ALASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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EFFECTIVENESS OF THREE INSECTICIDES APPLIED AT TWO DROPLET SIZES FOR CONTROL OF THE DOUGLAS-FIR TUSSOCK MOTH AND WESTERN SPRUCE BUDWORM

usda • douglas-fir tussock moth • research & development program

by

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ABSTRACT

Carbaryl, trichlorfon, and acephate were evaluated at two different droplet sizes against laboratory raised Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), and field populations of the western spruce budworm, *Choristoneura occidentalis* Freeman. Small droplets of carbaryl and trichlorfon caused higher mortality of both Douglas-fir tussock moth and western spruce budworm than did larger droplets. Small droplets of acephate gave a higher mortality of the western spruce budworm in the field but were less effective against the Douglas-fir tussock moth in laboratory bioassays.

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INTRODUCTION

In the western United States, two major forest defoliators are the Douglas-fir tussock moth, *Orgyia pseudotsugata*[4] (McDunnough), (Wickman 1963, Wickman et al. 1973) and the western spruce budworm, *Choristoneura occidentalis*[5] Freeman (Carolin and Honing 1972). Before 1973, the only extensively used control for these two pests was aerial applications of DDT. The U.S. Forest Service has undertaken an extensive research program to find alternate chemical insecticides. By 1975, field tests had indicated that three chemicals, carbaryl (SEVIN® 4 Oil),[6] trichlorfon (Dylox® 1.5 oil), and acephate (Orthene® 75S) were promising.

All earlier tests used boom-mounted conventional hydraulic pressure nozzles, and the question was raised as to whether other commerically available spray systems could effectively apply these materials. We were particularly interested in rotary atomizer systems, which are reported to increase the total number of droplets per given volume of spray, thus increasing their coverage of the treated area and their chance of contacting the target insect.

A series of tests was conducted in 1975 with the aforementioned insecticides, to compare a rotary atomizer system that produces a small droplet with a conventional hydraulic system that applies larger droplets for control of both the Douglas-fir tussock moth and the western spruce budworm.

MATERIALS AND METHODS

The spray plots were located in the Wenatchee National Forest on the east side of the Cascade Range approximately 32 km northwest of Ellensburg, Washington. Laboratory facilities for conducting the bioassay were at the Department of Biology, Central Washington State College at Ellensburg. Plots in a fir forest that contained an outbreak of budworm were treated, and population reduction was conventionally evaluated. Also, foliage samples were collected after treatment and brought into a laboratory where they were bioassayed by using laboratory reared tussock moth. A bioassay was necessary because, in 1975, no suitable outbreak populations of tussock moth existed.

Twenty-one rectangular plots, each about 6.5 ha in size and separated from each other by a minimum of 1 km, were selected for the test. In the center 1 ha of each plot, 15 open-grown trees, both Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, and grand fir, *Abies grandis* (Dougl.) Lindl., 9 to 18 m high were selected as sample trees.

Three of the 21 plots were randomly selected as untreated controls; the remaining plots were divided into three replicates of 6 plots, each at about the same elevation, giving a randomized block design. The assigning of a treatment to the six plots in each replicate was random. Treatment was made when 90 percent of the bud caps had fallen from the new growth of Douglas-fir.

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[4] Lepidoptera: Lymantriidae.

[5] Lepidoptera: Tortricidae.

[6] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

A Hiller 12E helicopter was used for applying all materials. Standard size spray droplets (referred to as large droplets) were applied with a 9.14-m boom equipped with Spraying Systems (Wheaton, Ill.) T8002 flat-fan nozzle tips. The small droplet size was obtained with five to eight spinning disc atomizers on a 5.49-m support boom. The atomizers were basically the modified version of the Bals Turbair spinning nozzle described by Boving et al. (1971).

Carbaryl (diluted 1:1 with diesel oil) was applied at the rate of 2.24 kg AI/9.35 liters per ha (2 lb AI/gal per acre). Trichlorfon was applied undiluted at 1.68 kg AI/ha (1.5 lb AI/acre). Acephate was applied at 1.12 kg AI/18.7 liters per ha (1 lb AI/2 gal per acre) in water. In mixing each of the formulations, 0.1 percent Rhodamine B dye was added to the finished spray solution to facilitate spray deposit assessment. The dye was first dissolved in oleic acid (2.5 percent of final spray solution) before mixing with trichlorfon and carbaryl.

Spray deposit was sampled from two aluminum plates and one white Kromekote card placed in an open area adjacent to each sample tree. The amount of spray deposit was determined by fluorescent methods (Yates and Akesson 1963). Deposit on the plates was converted to liters per hectare. The cards were used to determine volume median diameter (vmd)[7] and drop density with a Quantimet 720 (Imanco Image Analyzing Computer and Co., Monsey, N.Y.), which electronically counted and sized all spots formed by droplets larger than 20 µm.

[7] Volume median diameter (vmd) is the droplet diameter satisfying the requirement that half of the volume of liquid is in droplets smaller and half is in droplets larger than the vmd.

Samples to be used for bioassay with tussock moth were collected 24 h before treatment and at 30 min (carbaryl and trichlorfon) or 24 h (acephate) after treatment. Three branch tips 30 to 40 cm long were collected from the midcrown of each tree; they were placed in a perforated plastic sack, the sack sealed around the stems, and the base of the branches placed in water. Ten third-instar, laboratory-reared tussock moths were introduced into each sack and allowed to feed for 7 days, after which the number of dead and living larvae was counted to determine percent mortality.

