesized to be due to environmental differences. However, the imprecision of the chrononsequence method and the fact white and Shasta red fir do not overlap over a sufficient elevation distance means that species versus environmental controls could not be separated. Application of the study results to estimating slash decomposition, the impact of silvicultural treatments, and potential steady-state stores is discussed.

INTRODUCTION

The management of large dead and down trees has become a recent concern in Pacific Northwest forests. Whereas the steps needed to reach past management objectives were easy to define (remove and dispose as much material as possible), achieving the current objective of retaining ecologically meaningful levels of dead wood has proven problematic. Although we know that dead wood is associated with many ecological benefits (plant and animal habitat, nutrient and water storage, soil formation) these benefits all vary with the species of log, environment, and volume of dead wood on a site (Franklin et al. 1987, Harmon et al. 1986, Triska and Cromack 1980). Moreover, maintaining dead wood levels is a dynamic process requiring long-term planning. This means management must move beyond the current static view that focuses on amounts remaining after timber harvest or salvage operations (Spies et al. 1988).

The key to managing dead wood dynamically is an understanding of the rate this material decomposes. Given this information one can plan the silvicultural and other practices required to supply the inputs needed to maintain dead wood at desired levels. Unfortunately decomposition rates have been determined for very few species. In the Pacific Northwest, for example, the main species that have been sampled are Douglas-fir and western hemlock (Graham 1982, Grier 1978, Means et al 1985, Sollins et al 1987). The objective of this study was to determine, by the chronosequence method, the rate at which white fir (*Abies concolor*(Gord. & Glend.) Lindl.) and Shasta red fir (*Abies magnifica shastensis Lemm.*) logs decompose and release nutrients in the Klamath Ranger District of the Winema National Forest, Oregon.

STUDY AREA

The study was conducted on the Klamath Ranger District of the Winema National Forest, Oregon (122^{o} 10' W longitude 42^{o} 20' N latitude. Elevations of this Ranger District range from 1,277 to 2,430 m (4,200 feet to 8,000 feet). The topography is mountainous and dissected. The parent material for soils is generally volcanic andesites and basalts of late Miocene to Holocene age and ash deposits. Soils are generally well-drained, gravelly and cobbly fine sandy loams to loam, with 10-75% coarse fragments (Carlson 1979).

Climate has cold, snowy winters and warm, dry summers (Carlson 1979). The nearest climatic stations at Chiloquin Falls (elevation 1,263 m or 4,155 feet) and Crater Lake (elevation 1,968 m or 6,475 feet) indicate the wide range of temperature and precipitation found on the forest (Figure 1). Based on these two stations mean annual temperature can be expected to range from 5.5 C (42 F) at the lowest elevations to 3.3 C (38 F) at the highest elevations. Precipitation has the opposite trend with a mean annual total of 46 cm (18 inches) at the lowest elevations and 165 cm (65 inches) at the highest elevations. Mean daily short-wave radiation for the area was estimated using the SolarRad model (Harmon and Marks 1995) to range from 438 to 459 $cal/cm^2/day$.

Conifer forests are the dominant vegetation, and fall within the mixed conifer, white fir, Shasta red fir, and mountain hemlock zones of Franklin and Dyrness (1973). Mixtures of white fir, ponderosa pine (*Pinus ponderosa* Laws), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) occur at the lowest elevations and red fir, mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), western white pine (*Pinus monticola* Doug.) and lodgepole pine (*Pinus contorta* Doug.) occur at the highest elevations (Hopkins 1979).

METHODS

We used the chronosequence approach to determine decomposition rates of trees lying on the ground. These trees or parts of trees will hereafter be referred to as logs. In a chronosequence one ages many pieces in various states of decay and examines how a parameter such as density changes through time. This is a substitution of space for time, and while not as precise as a time series experiment (where individual pieces are followed through time) it provides an excellent first approximation of decomposition rates (Harmon and Sexton in press).

Site Selection. Field sites were selected to cover the full range of climatic conditions present where the two tree species of interest occurred. As a preliminary screening, the Klamath Range Districts records were searched for units that had been partially harvested or thinned within the last 30 years. These units were stratified into two elevation bands and by dominance of one of the two fir species. Candidate sites were then examined in the field to judge if sufficient material existed to sample and if the dates on the records corresponded to that indicated by living stumps. We also examined each candidate site for the presence of logs formed from natural mortality and whether fall scars were abundant at the site. High priority was given to sites that had an abundance of material of various ages that could be clearly dated from either the silvicultural records or tree fall scars.

A total of 13 sites were sampled for logs, ranging in elevations from 4220 to 6360 feet (Figure 2). Aspects varied, with no particular bias toward any cardinal direction. Slope steepness ranged from 0 to 30 degrees.

Mean annual temperatures, calculated by linearly interpolating based on elevation between the Chiloquin and Crater Lake climatic stations was estimated to range from 3.3 to 5.5 C (38 to 42 F). Mean annual precipitation, also calculated by linear interpolation based on elevation between these two stations, was estimated to range from 48 to 160 cm (19 to 63 inches).

Log Selection. Once a site was chosen selected individual logs were selected to represent as many decay stages as possible. In the case of logs left as a result of harvest or thinning, we examined the state of decay to make sure it roughly corresponded to the time left on the ground. Pieces that were either too decayed or too sound were not used as they might have been added at a time other than the activity date noted in the records. Trees adjacent to logs that resulted from natural mortality were examined for the presence of scars that may have been created when the log fell. To complete our decay class system we sampled logs in very advanced stages of decomposition. For these logs it was often impossible to find a tree fall scar or any other means to date the time of death. Priority was given to very decayed logs with the possibility of dating the time of death, however, some logs were selected without dates. To estimate the initial density of dead trees, we sampled a limited number of freshly killed, standing dead trees. For the most part these trees still had needles attached and it was likely they died in the past year.

Once logs had been selected fro sampling, they were tagged with an aluminum tag and their location was plotted on a rough sketch map (Appendix 1). The intent is to allow resampling of these logs in the future to narrow uncertainties about decomposition rates.

Log Aging. Dates of tree death or cutting were taken from fall scars and or living stumps (Harmon et al. 1986). In the case of logs added by harvest or thinning, we corroborated these dates by aging living stumps within the unit sampled. Fall scars and the upper portions of living stumps were removed with a chainsaw and air dried. These cut surfaces were then sanded with a fine grit sandpaper and examined under a binocular microscope at 10-X magnification. Rings formed since the scar were counted twice and if the counts differed were counted a third time.

General Description. For each log sampled we noted key characteristics that could be used to define a decay class system for the two fir species. Physical characteristics recorded included: the presence of leaves, twigs, branches, bark cover on branches and boles, sloughing of wood, collapsing and spreading of the log (indicating the transition from round to elliptic form), degree of soil contact, friability or crushability of wood, color of wood, and if the branch stubs could be moved (Harmon et al 1987). Biological indicators such as moss cover, fungal fruiting bodies, or presence of insect galleries were also be noted although past experience shows they are too variable at a local scale to be useful in separating decay classes (Harmon and Sexton in press).

Mass Remaining and Density. To determine rates of decomposition we determined the remaining mass of each log. Current mass remaining was determined from the current density and volume of the log. The current volume was determined by measuring the length and diameter systematically along the bole. Diameter measurements were taken at the base and top as well as the locations where cross-sections were removed. For each log segment defined by the end diameters or the cross-sections, we calculated the volume as a frustum of a cone (Harmon and Sexton in press).

The current density of the wood and bark was determined by removing 4 cross-sections along the length of each log. In the case of extremely decomposed or very short logs, only 2 cross-sections were removed. For each cross-section the diameter, mean longitudinal thickness, circumference covered by bark, radial thickness of bark and mean radial depth of decay were recorded. Diameters were usually measured using a diameter tape, however, in the case of extremely old logs the cross-sections were too decomposed to be measured with this method. We therefore excavated very decayed cross-sections and used a ruler to measure the long and short axes of the cross-section from the remaining portions of the log. The total mass of the bark and wood for each cross-section was weighed in the field on a portable electronic scale with a range of 1 to 6000 g (Ohaus Model XXX), and then 50-200 g subsamples were removed to determine the moisture content. When cross-sections had a range of decay or moisture conditions, we took samples from the different areas in rough proportion to the area in each condition. These samples were weighed in the field and then dried in an oven at 55 C until their mass was stable (usually 7 to 14 days). Total dry weight was calculated as the fraction of dry material in the subsamples multiplied by the total wet weight in the field. The volume of the bark or wood was determined from the dimensional data recorded in the field. Current density of bark or wood was calculated as the dry weight divided by the volume of in the cross-section. The overall cross-sectional density was calculated similarly, but using the total dry weight and volume.

To estimate the amount of each log that had decomposed we multiplied the current mean density for each log by the ratio of the current to the estimated initial volume. This accounted for fragmentation losses or totally decomposed portions and therefore represents the best estimate of mass loss rates especially for exceedingly decomposed logs (Harmon et al 1987). Adjustments were only performed for the wood and total density, as bark disappearance is difficult to estimate (in part because in very decomposed logs the bark is buried under wood). The initial volume was calculated from the diameter at breast height of the tree, after adjusting for losses of bark using the following equations for white and Shasta red fir, respectfully:

$V_i=0.0000485*DBH^{2.7727}$, and

$V_i=0.0000534*DBH^{2.7478}$,

where V_i, is the initial volume in m^3 and DBH is the estimated initial diameter at breast height in cm. These equations were derived from optical dendrometer data taken from white fir in the Cascade Range and red fir (*Abies magnifica* A. Murr.) from the Sierrra Nevada Mountains (unpublished data, Datacode TV009, Oregon State Univesity Forest Science Data Bank, Corvallis). Past work indicates this procedure estimates the initial volume within 10-20%; therefore this correction was applied to only those logs that were 10% smaller than the initial estimated volume (Figure 3). This meant that 8 out of 28 white fir logs had their current density adjusted, while 8 out of 30 Shasta red fir logs had their current density adjusted.

Samples have been saved for nutrient analysis, although the results of that portion of the study are not yet available. Samples of wood and bark from each trees sampled were coarse ground and mixed thoroughly before a smaller subsample (5-10 g) was taken for fine grinding (40 mesh). Nitrogen will be determined by micro-Kjeldahl and cations by ICAP (Inductively Coupled Argon Plasma). Standard wood samples will be run with all nutrient analyses.

Statistical Analysis. The mean and standard error for each decay class and species was calculated for the current density of bark, wood, and the combination of both layers using Proc Means of SAS (SAS Institute Inc, 1985).

The primary statistical analysis used was linear regression. To calculate the decomposition rate constant, the estimated age of the logs was used as the independent variable and the density of the separate or combined tissue layers (adjusted for fragmentation losses) was used as dependent variable. Before these calculations were done, however, a weighted mean for each log was calculated. The densities from each cross-section in a log were weighted by their mass, so that the smaller upper cross-sections contributed less to the log average than the larger lower cross-sections. The form of the regression equation used to calculate the decomposition rate constant was:

$$\ln(\mathrm{Density}_t) = \ln(\mathrm{Density}_0) - k\,t,$$

where ln is the natural logarithm of $\mathrm{Density}_t$ or $\mathrm{Density}_0$, the density at time t and 0, respectively and k which is the decomposition rate constant.

To estimate the effect of elevation on decomposition rate constants we calculated the decomposition rate constant for each site and regressed this against elevation. Although other factors such as temperature and moisture are the actual causes of elevation differences, these are largely derived from elevation data. We calculated the decomposition rate constant for each site and species as:

$$k = -[\ln(\mathrm{Density}_t/\mathrm{Density}_0)]/t,$$

where $\mathrm{Density}_0$ was assumed to be the value estimated from the overall regression calculations. The values for each site and species were averaged and then regressed against elevation.

RESULTS

Characteristics of Logs Sampled. A total of 42 white fir and 47 Shasta red fir logs were sampled (Table 2). Logs in each of the five decay classes were sampled with Decay Class 5 white fir logs having the least (6) and Decay Class 1

Shasta red fir logs having the most (12). The cause of death ranged from beetle kill, cutting, lightning, root-rot, wind-snap, wind-throw, and unknown causes (Table 3). The majority of trees were killed by cutting 30%, although wind-throw (roots were torn up) comprised 25% of the total. Unknown causes, particularly for the oldest, most decomposed logs comprised a 24% of the total, and although these could not be used for estimating decomposition rates, they represented the endpoint of the decay class system.

Decay Class Descriptions. The pattern of development observed for white and Shasta red fir in the Klamath Ranger District was quite similar to that of white fir in the California Sierra Nevada Mountains (Harmon et al. 1987). Decay Class 1 logs are the least decomposed, with most having needles still attached and all having intact bark, fine twigs and branches. If originating from cutting, logs of this class may not have branches and twigs, however, the cuts appear fresh and have not turned gray due to sun bleaching. Decay Class 2 logs are starting to decompose, needles are absent, and many of the fine twigs have fallen off the larger branches. Bark is loose, but only starting to fall off the log. There is evidence the surface layers of the wood are decomposing, but the inner, central region of the wood is undecayed unless previously infected with heart rots. For pieces originating from cutting, the ends are gray from sun bleaching. Decay Class 3 logs have only a few large branches remaining, often in the form of stubs, the bark is falling off in large patches, and evidence of sloughing of sapwood is also evident. The outer wood is easily crushed by hand, although the inner portions can be completely sound. Despite the large amount of decay, Decay Class 3 logs are able to support their own weight along most of their length. Decay Class 4 logs are unable to support their own weight and along most of their length conform to the contours of the underlying ground. Although circular cross-sections can remain, much of the log forms an elliptical cross-section. Branches, if present, are short stubs, that move when pulled. This indicates decay has spread to the innermost portions of the log and have weakened the wood considerably. Bark, if present, is in small loose patches and found in pile alongside or under the log. Decay Class 5 logs are the most decomposed, of elliptical shape (the long axis is often 10 times the length of the small axis) and beginning to be incorporated into the forest floor. The wood is extremely decayed, usually in the form of cubical brown-rot that can be easily crushed by hand. Bark is not evident from the surface, however, in most cases bark underlies the layer of extremely decomposed wood.

The mean age of the decay classes generally increased geometrically with age for both species of firs (Table 4). Decay Class 1 logs averaged 2 to 2.3 years, whereas Decay class 4 logs averaged 26-29.8 years. An exception to this trend was the single Decay Class 5 log that could be aged, which had an age of 19 years. We expect this log was somewhat of an outlier and would expect an average age of that decay class to exceed 40 years.

The current density (not adjusted for fragmentation losses) decreased for bark, wood, and the combined tissues for both species with decay class (Tables 5-7). Wood underwent larger changes in current density than bark for both fir species. In white fir, current wood density declined 55% from Decay Class 1 to 5, and for Shasta red fir the decrease was 75% for the same decay classes. In contrast, the change in current bark density of white and Shasta red fir decreased 33 and 21%, respectively. The differences between the decline in wood and bark is consistent with the generally lower decomposition rates expected for outer bark. It should be noted, however, that inner bark was rarely present in decay class 4 or 5 logs indicating this tissue decomposed much faster than wood.

Decomposition Rate-constants. Shasta red fir logs appeared to decompose 20% faster than white fir logs (Figure 4), despite the fact they occurred at higher elevations. The decomposition rate constant for the combined bark and wood layers was 0.035 and 0.043 year^{-1} for white and Shasta red fir respectfully (Table 8). The overall initial density of

Shasta red fir logs was also higher, 0.437 g cm^{-3} as opposed to 0.381 g cm^{-3} for white fir. This matches the results of the decay class densities.

Bark for both species decomposed slower than wood (Table 8). Again Shasta red fir bark decomposed faster than white for bark, with decomposition rate constants of 0.01 and 0.007 yr^{-1}, respectfully (Figure 5). The decomposition rate constants of wood for both species were higher than the combined layers by approximately 10% (Figure 6). That bark decomposed at a rate approximately 20% that of wood is to be expected, because it is generally more exposed to drying and is impregnated with many decay resistant extractives (Harmon et al. 1986). Inner layer of the bark, however, did decompose more rapidly than wood, and although we did not measure its density separately we noted that it was largely missing from logs in excess of 15 years. Another interesting observation supporting the very slow decomposition of outer bark, was the fact it was found under extremely decomposed logs, even when not apparent from surface inspection. Thus it possible for bark to "disappear" from logs in terms of cover very rapidly (Figure 7), but much of it remains hidden from view.

Effect of Elevation on Decomposition. Regression of the decomposition rate constant for combined density against elevation indicated a non-significant relationship (Figure

8). Unfortunately there were not enough sites in which both species co-occurred to test if the logs of one of the species was more decay resistant than another. On two of the three sites the species co-occurred, Shasta red for decomposed faster than white fir. Still, because of the imprecision inherent in the chronosequence method, the similarity of the species in terms of decay resistance in a common environment could not be ruled out.

DISCUSSION

Environmental Versus species Controls. The faster decomposition of Shasta red fir compared to white fir may be due to two factors: either the former species inherently decomposes faster or the environment in which it is found is more favorable to decomposition. The decay resistance of these two species is thought to be similar (USDA Forest Products Laboratory 1974), therefore differences in environment may cause the difference in decomposition rates that we measured. On average, Shasta red fir occurs at higher elevations than white fir. The mean elevations of the logs of white fir and Shasta red fir were 1,465 and 1,755 m (4,820 and 5,770 feet), respectively. Although this would lead to a decrease in mean annual air temperature of approximately 1 C (2 F), it would also mean an increase in precipitation of 51 cm/year (20 inches/year). While the decrease in air temperature is expected to decrease decomposer activity (5 to 10% based on a Q10 of 2-3), the possible increase of decomposition with elevation indicates moisture balance may be more critical in the Klamath Ranger District. Although temperature does increase as elevation decreases, so does the rate of drying. Furthermore, precipitation rapidly decreases at lower elevations and this coupled with increased drying rates might lead to lower moisture contents that might, in turn, limit decomposer activity during the summer months. This hypothesis would have to be tested, however, with a method more precise than the chronosequence approach. One possible experimental design would be a reciprocal transplant experiment in which both species are placed at the highest and lowest elevations. This would clearly separate the effects of species versus environment on decomposition.

Comparison to Other Firs. In comparison to other species of true firs, white and Shasta red fir appear to be intermediate in decomposition rates. At the H. J. Andrews Experimental Forest, where annual temperatures and precipitation average 8 C and 180 cm (46 F and 71 inches), respectfully, Pacific silver fir (*Abies amabilis* (Dougl.) Forbes) has a decomposition rate constant of 0.06 $year^{-1}$ (Harmon unpublished data). A similar decomposition rate constant of 0.05 $year^{-1}$ was measured for white fir in Sequoia National Park (Harmon et al. 1987). The higher rates of decomposition measured in California may be due to warmer, wetter conditions where annual temperature was 10 C (50 F) and annual precipitation was 113 cm (44 inches). At Fraser Experimental Forest in Colorado, subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) was measured to have a decomposition rate constant of 0.026 year^{-1} (Moir et al. in prep), a value expected given the cool dry nature of the site (mean annual temperature 4.5 C or 40 F and precipitation 60 cm or 24 inches). Thus, while the true firs at Klamath Ranger District are intermediate between the warmest, wettest sites and the coolest driest sites, there are still not enough data from other sites to disentangle the relationship between temperature, precipitation, and moisture balance.

Comparison to Other Genera. Relative to non-true fir species of conifers within the Pacific Northwest region, both white and Shasta red fir appear to decompose appreciably faster. Douglas-fir, perhaps the most studied species to date, has a decomposition rate constant of 0.01 to 0.0:05 year-1 (Sollins et al. 1987, Edmonds and Eglitis 1989). The higher value may be an anomaly as the log length in this study was 1 m, a length subject to substantial end rot. More typical values for this species would be 0.015-0.02 year^{-1} (Harmon and Chen 1992). We would therefore expect that this species would decompose substantially slower than true firs in the Klamath Ranger District. Lodgepole pine, a species growing in association with Shasta red fir, had a decomposition rate constant of 0.027 $year^{-1}$ on a much drier site 28 cm (11 inches year) in Central Oregon (Busse 1994). One would expect that this species would decompose at similar rates to firs on the Klamath Ranger district where moisture is less limiting. Finally, there are as of yet no published data on ponderosa pine decomposition. We would expect it to decompose similarly to lodgepole pine at the Klamath Ranger District.

APPLICATION OF RESULTS

Spatial Distribution of Decomposition Rate Constants. There are several options regarding the application of the decomposition rate constants estimated over the Klamath Ranger District. The most conservative approach would be to apply an average rate of 0.039 $year^{-1}$ over the entire area. This value represents the value computed from a regression where both species were combined and would give values at least within 10% of either species. Another alternative is to use the values of the species most appropriate for the plant association in question (e.g., use white for the mixed conifer or white fir dominated plant associations). Probably the least desirable system would be to adjust the decomposition rate constants as a function of elevation or some other site variable. Although decomposition does undoubtedly vary along these gradients, the imprecision of the chronosequence method, combined with the complex way temperature and precipitation interact would make this difficult to justify scientifically at this point.

Use of the Decomposition Rate Constants in Management. The decomposition rate constants can be used in a number of ways. First, the rate large slash left after thinning can be estimated. The following equation would describe the loss of slash mass:

$$Mass_t = Mass_0 \ e^{-k*t},$$

where $Mass_t$ and $Mass_0$ are the mass of slash after t years and initially, respectfully, e is the base of the natural logarithms (2.7183), and k is the decomposition rate constant appropriate for the species. The initial mass of the slash can be calculated from the volume (Vol_0) estimated to be left and the appropriate initial density ($Density_0$) from Table 8:

$$Mass_0 = Vol_0 * Density_0.$$

A second, similar use would be to project the future mass of logs. The same equations would be applied, only in this case the mass at time 0 would be based on the sum of the mass for each decay class. This sum can be computed from the volume estimated from planar intercepts or fixed plots as long as the pieces inventoried are separated by species and decay class. The densities in Table 7 would then be multiplied by the volume of the appropriate species and decay class.

Estimating changes in total mass due to silvicultural treatments (slash) or from natural mortality would represent a combination of the two approaches outlined above. This could be accomplished by hand calculator, but would be easiest to apply in the long-term using a spreadsheet program.

Finally, the decomposition rate constants can be used to estimate the theoretical steady-state store a forest is capable of sustaining. Although this value is rarely realized in natural of managed stands, it does provide an excellent reference point to judge the current condition. It is most likely to be found in old-growth stands that have not be subjected to salvage. The steady-state mass ($Mass_{SS}$) is calculated from the input of dead wood mass (I_{mass}) and the decomposition rate constant k:

$$Mass_{SS} = I_{mass}/k.$$

I_{mass} can be estimated from the live bole mass of an old-growth stand. Suppose for example, a white fir stand had a bole mass of 300 Mg/ha, assuming 0.5% of these boles die each year, $Mass_{SS}$ would be equal to 1.5/0.35 or 42.8 Mg/ha.

The fraction of bole mass dying each year can be based on local experience, actual measurements, or values derived from regional inventory reports.

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List of Tables

Table 1. Characteristics of sites on Klamath Ranger District that logs and snags were sampled.

Plot	Elevation feet	Aspect degrees		Slope degrees	Temperature degrees F	Precipitation inches	Radiation $cal/cm^2/day$
1	5100	115	10	40.0	37.5	447	
2	5600	179	10	39.1	47.8	452	
3	6000	29	10	38.4	56.0	454	
4	4300	84	15	41.4	21.0	438	
5	4310	180	0	41.4	21.2	438	
6	4760	100	15	40.6	30.5	443	
7	5380	279	30	39.5	43.2	449	
8	4500	22	30	41.1	25.1	437	
9	5960	194	15	38.4	55.2	456	
10	6020	59	10	38.3	56.4	455	
11	6360	274	10	37.7	63.4	459	
12	5470	109	5	39.3	45.1	450	
13	4220	69	5	41.6	19.3	437	

Table 2. Number of logs sampled for each species and decay class.

Decay Class	Species of Log White fir	Red Fir	Total
	-------number of logs-------		
1	8	12	20
2	9	8	17
3	9	10	19
4	10	8	18
5	6	9	15

Table 3. Cause of death of logs sampled.

Cause of Death	White fir	Red fir	Total
	------------number of logs-------------		
Beetle-kill	1	3	4
Cut	17	10	27
Lightning	0	1	1
Root-rot	1	2	3
Wind-snap	3	8	11
Wind-throw	11	11	22
Unknown	9	12	21

Table 4. Mean age of logs sampled for each species and decay class.

Decay Class	White fir				Red Fir			
	Mean	Minimum	Maximum	N	Mean	Minimum	Maximum	N
1	2.0	1	4	7	2.3	1	9	12
2	10.8	8	15	7	6.2	1	9	5
3	21.7	11	25	9	20.6	17	23	8
4	29.8	23	36	5	26.0	18	32	5
5					19.0			1

Table 5. Mean density (g cm^{-3}) of wood sampled for each species and decay class.

Decay Class	White fir			Red Fir		
	Mean	Standard Error	N	Mean	Standard Error	N
1	0.331	0.012	32	0.384	0.013	44
2	0.275	0.011	36	0.362	0.018	32
3	0.194	0.012	36	0.195	0.013	40
4	0.129	0.007	38	0.139	0.009	34
5	0.151	0.021	16	0.094	0.008	26

Table 6. Mean density (g cm^{-3}) of bark sampled for each species and decay class.

Decay Class	White fir			Red Fir		
	Mean	Standard Error	N	Mean	Standard Error	N
1	0.449	0.013	32	0.386	0.013	43
2	0.347	0.015	32	0.386	0.036	32
3	0.303	0.016	28	0.313	0.018	38
4	0.364	0.019	36	0.251	0.019	31
5	0.303	0.020	16	0.304	0.018	25

Table 7. Mean density (g cm^{-3}) of combined wood and bark sampled for each species and decay class.

Decay Class	White fir			Red Fir		
	Mean	Standard Error	N	Mean	Standard Error	N
1	0.349	0.010	32	0.377	0.006	44
2	0.285	0.010	36	0.354	0.014	32
3	0.201	0.012	36	0.205	0.011	40
4	0.156	0.006	38	0.153	0.008	34
5	0.184	0.014	16	0.132	0.009	26

Table 8 Initial density and decomposition rate-constant (k) for white and red fir logs as a function of time. The regression equation used to model decomposition was $D_t=D_0\exp[-k*age]$. Note bark densities were not corrected for volume losses. All regressions were significant.

Component	Species of Log: White fir				Red Fir			
	Initial Density ($g\ cm^{-3}$)	k (yr^{-1})	r2	N	Initial Density ($g\ cm^{-3}$)	k (yr^{-1})	r2	N
wood	0.376	0.038	0.68	28	0.451	0.049	0.70	30
bark	0.392	0.007	0.15	28	0.339	0.011	0.35	30
combined	0.381	0.035	0.71	28	0.437	0.043	0.73	30

Figure Headings

Figure 1. Mean monthly temperature and precipitation at Chiloquin and Crater Lake, Oregon.

Figure 2. Location of the log sample plots on the Klamath Ranger District, Winema National Forest.

Figure 3. Comparison of estimated initial volume to current volume of logs.