The sample procedure for the budworm was basically that described by Carolin and Coulter (1972); it consisted of counting the number of larvae and buds on two 40-cm branches removed from midcrown of each sample tree at prespray (24 h) sampling and four branches at three postspray sampling intervals (3, 7, and 14 days). The population was expressed as the number of budworm larvae per 100 buds.

Applications began on June 15 and were completed by June 19, 1975. Temperatures ranged from 0° to 17°C. Windspeeds were below 8 km/h and averaged 1-3 km/h. Two short rain showers late in the afternoons of June 18 (0.8 cm) and June 19 (0.5 cm) occurred 7 to 10 h after the applications had been made on the morning of those days. No detectable rainfall occurred during the remaining weeks of the study.

RESULTS

Table 1 shows the analysis of spray deposit that reached the cards and plates. The Bals Turbair type spinning nozzle was found capable of applying all three insecticides and produced droplets with smaller vmd's than the conventional spray system. It also increased the number of droplets recovered per unit of area. If we use the vmd as an average droplet size to determine the volume for that diameter

Table 1--*Results of 1976 Douglas-fir tussock moth and western spruce budworm test using two droplet sizes of three different insecticides*

Treatment	Droplet size	Vmd[1/]	Spray deposit assessment		Tussock moth percent mean mortality[2/]		Pretreatment	Budworm percent population reduction		
			Drops/cm^2	liters/ha	Pretreatment	Posttreatment	No/100 buds	3-day	7-day	14-day
Carbaryl	Large	302	15.3	0.87	3.7a	86.8a	26.7	66.0a	72.3a	85.3a
	Small	192	44.1	1.57	2.0a	98.5a	14.5	79.0a	76.9a	88.3a
Trichlorfon	Large	338	4.9	2.05	1.7a	66.3a	20.7	66.1a	68.0a	63.1a
	Small	208	33.9	2.01	2.3a	90.2b	31.3	92.2b	97.3b	96.2b
Acephate	Large	251	17.9	6.02	1.1a	80.9a	23.3	66.0a	73.1a	83.8a
	Small	200	24.5	2.94	0.4a	68.9a	27.3	79.5a	90.9a	90.8a
Control	--	--	--	--	0.7	5.0	20.8	--	20.9	29.4

[1/] Volume median diameter (vmd) is the droplet diameter satisfying the requirement that half of the volume of liquid is in droplets smaller and half is in droplets larger than the vmd.

[2/] For each pair of treatments (large droplets vs. small droplets), means followed by the same letters are not significantly different ($P=0.05$). Pairs compared by t test for independent means.

droplet, the small droplets of carbaryl were 26 percent of the volume of the large droplets, trichlorfon 23 percent, and acephate 50 percent.

Douglas-fir Tussock Moth

Large droplets of carbaryl gave a mean mortality of 86.8 percent and small droplets, 98.5 percent. This difference was not statistically significant (P = 0.05).

The large droplets of trichlorfon produced 66.3 percent mean mortality. When droplet size was reduced, a sixfold increase occurred in the number of droplets recovered, and the mean mortality increased to 90.2 percent, a statistically significant difference (P = 0.05).

Although the two spray systems satisfactorily atomized the oil-based trichlorfon and carbaryl, giving droplets with a fourfold difference in volume, the same systems used with the water-based acephate produced droplets with only a twofold difference in volume.

The mean mortality obtained from the bioassay of acephate was poorer than expected. Neisess et al. (1976), using a droplet of 533-µm vmd, produced a mean mortality of 97 and 98 percent with a 303-µm vmd droplet. In comparison with these two tests, both sizes of droplets produced less mortality, possibly because much of the mortality of acephate comes from initial contact of the droplets on the target insects, which our bioassay did not measure.

Western Spruce Budworm

Table 1 shows effectiveness of the two droplet sizes in reducing natural populations of the western spruce budworm. No significant difference (P = 0.05) occurred between small and large droplets for carbaryl or acephate at any of the three sample intervals. As with the tussock moth, trichlorfon produced the only statistically significant change in mortality, increasing the population reduction from 63.1 to 96.2 percent (P = 0.05).

DISCUSSION

This study demonstrated that other spray systems besides conventional hydraulic pressure nozzles are capable of applying the three candidate insecticides for control of two important defoliators of western forests. The Bals Turbair type system effectively reduced the vmd for all three materials with corresponding increase in number of droplets recovered at the sampling sites. Use of smaller droplets did not decrease the volume of the spray recovered with the oil-based carbaryl and trichlorfon. The volume of acephate recovered at ground level, however, was less for the smaller droplets than with the large droplets. Future tests with acephate using smaller droplets should take into consideration the possibility of loss by evaporation in the drier climates of the West and the use of antievaporants.

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BIG HUCKLEBERRY ABUNDANCE AS RELATED TO ENVIRONMENT AND ASSOCIATED VEGETATION NEAR MOUNT ADAMS, WASHINGTON

by

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and

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ABSTRACT

Big huckleberry abundance was correlated with associated vegetation and soil pH in a 625 square kilometer (241 square mile) area southwest of Mount Adams, Washington. Annual berry production appeared to be influenced by weather more than by site factors in this area. Douglas-fir site index was not correlated with either *Vaccinium membranaceum* abundance or berry production.