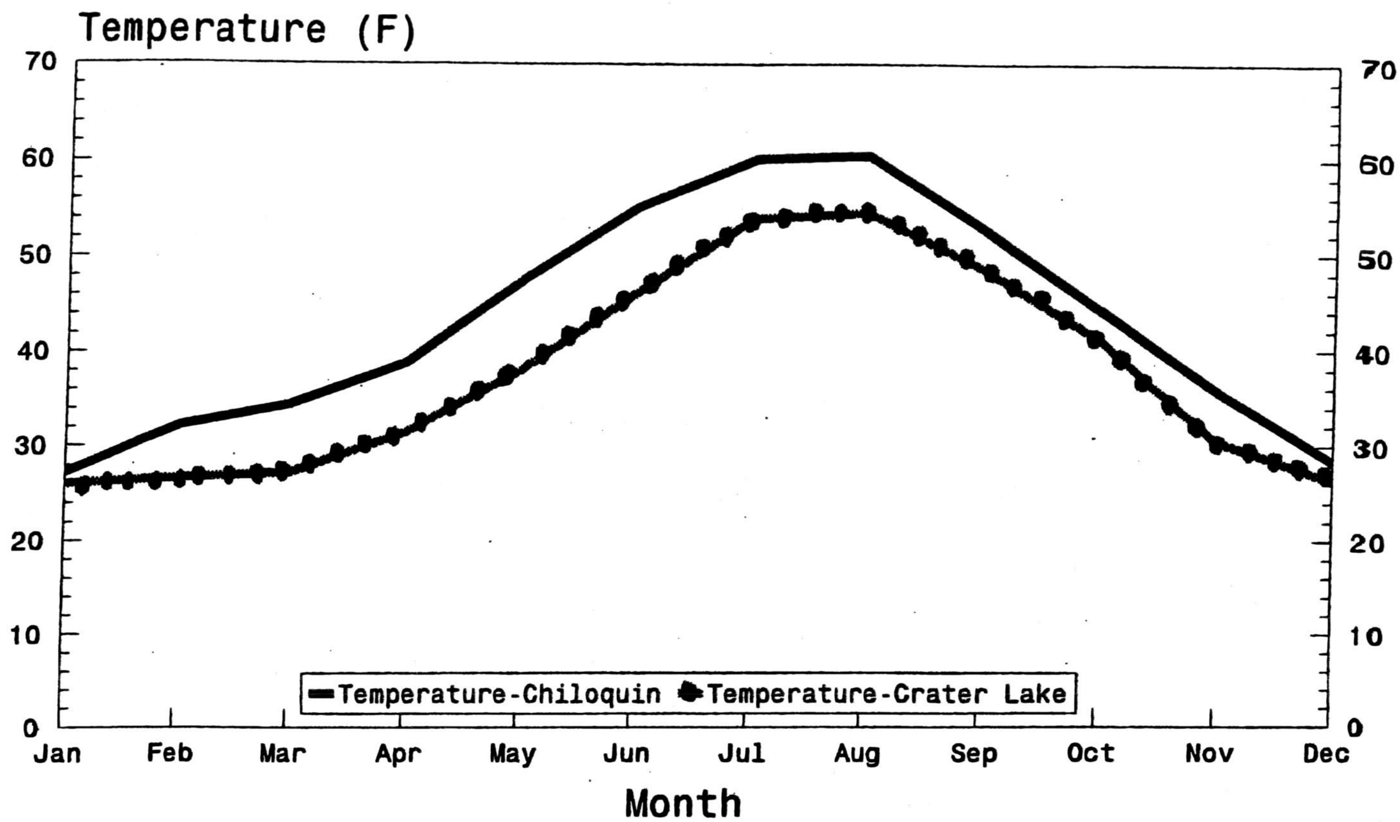
Figure 4. Combined density of white and red fir logs as a function of time exposed to decomposition on Winema National Forest.

Figure 5. Bark density of white and red fir logs as a function of time exposed to decomposition on Winema National Forest.

Figure 6. Wood density of white and red fir logs as a function of time exposed to decomposition on Winema National Forest.

Figure 7. Proportion of logs covered by bark in white and Shasta red fir logs in Winema National Forest.

Figure 8. Decomposition rate-constant (k) for each plot as a function of elevation on Winema National Forest.



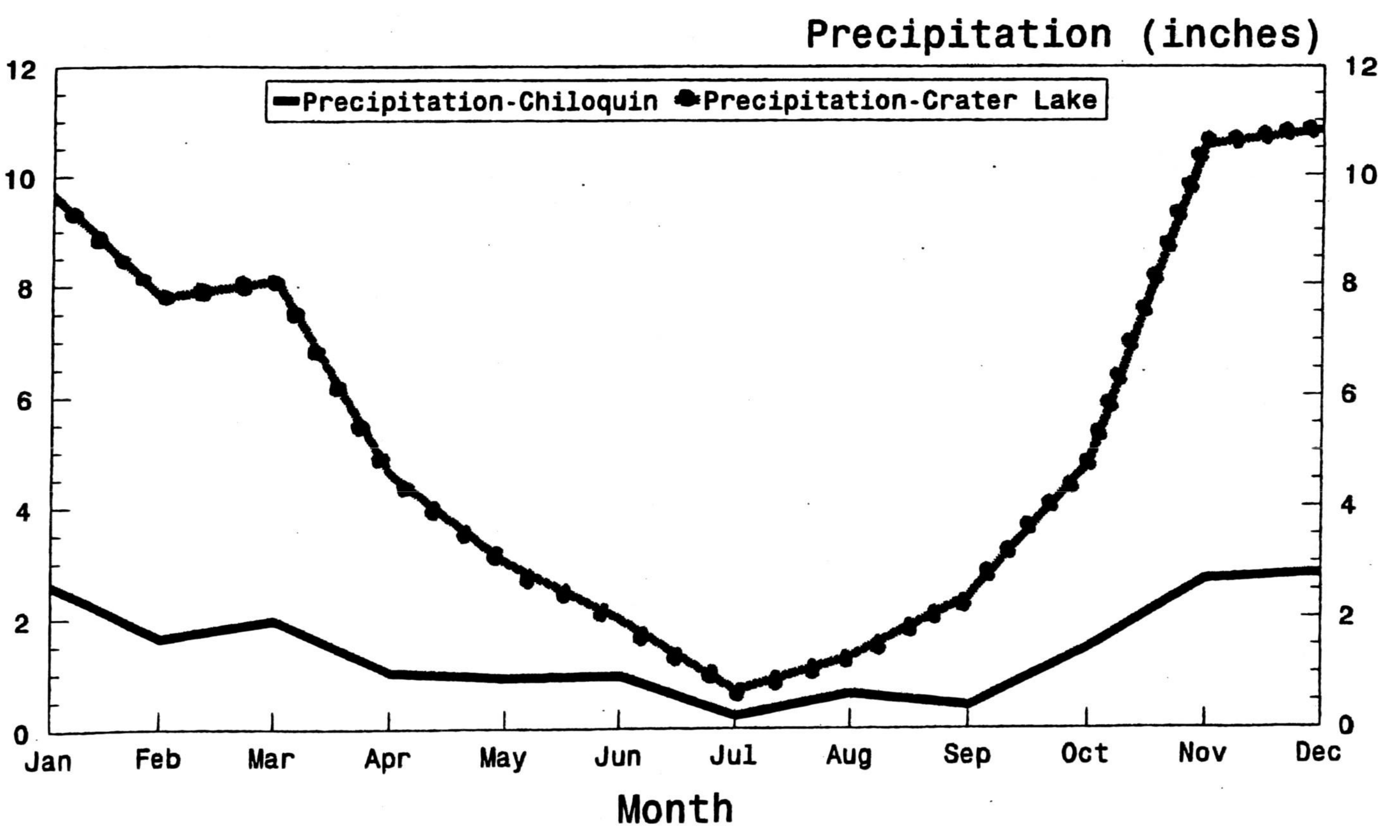


Figure 1. Mean monthly temperature and precipitation at Chiloquin and Crater Lake, Oregon.

Klamath Ranger District, Winema National Forest
Location of 1995 O.S.U. Fir Decomposition Plots
(circled numbers show plot locations)

Northern Half

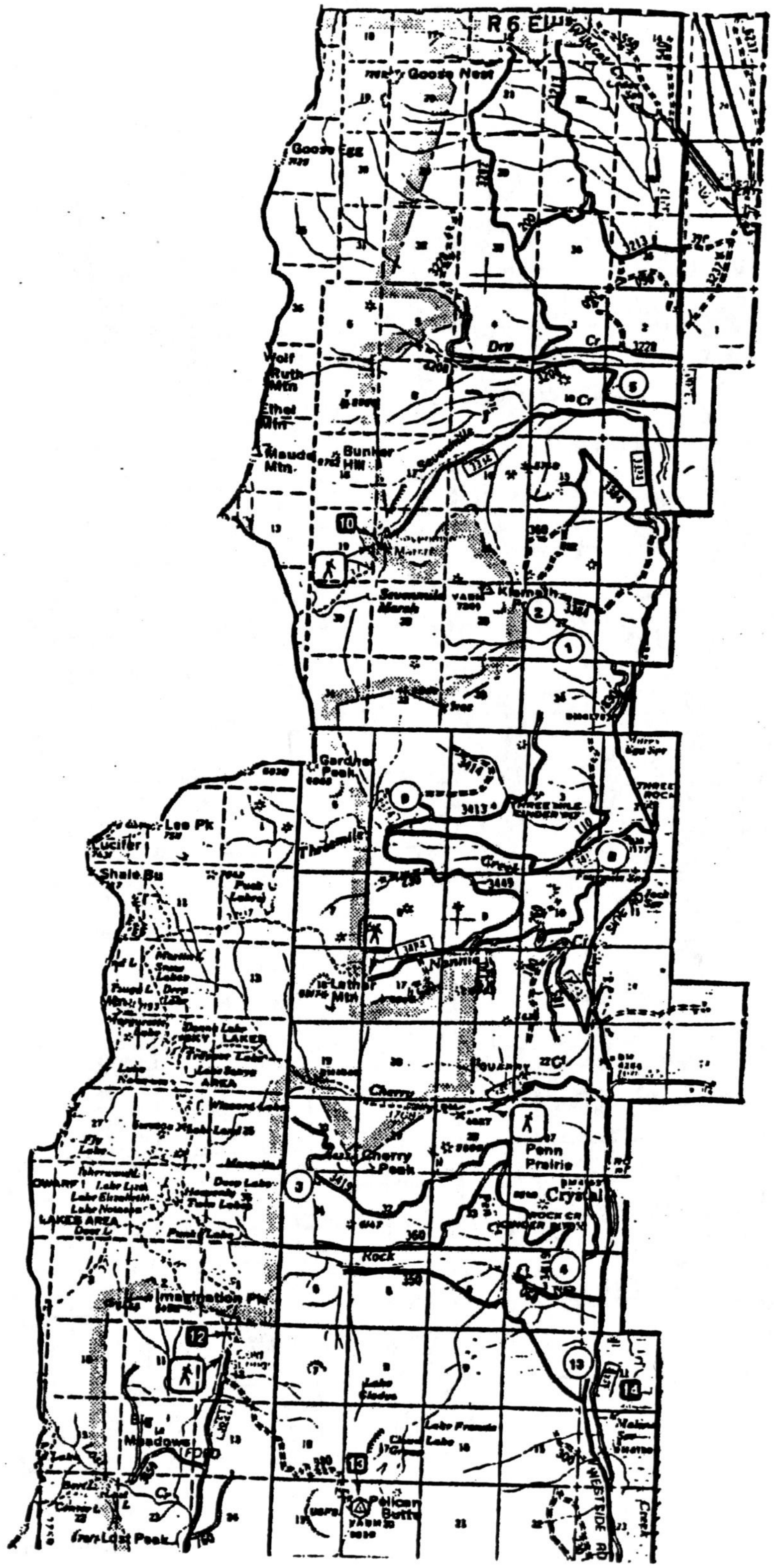


Figure 2. Location of the log sample plots on the Klamath Ranger District, Winema National Forest.

Klamath Ranger District, Winema National Forest
Location of 1995 O.S.U. Fir Decomposition Plots
(circled numbers show plot locations)

Southern Half

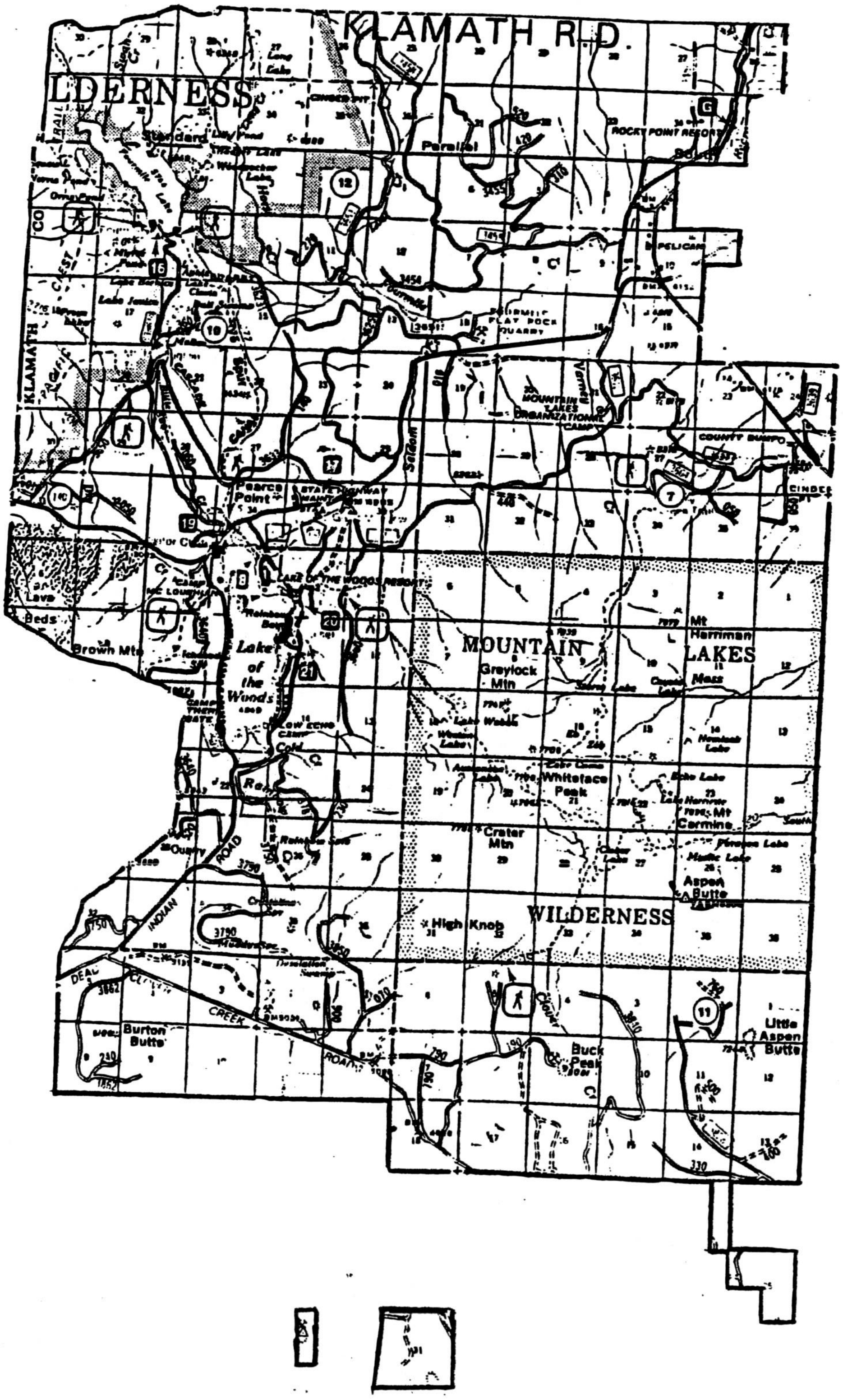


Figure 3. Comparison of estimated initial volume to current volume of logs.

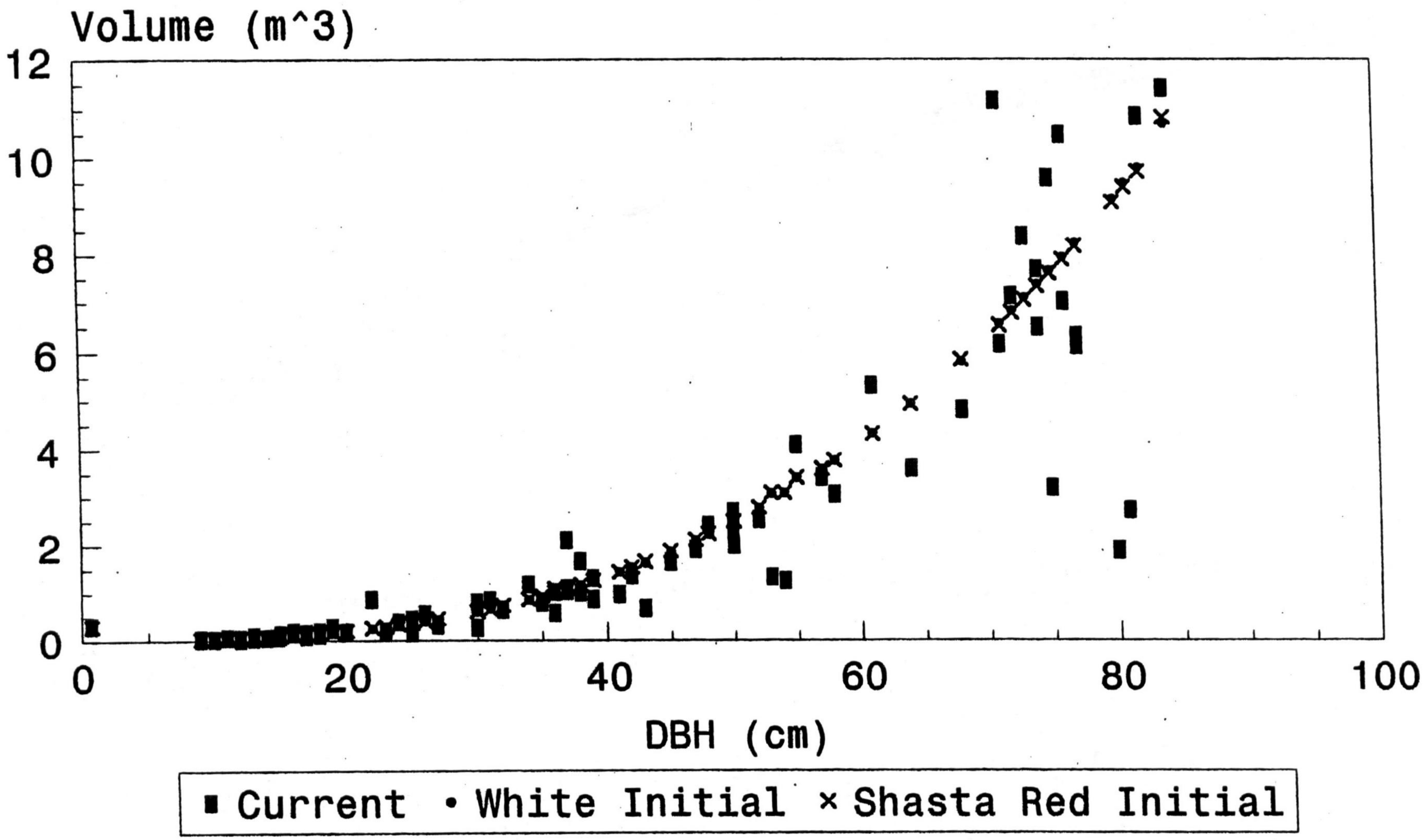


Figure 4. Combined density of white and red fir logs as a function of time exposed to decomposition on Winema National Forest.

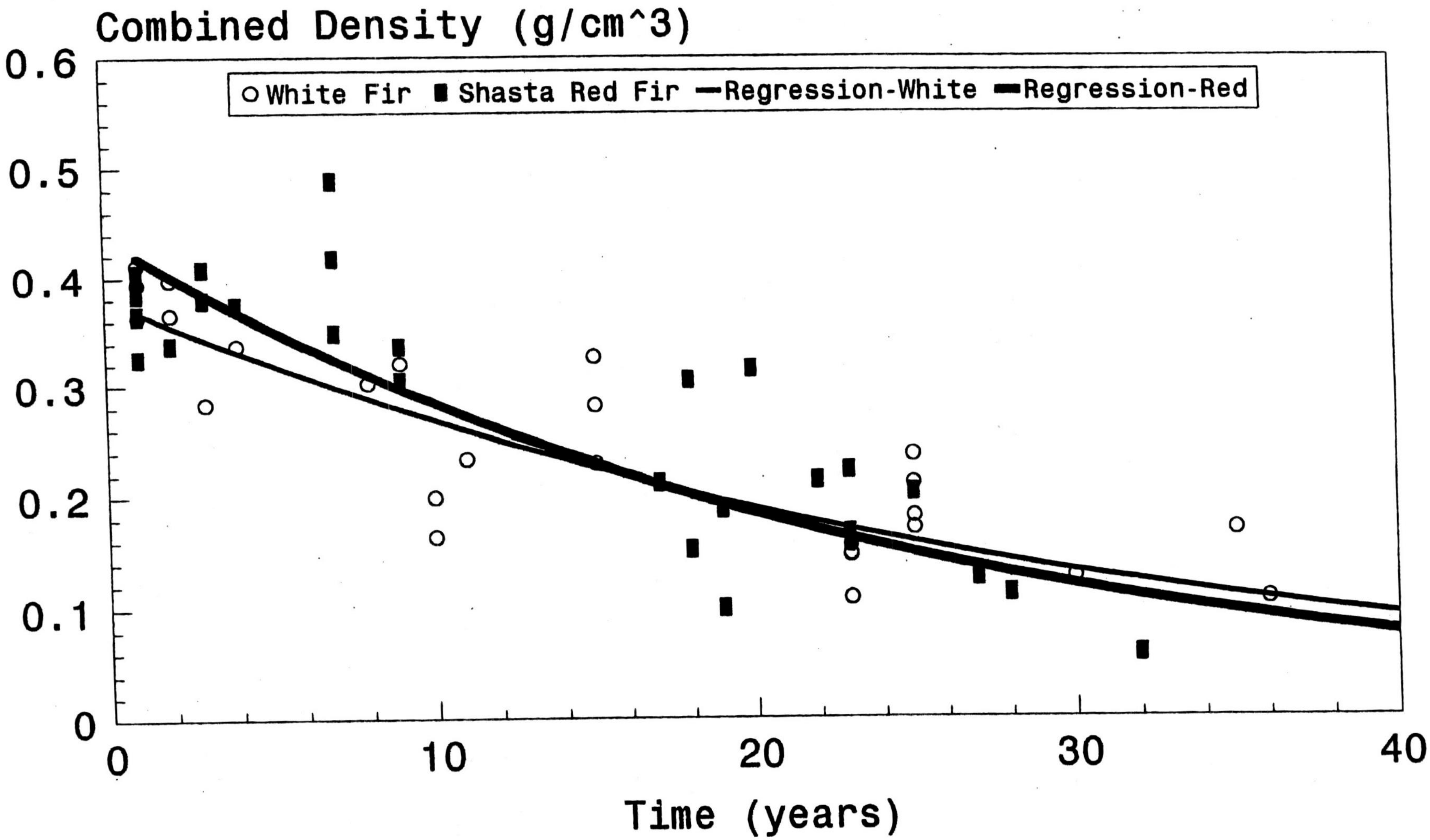


Figure 5. Bark density of white and red fir logs as a function of time exposed to decomposition on Winema National Forest.

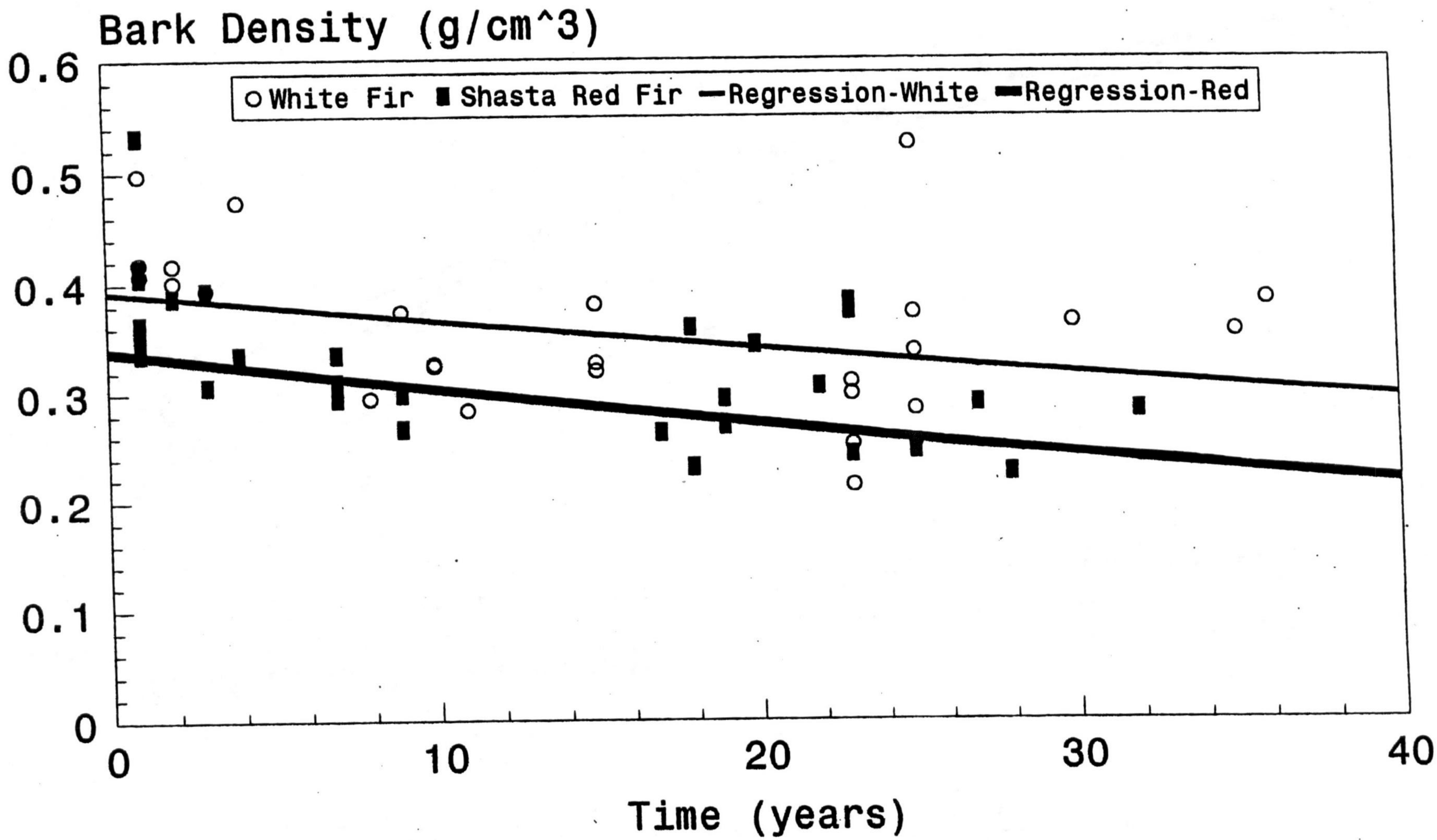
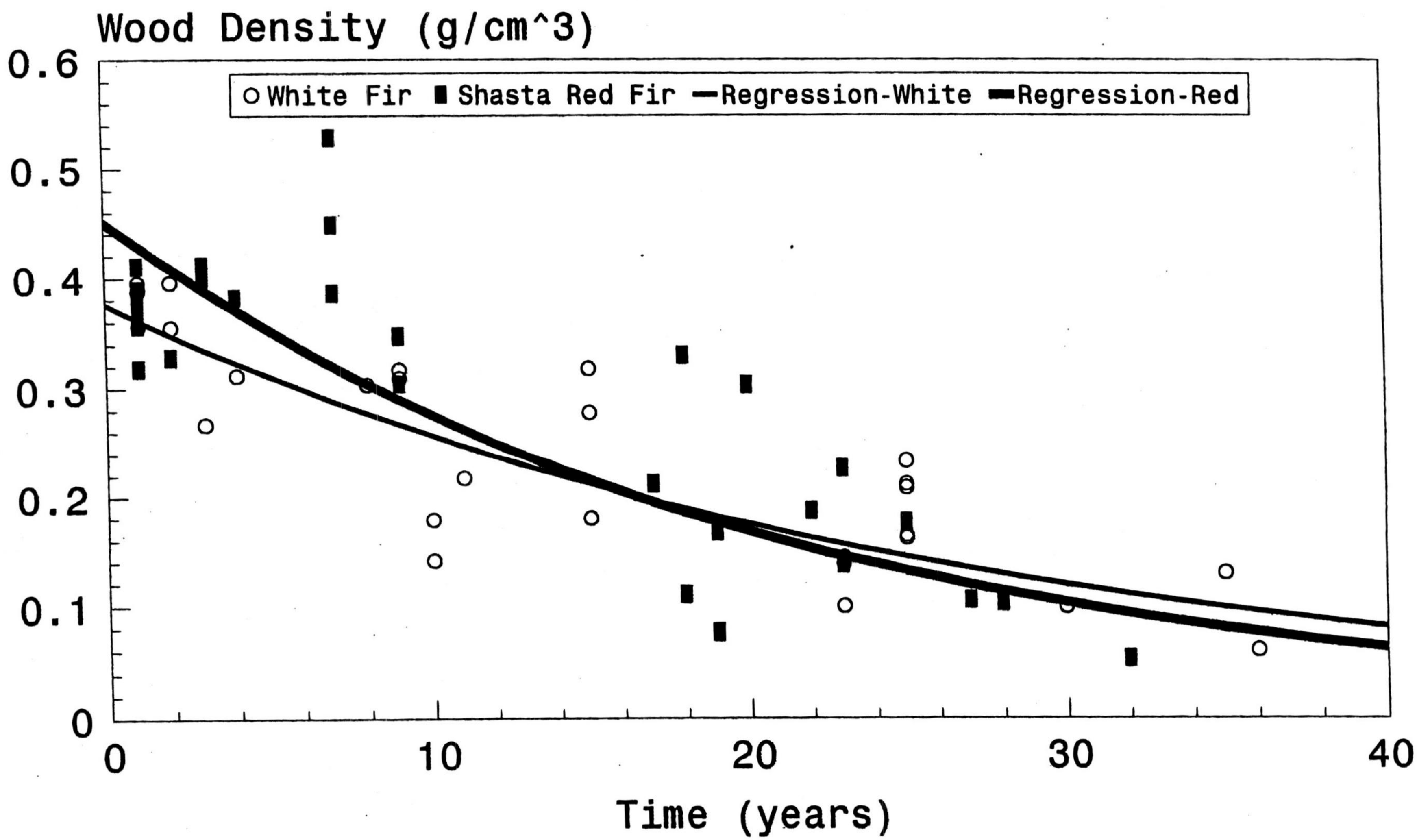


Figure 6. Wood density of white and red fir logs as a function of time exposed to decomposition on Winema National Forest.