KEYWORDS: Huckleberries, *Vaccinium membranaceum*, ecology (plant), indicator plants, soil pH, climate (-plant adaptation.

Many mountain huckleberry fields in northwestern America are declining as forest trees invade the old burns that provided suitable conditions for huckleberry production early in this century (Minore 1972). Modern fire control techniques have all but eliminated large wildfires in recent decades, and the dwindling areas now suitable for big huckleberry (*Vaccinium membranaceum* Doug. ed Hook.), the most frequently picked species, appear insufficient to maintain the huckleberry resource. If this resource is to be preserved, some forest land should be managed for huckleberries, but only where optimum environments occur. Huckleberry management may be costly, and it should be concentrated on the areas best suited to *V. membranaceum* growth and berry production.

Emmett and Ashby (1934) studied the relationships between soil pH and distribution of *Vaccinium myrtillus* in Britain, only to conclude that their data represented the distribution of acidity in random soil samples rather than the effects of pH on species occurrence. Lilly et al. (1972) compared adjacent areas and found that soil profile characteristics influencing soil moisture status differed between successful and unsuccessful sites, but their conclusions applied only to cultivated highbush blueberries grown in North Carolina. Unfortunately, optimum environments for growth of *V. membranaceum* have not been identified or described.

If meaningful conclusions are to be obtained for *V. membranaceum*, western huckleberry environments should be studied and compared. Some of the most heavily used huckleberry fields in the Northwest are located near Mount Adams, Washington. We studied this area in 1976 and 1977, seeking answers to the following questions:

1. Can easily measured environmental factors and vegetation be correlated with the abundance and productivity of *V. membranaceum*? If they can, what are the correlations?

2. Are Douglas-fir site quality and *Vaccinium* abundance or productivity related? If they are, do the best *V. membranaceum* areas occur on high or low quality forest land?

METHODS

Vaccinium membranaceum environments and associated vegetation were sampled within a 625-square-kilometer[1/] area approximately 25 kilometers southwest of Mount Adams. Located in the Mount Adams District, Gifford Pinchot National Forest, the area includes a variety of soils, vegetation types, and landforms. Sample plots were established at 30 locations chosen to represent a wide range of slope, aspect, elevation, and vegetative conditions. Each plot consisted of sixteen 4-square-meter circular subplots spaced 20 meters apart to sample an area of 0.65 hectares. The sample plots all supported *V. membranaceum*. None were disturbed by logging. There was great variation among plots; but soil, aspect, slope, and vegetation were homogeneous within each plot.

On each sample plot, 13 variables were measured: average aspect azimuth, elevation, slope percent, overstory canopy density, stone cover, stone frequency percent, species presence of all seed plants, species cover percent, species frequency percent, soil pH, silt + clay percent, total nitrogen percent, and acetate exchangeable iron. Because azimuth degrees are poor quantitative expressions of aspect (1° and 359° represent almost identical aspects), aspect azimuths were coded for regression

[1/] English equivalents are given on page 8.

analyses. Coding was accomplished by determining an optimum aspect according to the procedure described by Stage (1976). This optimum value then was used with the aspect transformation equation published by Beers et al. (1966). Overstory canopy densities were measured on each subplot with a spherical densiometer, then averaged for the plot. Cover and frequency percentages for each plot also were based on individual subplot data. Soil analyses were performed in the laboratory on plot samples comprised of blended subsamples collected at 25-centimeter depths from four diagonal subplots in each plot. Where Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees were available, site indices were obtained from total height, age at breast height, and the curves of Curtis et al. (1974).

As plots were established and measured in July and August 1976, each subplot center was flagged. All 30 plots (480 subplots) were revisited in September 1976. Berry production was measured during this second visit; all green and ripe *V. membranaceum* berries within each subplot boundary were picked and combined for each plot. The berries from each plot were labeled, refrigerated, and taken to the laboratory for weighing. Because *V. membranaceum* berries ripened irregularly on every plot and the berries were at different phenological stages in the differing plot environments, all weights of harvested berries were converted to ripe weights. Several hundred randomly selected ripe berries from each plot were weighed and counted to obtain an average weight per ripe berry for that plot. Similarly, a random sample of all berries (ripe and green) from the same plot were counted and weighed to obtain an average weight per berry for all berries harvested. Ripe weight for each plot was then calculated; these calculated weights were used as measures of 1976 *V. membranaceum* berry production on the sample plots.

Plot vegetation was classified into plant communities by using species cover data. Species presence (occurrence on one or more subplots) and frequency (number of subplots supporting species times 100 divided by 16) were used to calculate indices similar to those of Warner and Harper (1972).

In calculating species indices for *V. membranaceum* abundance, we ranked the 30 plots by *V. membranaceum* cover percent, then divided them into three equal groups: high, low, and intermediate. The high and low groups were compared in terms of associated species presence, species by species. (Where identification of individual species was difficult late in the season, as with some grasses, genera were used.) The species differing most between high and low groups were selected as indicators and assigned numerical values based on the magnitude of these differences (table 1). Of the 57 species compared in this way, 13 were selected (table 2).