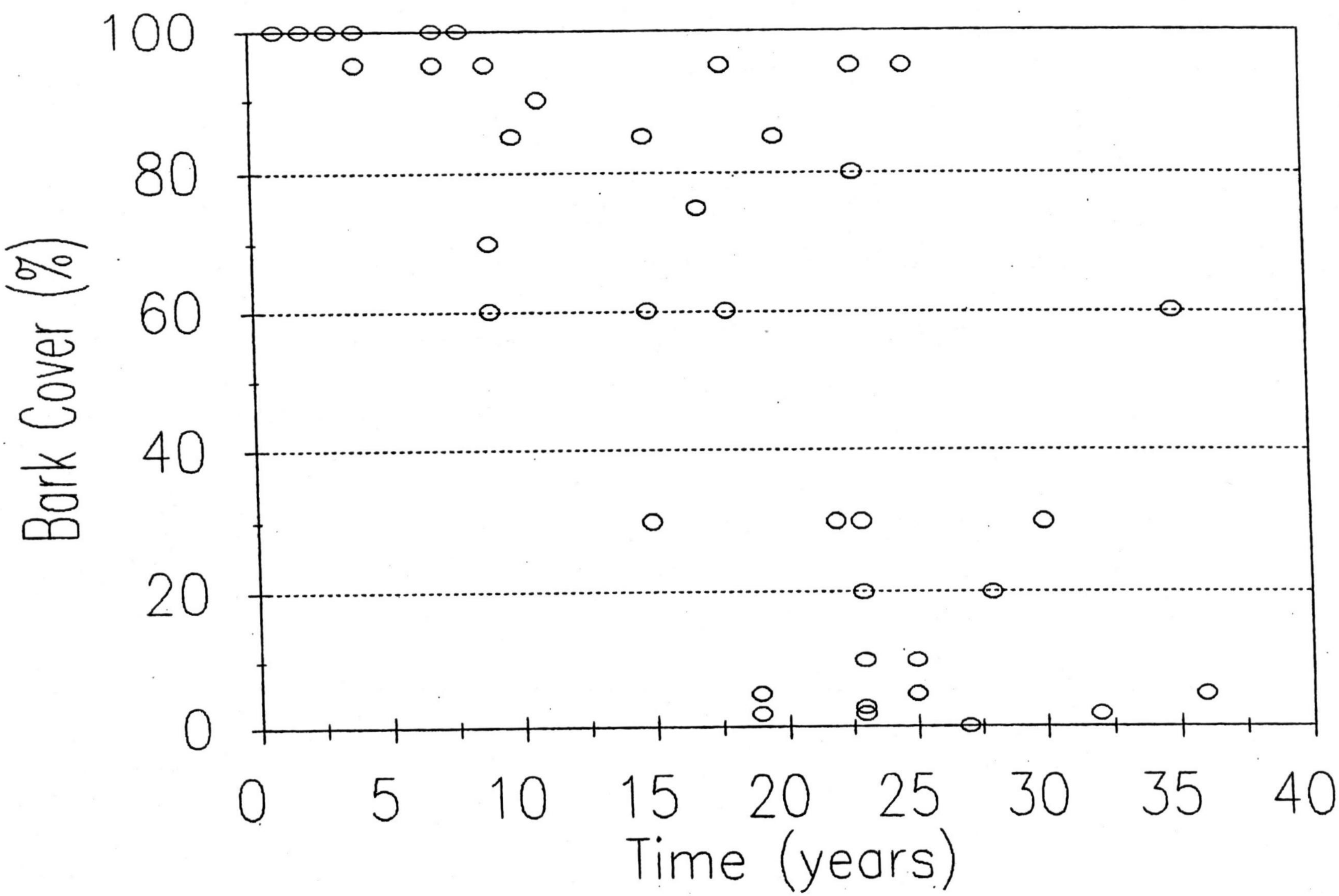


Figure 7. Proportion of logs covered by bark in white and Shasta red fir logs in Winema National Forest.

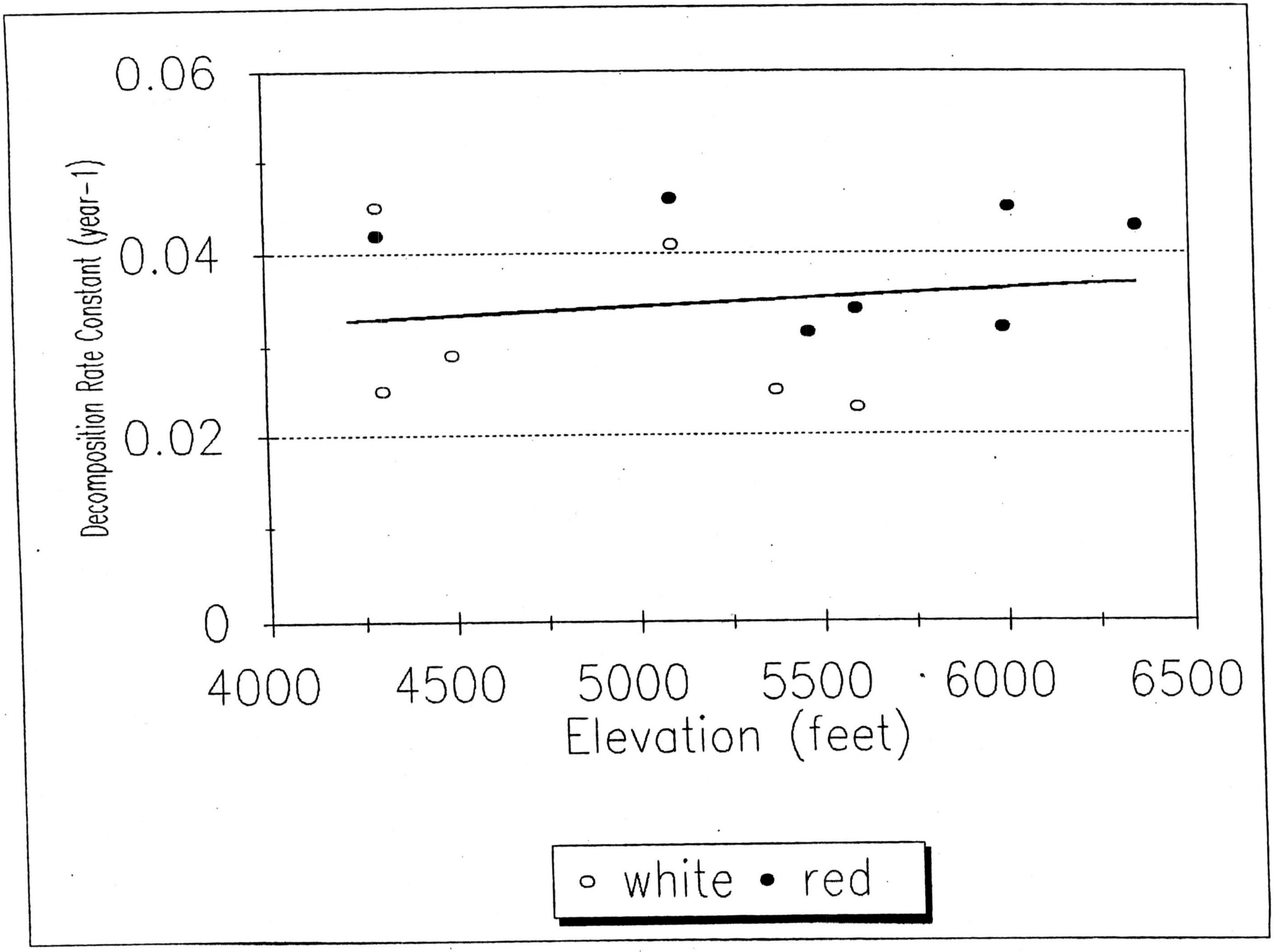


Figure 8. Decomposition rate-constant (k) for each plot as a function of elevation on Winema National Forest.