In calculating indices for 1976 berry production, we ranked the 30 plots by weights of ripe berries, then divided them into heavy, light, and intermediate groups. The heavy and light groups were compared in terms of species presence and frequency. As with the abundance index, the species differing most between heavy and light groups were selected as indicators and assigned numerical values based on the magnitude of these differences. Twelve species were selected for a productivity index based on frequency. Indices based on presence were calculated by averaging the values of all indicator species persent on a plot. Indices based on frequency were calculated by Warner and Harper's (1972) procedure.

Table 1--*Example of indicator species selection and value determination for the* Vaccinium membranaceum *abundance index*[1]

Species	Number of plots supporting species		High minus low	Indicator value
	High group	Low group		
Achlys triphylla	2	4	-2	--
Anemone deltoidea	3	2	1	--
Pachystima myrsinites	7	1	6	12
Pinus contorta	5	8	-3	3
Rumex acetosella	--	5	-5	1
Sorbus scopulina	7	2	5	11
Tsuga mertensiana	8	6	2	--
Xerophyllum terax	10	10	0	--

[1] The number of plots supporting the species in the group of 10 high *Vaccinium* cover plots was compared with the number of plots supporting the species in the group of 10 low *Vaccinium* cover plots. Species with differences of 2 or less (e.g., *Achlys, Anemone, Tsuga,* and *Xerophyllum*) were rejected. Species with differences of 3 or more (e.g., *Pachystima, Pinus, Rumex,* and *Sorbus*) were selected and assigned indicator values determined by relative differences in presence. Negative differences were converted to positive values by adding 6 to all differences.

Table 2--*Indicator species and values used in calculating* Vaccinium membranaceum *abundance indices*[1]

Species	Indicator value
Pachystima myrsinites	12
Sorbus scopulina	11
Abies lasiocarpa	10
Aster spp.	10
Penstemon spp.	10
Epilobium angustifolium	9
Lupinus spp.	9
Pinus contorta	3
Vaccinium ovalifolium	3
Festuca spp.	3
Spirea spp.	2
Agoseris heterophylla	2
Rumex acetosella	1

[1] Index value is the average of the values of all indicator species present on a given plot.

The environmental and vegetative parameters measured on each of the 30 plots were treated as independent variables in two stepwise multiple regression analyses, with *V. membranaceum* ripe berry weight as the dependent variable in one analysis, *V. membranaceum* cover percent as the dependent variable in the other. Significant variables were combined in regression equations relating them to 1976 berry production and abundance of *V. membranaceum* on the areas sampled. Simple regression analyses were used in investigating Douglas-fir site index--*Vaccinium* abundance relationships on plots supporting Douglas-fir site trees.

RESULTS

Elevations ranged from 914 to 1 570 meters in the study area. Slopes varied from 2 to 53 percent, and aspects were well districuted from 4° through 352°. Overstory canopy densities ranged from 4 to 91 percent. Ripe weights of the berries harvested in September 1976 varied from 1 to 4 080 grams per plot (0.15 to 630.12 kilograms per hectare). When these ripe weights were converted to equivalent volumes, the highest yielding plot produced 935 liters per hectare. Huckleberries were marketed at $2 to $3 per liter in 1976, so economic yield on the best area would have been over $1,870 per hectare if all berries had been picked. Big huckleberry cover varied from 5 to 63 percent on the sample plots.

On the 30 plots, eight plant communities were recognized. When plots were classified by these plant communities and the resulting groups compared in terms of berry production and *V. membranaceum* cover percent, variation within community groups was almost as great as variation among groups (table 3). *Abies lasiocarpa/ V. membranaceum/Xerophyllum* may represent an optimum huckleberry community, but no consistent relationships are evident.

Table 3--*Plant communities as related to* Vaccinium membranaceum *berry production and cover*

Plant community[1/]	Number of plots	Average weight of ripe berries	Range in ripe weights	Average *V. membranaceum* cover	Range in cover
		- Kilograms per hectare -		- - - Percent - - -	
Abies lasiocarpa/ V. membranaceum/ Xerophyllum	5	231	139-313	52	36-63
Abies amabilis/ V. membranaceum/ Rubus lasiococcus	4	286	17-630	40	32-47
Abies amabilis/ V. membranaceum/ Erythronium montanum	3	115	12-303	38	36-41
Pinus contorta/ V. membranaceum/ Xerophyllum	4	88	5-252	32	12-55
Pinus contorta/ V. membranaceum/ Lupinus-Carex	5	135	0-574	28	8-48
Pseudotsuga/ V. membranaceum/ Xerophyllum	6	55	3-126	48	38-55
Pseudotsuga/ V. membranaceum/ Linnaea	2	43	38-49	35	25-45
Tsuga-Thuja/ V. alaskaense- V. ovalifolium/ Cornus canadensis- Linnaea	1	6	--	5	--

[1/]These communities are comprised of the dominant species as indicated by cover estimates on each plot. Plots with similar dominants were grouped.

When subjected to regression analyses, elevation, aspect, and the productivity index based on species presence were well correlated with 1976 berry production (r^2 = 0.77). Berry production, however, is often influenced by meteorological factors that vary from year to year. Therefore, we tested our equation by picking berries from additional plots in 1977. Although a light snowpack during the winter of 1976-77 affected berry production, green berries were abundant in July. Unfortunately, a severe hailstorm swept erratically through the study area early in August 1977. Many study plots were denuded; others were undamaged. As a result, the regression equation developed from 1976 data was not applicable to 1977 berry production.