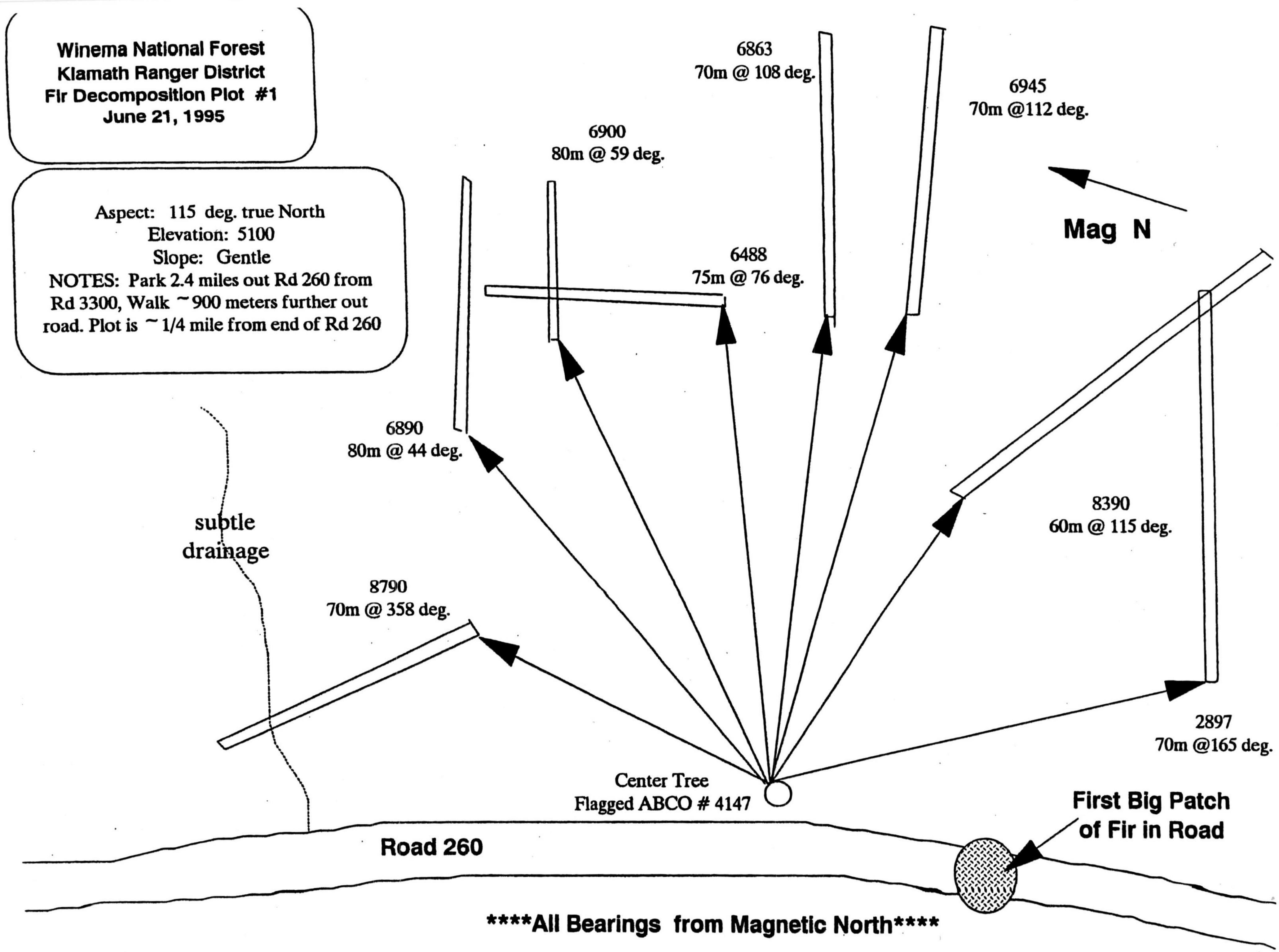
Appendix 1

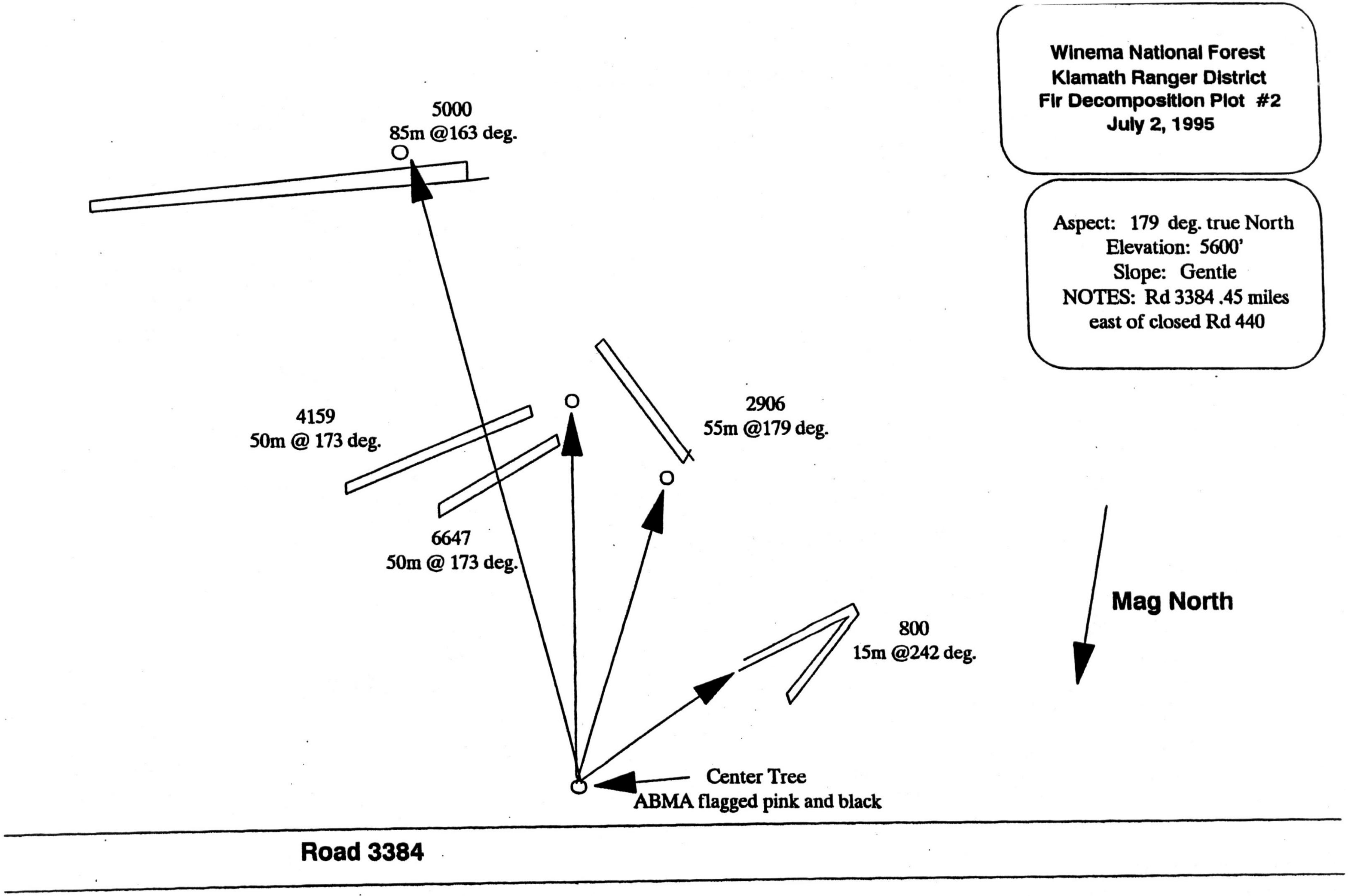
Location of Logs Sampled

at Each Site

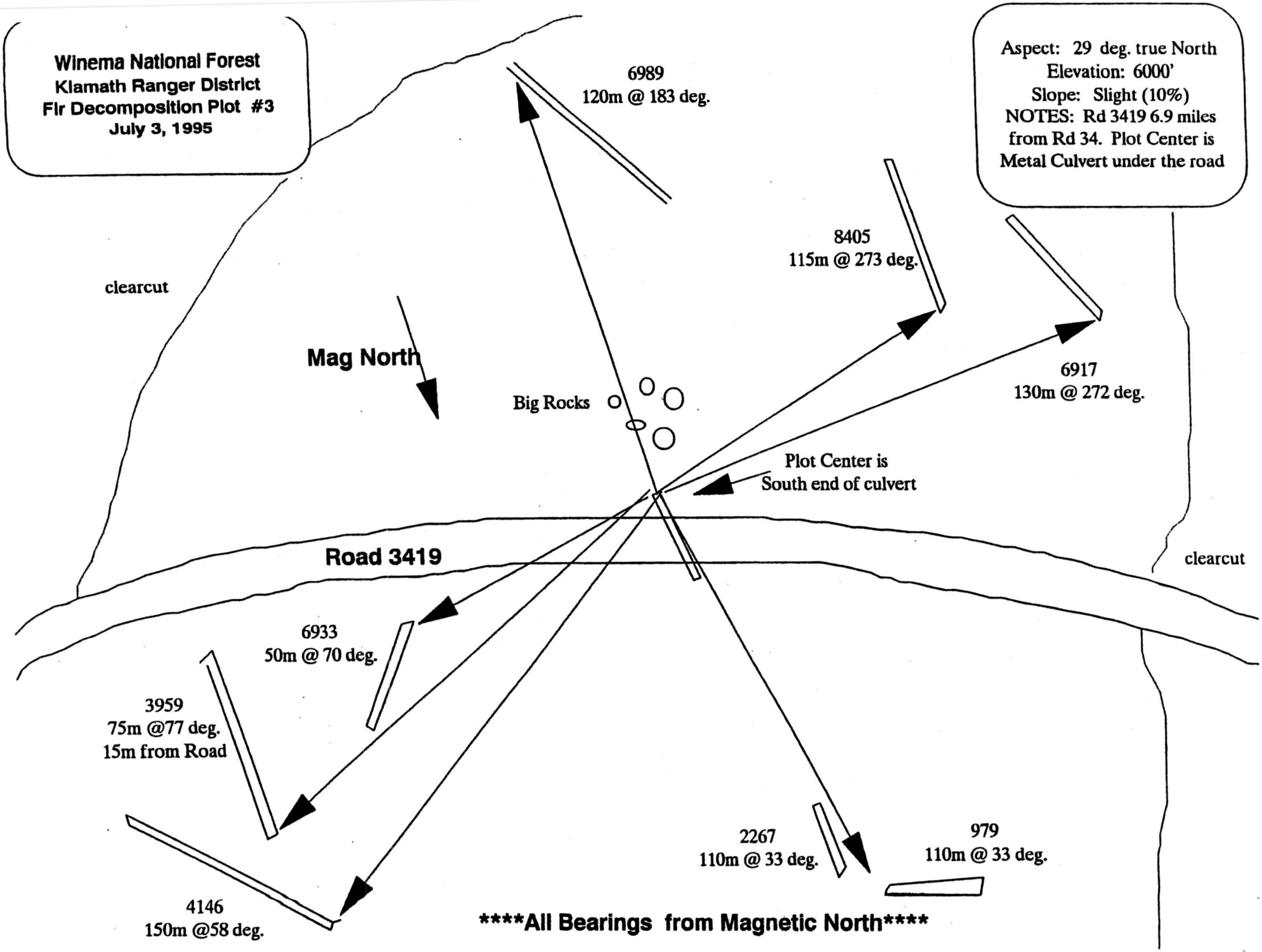
on the

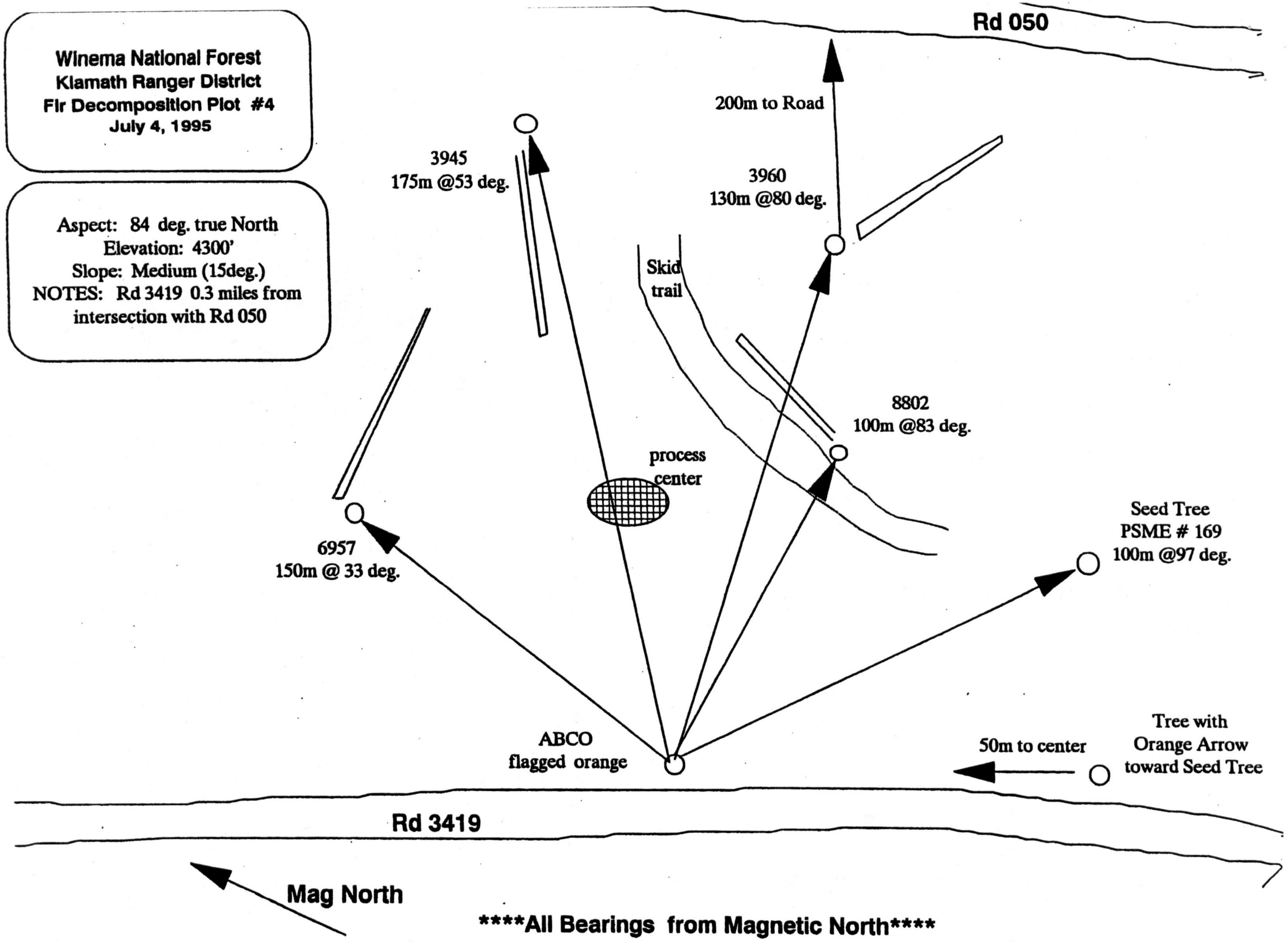
Klamath Ranger District


Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #1
June 21, 1995
Aspect: 115 deg. true North
Elevation: 5100
Slope: Gentle
NOTES: Park 2.4 miles out Rd 260 from Rd 3300, Walk ~900 meters further out road. Plot is ~1/4 mile from end of Rd 260
6863
70m @ 108 deg.
6945
70m @112 deg.
6900
80m @ 59 deg.
Mag N
6488
75m @ 76 deg.
6890
80m @ 44 deg.
8390
60m @ 115 deg.
subtle drainage
8790
70m @ 358 deg.
2897
70m @165 deg.
Center Tree
Flagged ABCO # 4147
First Big Patch of Fir in Road
Road 260
****All Bearings from Magnetic North****