Fortunately, *V. membranaceum* shrub abundance (cover percent) is less influenced by meteorological factors. Unlike berry production, shrub cover remains quite constant from year to year. Two of the regression variables were significantly correlated with *V. membranaceum* cover--soil pH and the abundance index described in tables 1 and 2. When expressed in a multiple regression equation, these correlations accounted for more than half the cover variation among plots:

$$VMC\% = -1.302.79 + 5.0074(AI) + 475.815(pH) - 43.1596(pH^2),$$

r^2 = 0.602, and

standard error of estimate = 9.74;

where VMC% = *V. membranaecum* cover percent,
AI = abundance index,
pH = soil pH.

The calculated relation of pH to VMC% at three AI values is shown in figure 1. When this equation is used, the resulting optimum soil pH for *V. membranaceum* cover is 5.5.

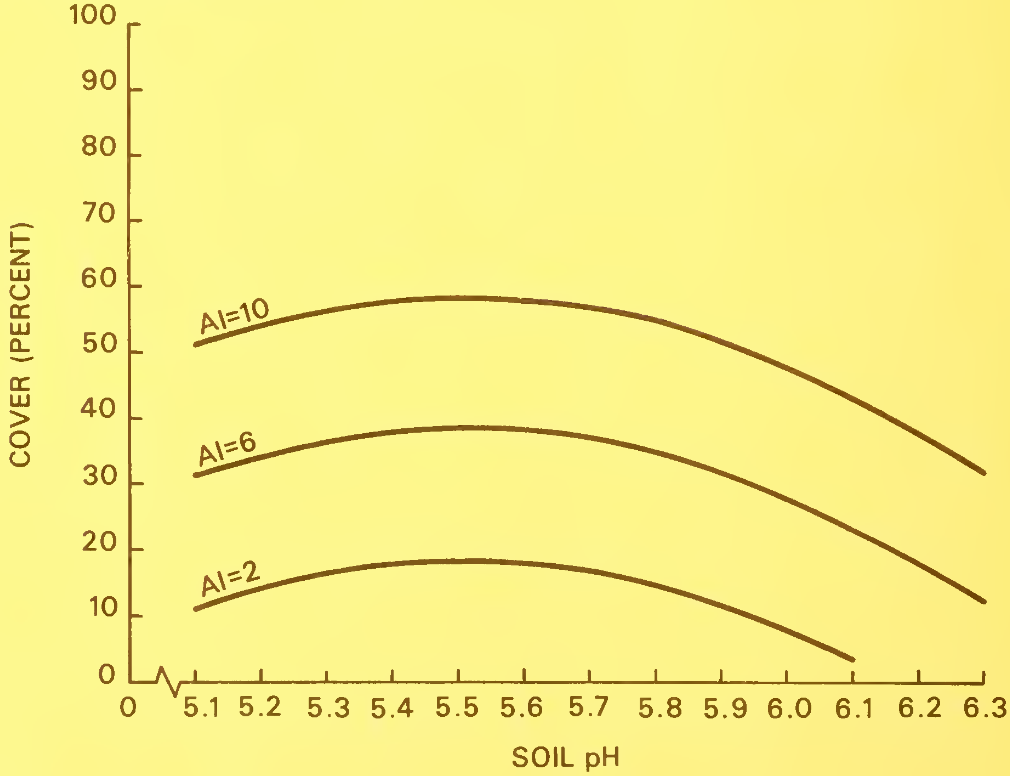

Figure 1.--Calculated relation of soil pH to Vaccinium membranaceum *cover at three abundance indices (AI). Calculated from VMC% = -1.302.79 + 5.0074(AI) + 475.815(pH) − 43.1596(pH²); r² = 0.602).*

None of the other measured environmental variables were sufficiently correlated with *Vaccinium* cover to have significant coefficients in the multiple regression analysis. Separate analyses of 17 plots with Douglas-fir site trees showed no correlation of *Vaccinium* cover or berry production with Douglas-fir site index.

DISCUSSION

Unmeasured meteorological influences apparently are more important than local environmental factors in determining annual berry production, and one or two annual berry crops cannot be used to assess the relative favorability of *V. membranaceum* areas. Depth and duration of the previous winter snowpack, the occurrence of killing frosts, and erratic phenomena like the 1977 hailstorm often obscure the effects of soil, topography, and elevation on berry production in any given year. Meteorological influences are less important in determining huckleberry cover.

Vaccinium cover and berry production are influenced by vegetative succession, however, and suitable environments produce abundant *V. membranaceum* cover only at optimal seral stages. Conversly, optimal seral stages result in abundant cover only in suitable environments. As our association indices are strongly influenced by both succession and local environment, a low AI does not necessarily indicate a poor *V. membranaceum* area--it may reflect a pre- or post-*Vaccinium* stage in succession. Nevertheless, a high AI occurs only at a favorable seral stage on a good area, and it can be used to identify favorable areas in the Mount Adams vicinity.

Soil pH is less affected by succession than the abundance index, and it is significantly related to *Vaccinium* cover. When the regression equation derived from our data is used, the calculated relationship is curvilinear, with an optimum value of 5.5 for all abundance indices (fig. 1). This field observation agrees with the greenhouse observations of Nelson (1974), who found that *V. membranaceum* seedlings grew better at pH 5 than at 3, 4, or 6. Land managers involved in huckleberry management would do well to concentrate their efforts on areas having soil pH values near 5.5. They should choose successional stages having high AI values on these areas.

V. membranaceum abundance, expressed as cover percent, should be a good indicator of area favorability for the species. All other things being equal, good areas have more *Vaccinium* cover than poor areas. Furthermore, areas with more *Vaccinium* cover should produce more berries than those with less cover when annual weather phenomena are averaged over many years.

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ENGLISH EQUIVALENTS

1 centimeter	= 0.3937 inch
1 gram	= 0.035 ounce
1 hectare	= 2.4710 acres
1 kilogram	= 2.2046 pounds
1 kilogram per hectare	= 5.4477 pounds per acre
1 kilometer	= 0.62137 mile
1 square kilometer	= 0.3861 square mile
1 liter	= 0.2642 gallon
1 liter per hectare	= 0.1069 gallon per acre
1 meter	= 3.2808 feet
1 square meter	= 10.7639 square feet 0.0002471 acre

GPO 987-009

ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-323 November 1978

EFFECT OF DEFOLIATION BY THE DOUGLAS-FIR TUSSOCK MOTH ON MOISTURE STRESS IN GRAND FIR AND SUBSEQUENT ATTACK BY THE FIR ENGRAVER BEETLE (COLEOPTERA: SCOLYTIDAE)[1]

by

L. C. Wright[2] and A. A. Berryman[2]

Abstract

The moisture status of grand fir trees defoliated artificially and by the Douglas-fir tussock moth was measured using the pressure bomb technique. Measurements were made from the time of defoliation through the 2 following years. The daily maximum moisture stress was significantly reduced by defoliation in the year of defoliation, but was not significantly affected in the following 2 years. Daily minimum plant moisture stress was not altered significantly. Other variables significantly correlated with moisture stress were vapor pressure deficit, crown class, tree height, and needle length.

Fir engraver attacks and survival in defoliated trees were not correlated with high moisture stress.

KEYWORDS: Plant-moisture relations, defoliation damage, Douglas-fir tussock moth, *Orgyia pseudotsugata*, fir engraver beetle, *Scolytus ventralis*, grand fir, *Abies grandis*.

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INTRODUCTION

Insect defoliation of forest trees can result in growth loss, defect, and mortality of defoliated trees (Wickman 1958 and 1963, Wickman and Scharpf 1972). Much of the mortality may be due to bark beetles which attack the weakened trees (Wickman 1958, 1963) and may subsequently develop into epidemics causing further losses (Patterson 1929, Berryman 1973, Dewey et al. 1974). Most species of bark beetles require trees to be under physiological stress before they can make successful attacks (Caird 1935, Rudinsky 1962, Kozlowski 1969, Berryman 1972). In California, Wickman (1958) studied the mortality of white fir, *Abies concolor* (Gordon and Glendenon Lindley), defoliated by the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) and found that 75 percent of all trees that died were infested by the fir engraver beetle (*Scolytus ventralis* LeConte) and flatheaded and roundheaded borers. In addition, Berryman (1973) concluded that tussock moth outbreaks were a major cause of fir engraver epidemics in grand fir, *Abies grandis* (Douglas) Lindley, in northern Idaho.

Stand and environmental factors, including insect defoliation, have been found to influence plant moisture stress (PMS) of trees (Stephens et al. 1972; Wambolt 1973). High PMS has been correlated with successful bark beetle attack (Vite 1961, Stoszek 1973, Ferrell 1974).

Redmond (1959) found that spruce budworm defoliation resulted in mortality of balsam fir rootlets. Conceivably, this could result in water stress during refoliation in the years following defoliation due to root-crown imbalance. The objective of the present study was to test the hypotheses that moisture stress increases in direct relationship to percent defoliation in the years during and following outbreaks of the Douglas-fir tussock moth and that bark beetle attacks are associated with this increased moisture stress.

MATERIALS AND METHODS

Experimental Plots

Four plots defoliated by the tussock moth were chosen to represent different intensities and years of defoliation. Mensurational data for these plots are given in table 1. In addition to this information the following variables were measured on each sample tree: crown class, crown ratio, 1974 basal area growth, and needle lengths in 1975. Percent defoliation was visually estimated. Vapor pressure deficit was also recorded on the plots at the time of sampling.

Table 1--Summary of measurements made on each plot

Plot	Mean plot mensurational data					PMS measurements						Years since last defoliation
	D.b.h. (inches)	Height (feet)	Age (years)	Percent grand fir	Percent defo-liation	Date	Time[1/]				Number of trees	
							1	2	3	4		
North-South	10.2	47.3	82	--	0-45	IX-3-74	--	--	X	--	7	0
Palouse Divide	8.4	50.2	50	45.7	0-45	VII-20-74	X	X	X	X	5	1
Twin Buttes	10.6	68.1	61	62.2	[2/]10-80	VII-23-74	X	X	X	X	6	1
						VII-22-75	X	--	X	--	5	2
Fox Prairie	4.7	29.1	55	78.1	[3/]0-95	VII-10-75	X	--	X	--	[4/]15	2
						VIII-8-75	X	--	X	--	[4/]14	2
Artificial defoliation	[5/]	6.1	[5/]	[5/]	0-100	VII-25-75	--	--	X	--	12	0
						IX-5-75	X	--	X	--	12	0

[1/] 1 = presunrise, 2 = midmorning, 3 = midafternoon, 4 = sunset. An X indicates measurements were made.