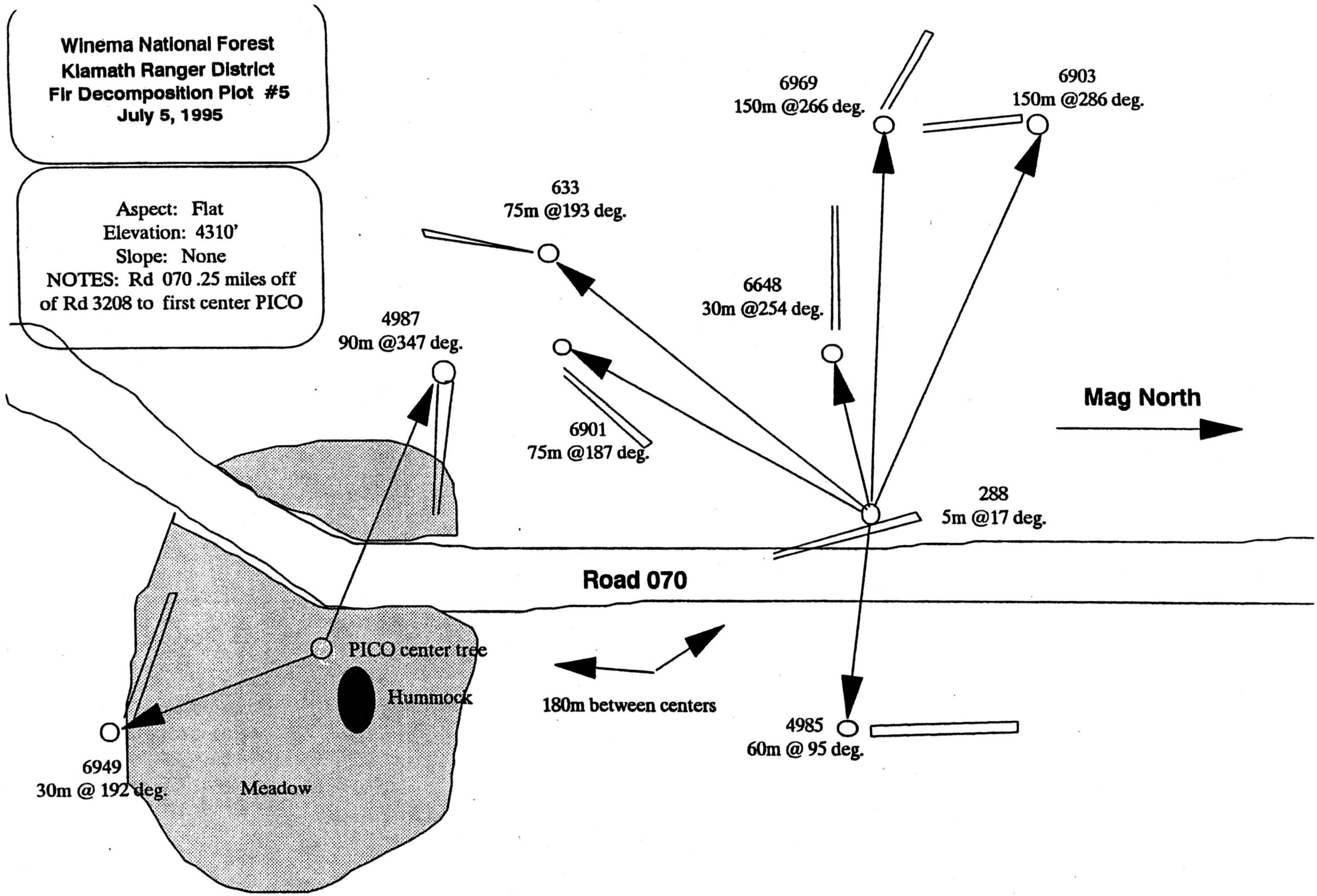


******All Bearings from Magnetic North******

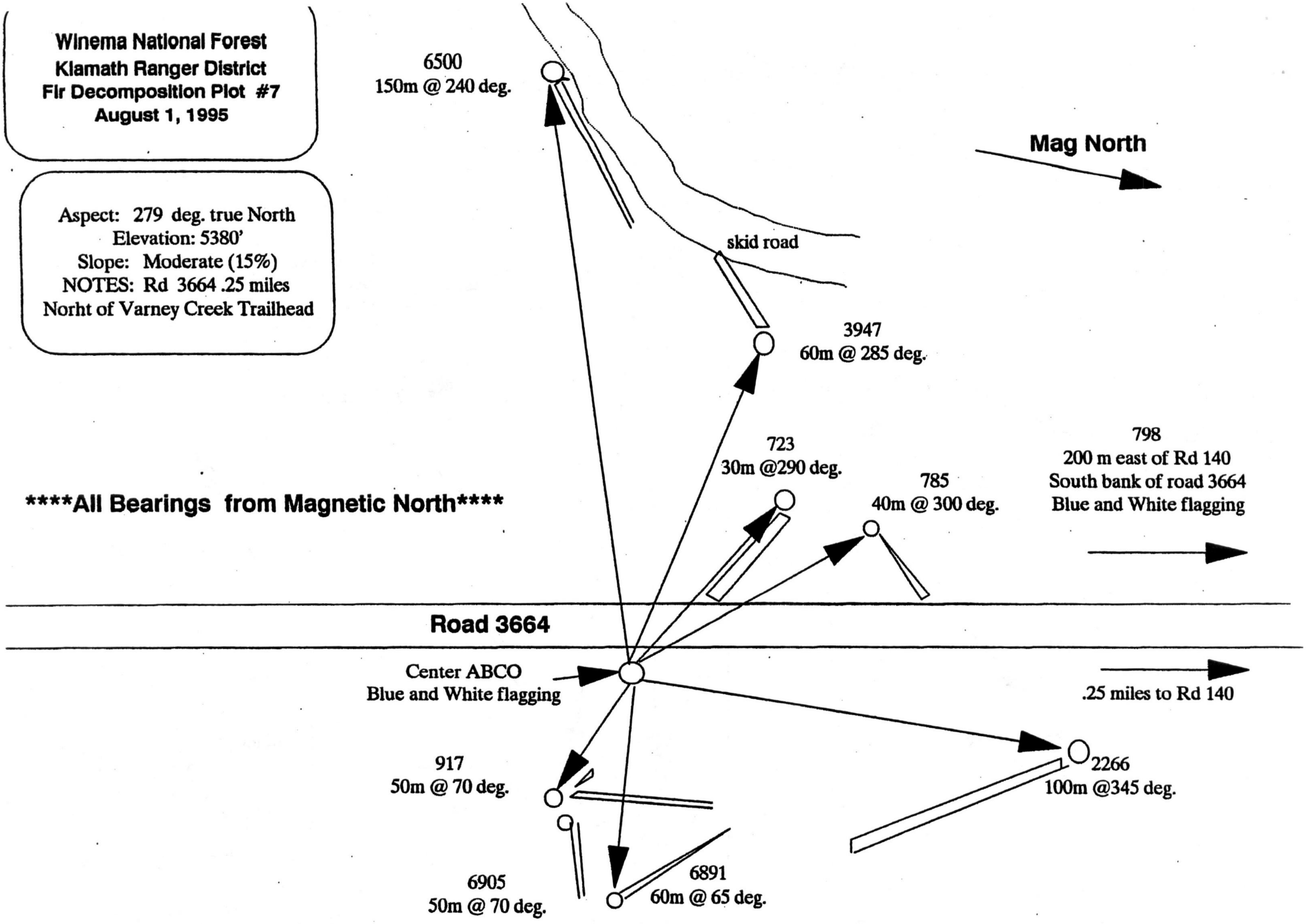

Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #3
July 3, 1995
Aspect: 29 deg. true North
Elevation: 6000'
Slope: Slight (10%)
NOTES: Rd 3419 6.9 miles from Rd 34. Plot Center is Metal Culvert under the road
6989
120m @ 183 deg.
8405
115m @ 273 deg.
clearcut
Mag North
6917
130m @ 272 deg.
Big Rocks
Plot Center is
South end of culvert
Road 3419
clearcut
6933
50m @ 70 deg.
3959
75m @77 deg.
15m from Road
2267
110m @ 33 deg.
979
110m @ 33 deg.
4146
150m @58 deg.
****All Bearings from Magnetic North****

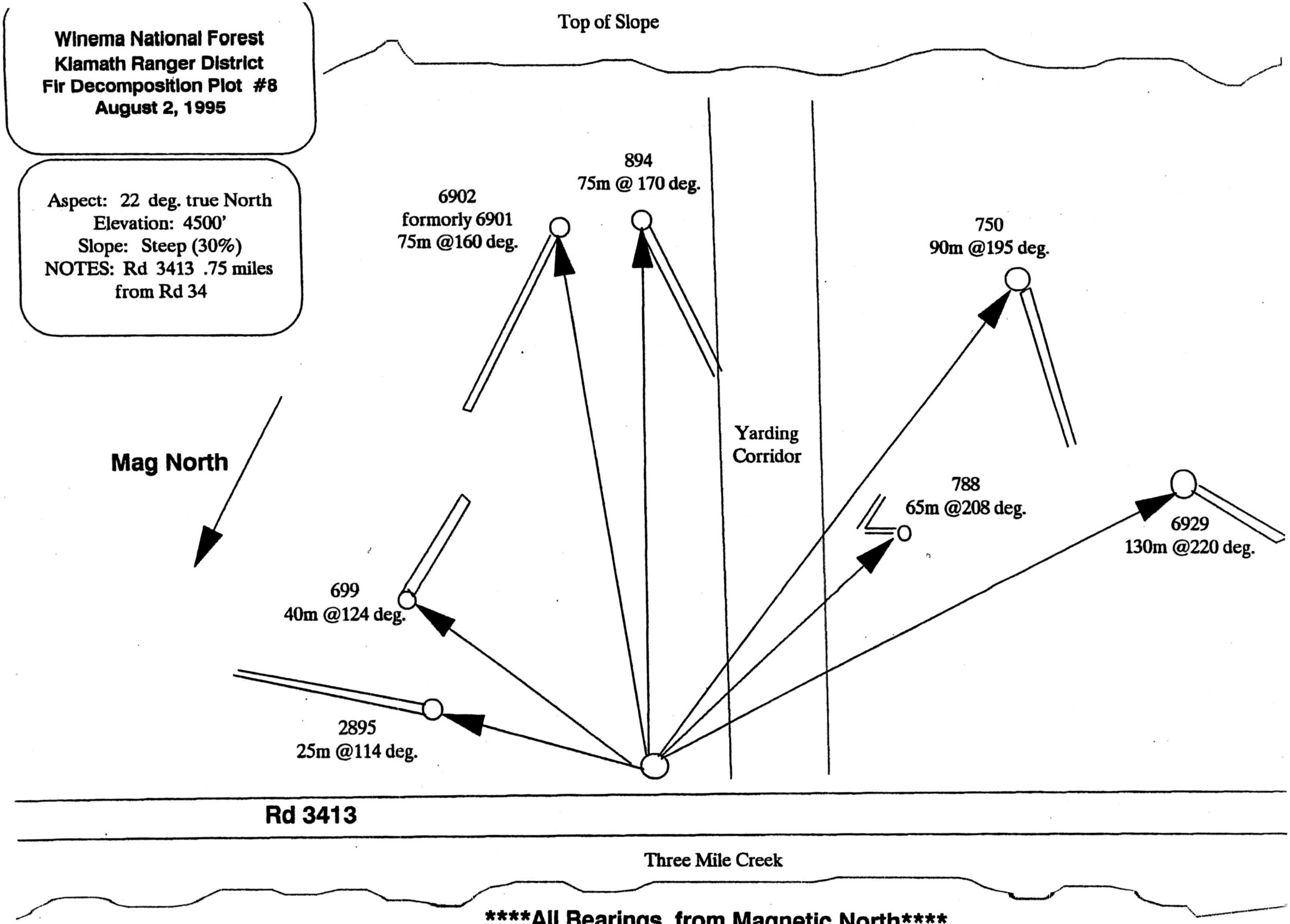


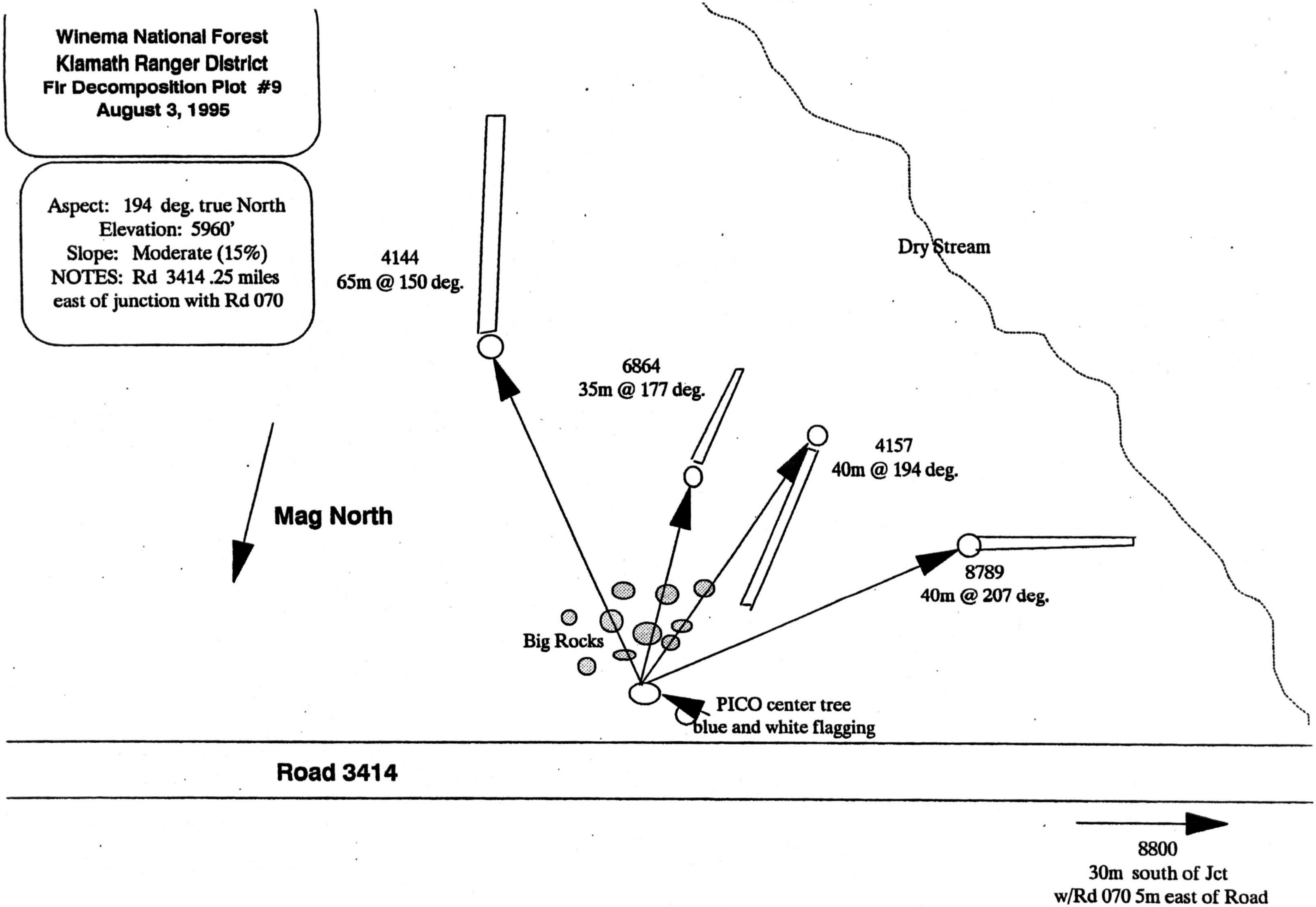
Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #4
July 4, 1995
Aspect: 84 deg. true North
Elevation: 4300'
Slope: Medium (15deg.)
NOTES: Rd 3419 0.3 miles from intersection with Rd 050
Rd 050
200m to Road
3945
175m @53 deg.
3960
130m @80 deg.
Skid trail
8802
100m @83 deg.
process center
6957
150m @ 33 deg.
Seed Tree
PSME # 169
100m @97 deg.
ABCO
flagged orange
50m to center
Tree with
Orange Arrow
toward Seed Tree
Rd 3419
Mag North
****All Bearings from Magnetic North****