[2/] This plot was defoliated with approximately equal intensity in 72 and 73.

[3/] Suffered two years of defoliation but only final (73) defoliation known.

[4/] One additional tree measured in midafternoon only.

[5/] Not measured because only simple regressions done with data from this plot.

The North-South plot, located on the St. Joe National Forest in northern Idaho, was used to determine the immediate effects of defoliation. The Palouse Divide plot located near the North-South plot, and the Twin Buttes plot on the Umatilla National Forest in southeastern Washington, were used to measure moisture status of trees in the year following the last defoliation. None of these plots were defoliated heavily enough to cause significant tree mortality and fir engraver beetle populations were rather low. In order to correlate beetle attack with PMS, the Fox Prairie plot on the Umatilla National Forest in northeastern Oregon was added in 1975. Many grand fir on this plot had been attacked by the fir engraver beetle in 1974.

A plot of artificially defoliated trees was set up near Harvard, Idaho to measure the physiological effects of defoliation by carefully controlled experiments. Twelve trees were defoliated by clipping the foliage with scissors on July 17 and 18, 1975. The trees were sparsely distributed, open grown, and all vegetation was removed around each one to minimize variation due to competition. Defoliation intensities were 99, 67, 33, and 0 percent of the total crown area with three replicates per defoliation class. The foliage was removed from the top down which is similar to the pattern of tussock moth defoliation. Artificial defoliation, however, does not necessarily mimic natural tussock moth defoliation.

Plant Moisture Stress

The pressure bomb method was used to evaluate moisture stress of defoliated trees (Scholander et al. 1965, Waring and Cleary 1967). This procedure measures the negative pressure on the column of water in the xylem. Plant moisture stress is defined as the absolute value of the negative xylem pressure.

Naturally defoliated trees were selected as close together as possible but had suffered different amounts of defoliation. Three twigs were removed from each tree using a pole pruner or a 12-gauge shotgun; one from the top third of the crown, one from the middle third, and one from the lower third. PMS was measured immediately following twig removal. Only twigs with needles were used, although many of the twigs had received some defoliation. Daylight readings were taken from sunlit portions of the crown. The readings from each tree were averaged to give one value per tree. A single midcrown branch was used to measure PMS on the artificially defoliated trees.

Measurements were made once each summer during peak *S. ventralis* flight, with the exception that the North-South plot was sampled at the end of defoliation, and the Fox Prairie plot at the beginning and middle of *S. ventralis* flight in 1975. (See table 1 for dates and the times measurements were taken.)

Fir Engraver Beetle Attacks

Each tree on the Fox Prairie plot was carefully examined on July 9-10, August 14, and October 1, 1975, for external evidence of bark beetle attack. The plots were visited again in the summer of 1976, and the dead trees were felled and sampled using the techniques of Berryman (1973).

Statistical Analysis

Linear regression and correlation were used to determine the effects of each independent variable on PMS. Trial calculations and graphical analysis indicated all relationships were approximately linear within the ranges measured. Multiple regression and correlation were used to determine the combined effects of the independent variables on moisture stress. Differences in PMS means between crown levels were analyzed using the t test.

RESULTS

Grand fir exhibited a daily PMS cycle of increasing stress from sunrise until midafternoon followed by a decrease until sunrise, a pattern which has been observed in many plants (Scholander et al. 1965, Klepper 1968, Lassoie 1973, Hellkvist et al. 1974). The daily grand fir PMS was highly correlated with vapor pressure deficit of the air ($r=0.827$, $p<0.001$, $N=20$, $Y=5.17+0.60X$).

The Year of Defoliation

Maximum daytime moisture stress during the season of defoliation was significantly decreased by both tussock moth and artificial defoliation (fig. 1). Artificial defoliation did not reduce PMS until it exceeded 33 percent. Minimum PMS, which occurs in the early morning, was not significantly affected by defoliation ($r=0.138$, $p>0.10$).

Multiple regression analysis of the North-South data revealed that defoliation was the most important variable in determining maximum PMS, explaining 72.6 percent of the variation (table 2).

The maximum (afternoon) PMS of naturally defoliated crown tops was significantly lower than that of the undefoliated bases ($\bar{X}$(top)=12.2 atm., $\bar{X}$ (base)=15.1 atm., $t=6.7$, $p<0.01$). In undefoliated trees, however, this