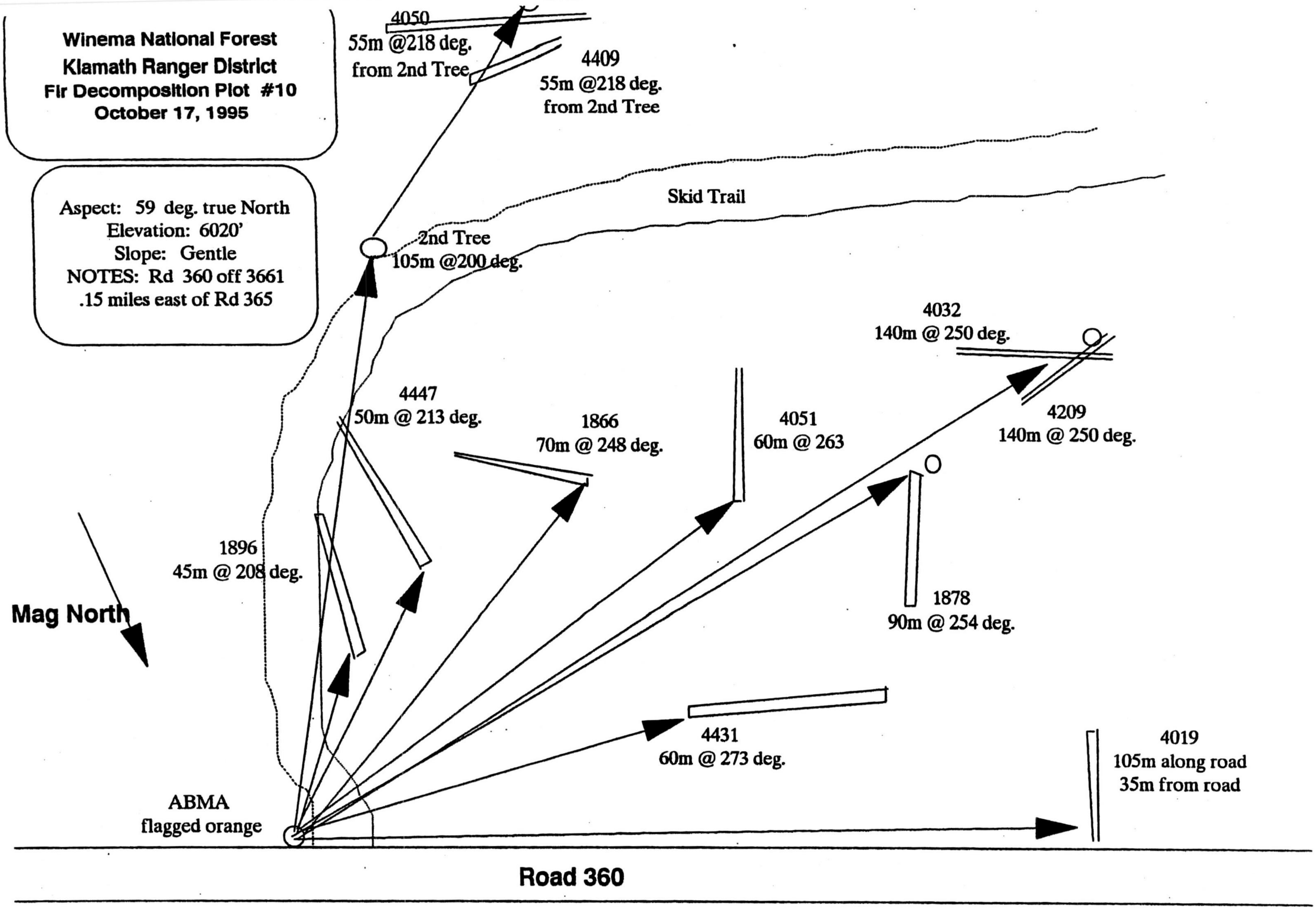
****All Bearings from Magnetic North****


Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #7
August 1, 1995
Aspect: 279 deg. true North
Elevation: 5380'
Slope: Moderate (15%)
NOTES: Rd 3664 .25 miles
Norht of Varney Creek Trailhead
6500
150m @ 240 deg.
Mag North
skid road
3947
60m @ 285 deg.
723
30m @290 deg.
785
40m @ 300 deg.
798
200 m east of Rd 140
South bank of road 3664
Blue and White flagging
****All Bearings from Magnetic North****
Road 3664
Center ABCO
Blue and White flagging
.25 miles to Rd 140
917
50m @ 70 deg.
2266
100m @345 deg.
6891
60m @ 65 deg.
6905
50m @ 70 deg.

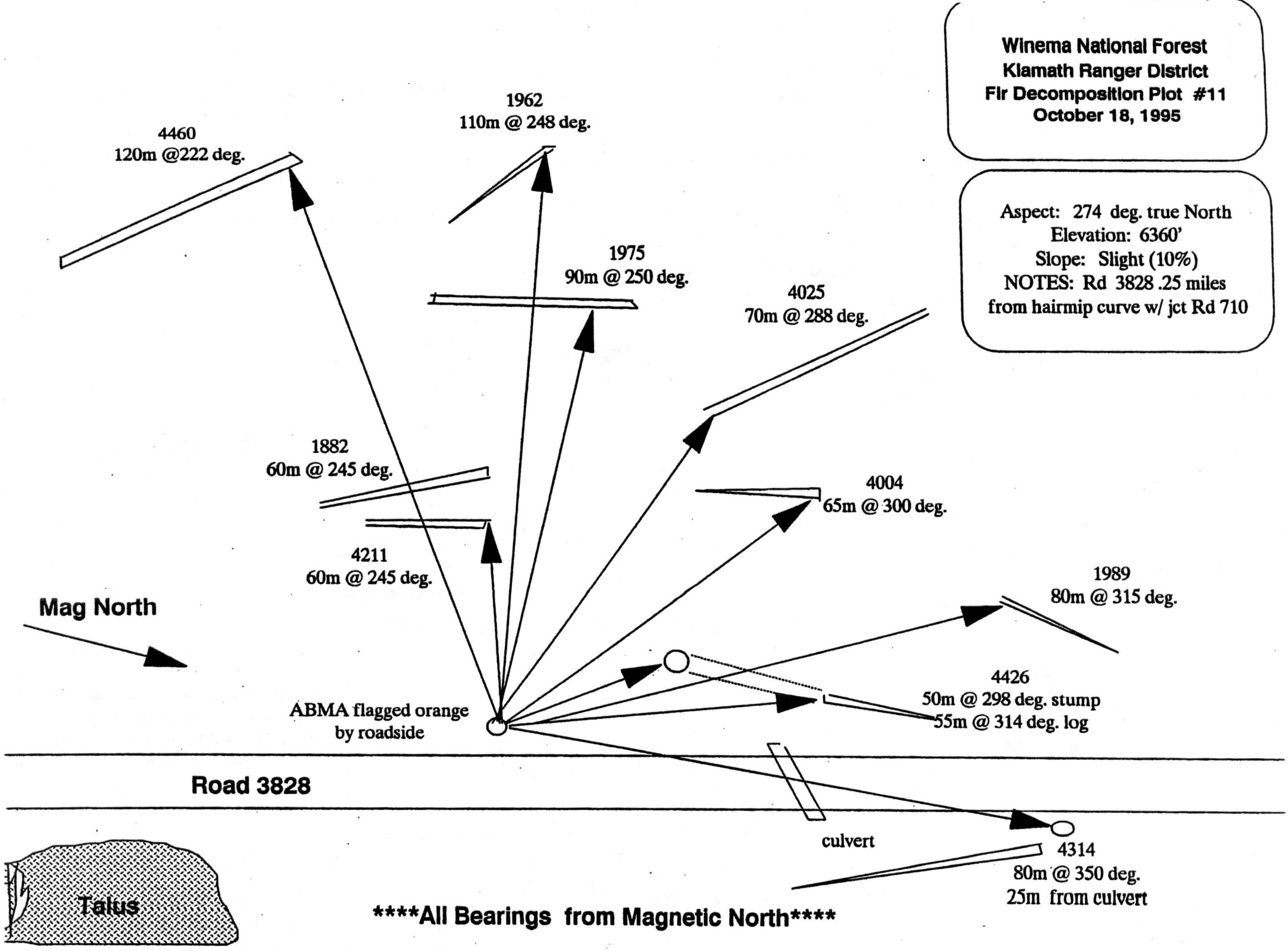

Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #8
August 2, 1995
Top of Slope
Aspect: 22 deg. true North
Elevation: 4500'
Slope: Steep (30%)
NOTES: Rd 3413 .75 miles
from Rd 34
6902
formorly 6901
75m @160 deg.
894
75m @ 170 deg.
750
90m @195 deg.
Yarding
Corridor
Mag North
788
65m @208 deg.
6929
130m @220 deg.
699
40m @124 deg.
2895
25m @114 deg.
Rd 3413
Three Mile Creek
****All Bearings from Magnetic North****

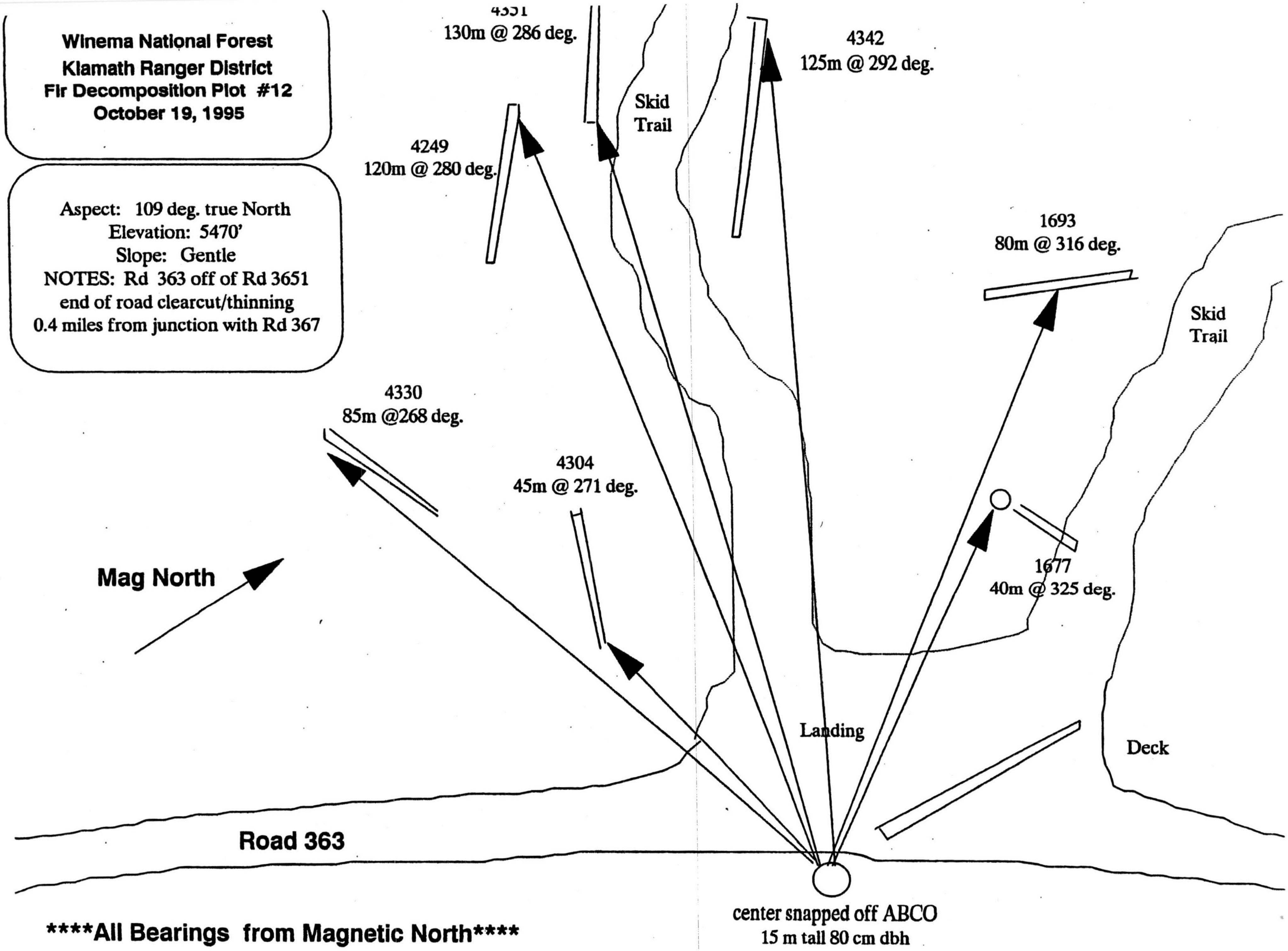


****All Bearings from Magnetic North****



****All Bearings from Magnetic North****


Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #11
October 18, 1995
Aspect: 274 deg. true North
Elevation: 6360'
Slope: Slight (10%)
NOTES: Rd 3828 .25 miles
from hairmip curve w/ jct Rd 710
1962
110m @ 248 deg.
4460
120m @222 deg.
1975
90m @ 250 deg.
4025
70m @ 288 deg.
1882
60m @ 245 deg.
4004
65m @ 300 deg.
4211
60m @ 245 deg.
1989
80m @ 315 deg.
Mag North
4426
50m @ 298 deg. stump
55m @ 314 deg. log
ABMA flagged orange
by roadside
Road 3828
culvert
4314
80m @ 350 deg.
25m from culvert
Talus
****All Bearings from Magnetic North****


Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #12
October 19, 1995
Aspect: 109 deg. true North
Elevation: 5470'
Slope: Gentle
NOTES: Rd 363 off of Rd 3651
end of road clearcut/thinning
0.4 miles from junction with Rd 367
130m @ 286 deg.
4342
125m @ 292 deg.
Skid
Trail
4249
120m @ 280 deg.
1693
80m @ 316 deg.
Skid
Trail
4330
85m @268 deg.
4304
45m @ 271 deg.
1677
40m @ 325 deg.
Mag North
Landing
Deck
Road 363
center snapped off ABCO
15 m tall 80 cm dbh
****All Bearings from Magnetic North****

Winema National Forest
Klamath Ranger District
Fir Decomposition Plot #13
October 20, 1995

Aspect: 69 deg. true North
Elevation: 4220'
Slope: Very Gentle
NOTES: Rd 382 0.1 miles from Rd 34