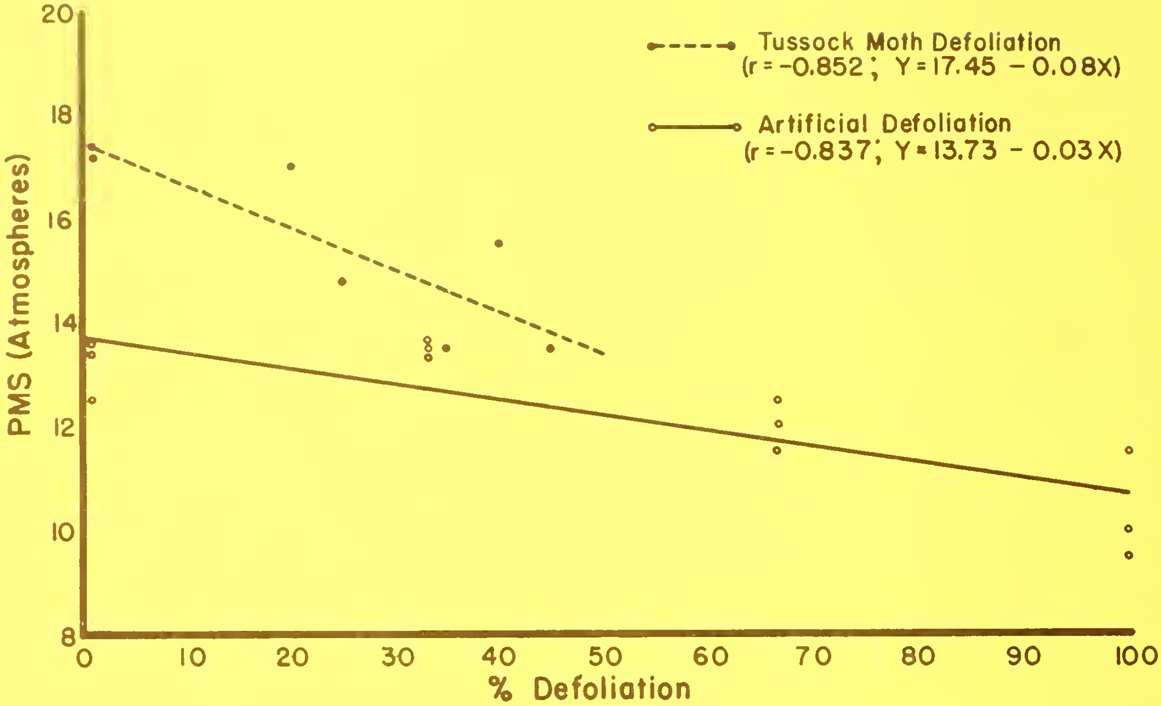

Figure 1.--The effect of current defoliation on daily maximum plant moisture stress; correlation coefficients significant at the 0.05-(tussock moth defoliation) and 0.01-(artificial defoliation) levels.

relationship was reversed ($\bar{X}$(top)=19.0 atm., $\bar{X}$(base)=15.8 atm., $t=19.0$, $p<0.01$).

The afternoon PMS of artificially defoliated trees was not altered until defoliation surpassed 33 percent (fig. 1). This is because only one midcrown branch was measured and the defoliation did not extend down to midcrown until the trees were defoliated more than 33 percent. The relationship between artificial defoliation and PMS was remarkably similar on the two sampling dates; i.e., July 25, $r=-0.837$, $Y=13.73 - 0.03X$, $\bar{X}=12.25$ (fig. 1) September 5, $r=-0.648$, $P<0.05$, $Y=14.3 - 0.02X$, $\bar{X}=13.29$.

One Year Following Defoliation

The influence of defoliation on PMS was considerably reduced in the year after defoliation. Neither early morning nor midafternoon PMS was significantly affected by percentage defoliation (tables 2 and 3). However, there was a tendency for morning (minimum) PMS to be directly associated with defoliation suggesting that increased stress may occur in the year following defoliation.

Table 2--Simple and multiple correlation between selected independent variables and mid-afternoon (daily maximum) plant moisture stress from the year of defoliation through the 2 following years

Years since last defo-liation	Statistic	Variable and order of entry into multiple regression model[1]								N
		1	2	3	4	5	6	7	8	
		Defoli-ation	Height	Crown class	Crown ratio	Age	D.b.h.	Growth rate	[2]	
0	Simple r	-0.852**	-0.619	0.507	-0.609	0.004	-0.167	-0.140		7
	Percent variation explained by model ($100R^2$)	72.6**	94.6**	98.5***	99.5**	[3]	[3]	[3]		
		Crown class	Age	Plot	Growth rate	Height	D.b.h.	Defoli-ation	Crown ratio	
1	Simple r	0.737***	0.001	0.412	0.112	-0.004	0.419	-0.354	-0.191	11
	Percent variation explained by model ($100R^2$)	54.3***	71.0***	89.6***	93.2***	93.5***	94.1***	96.3**	96.4	
		Crown class	Needle length	Height	D.b.h.	Defoli-ation	Plot	Crown ratio	Age	
2	Simple r	0.354	-0.338	-0.030	0.193	0.084	0.053	0.046	0.061	19
	Percent variation explained by model ($100R^2$)	12.5	24.7**	27.6**	31.6**	32.9**	33.5**	33.9**	34.0*	

1/ Variables were added in decreasing order of importance to regression model according to their contribution to R^2.

2/ No plot variable because only the North-South plot was used for this year's data.

3/ Zero degrees of freedom.

*, **, *** Significant at the 0.1-, 0.5-, and 0.01-levels, respectively.

Table 3--Simple and multiple correlation between selected independent variables and predawn (daily minimum) plant moisture stress for 1 and 2 years following defoliation

Years since last defo-liation	Statistic	Variable and order of entry into multiple regression model[1/]								
		1	2	3	4	5	6	7	8	N
		D.b.h.	Crown class	Defo-liation	Age	Height	Plot	Crown ratio	Growth rate	
1	Simple r	0.734***	0.629**	0.393	0.155	0.555*	0.197	0.081	-0.082	11
	Percent variation explained by model ($100R^2$)	53.9***	69.9***	82.7***	84.7***	85.7***	86.6**	86.7*	87.4	
		Needle length	Plot	Defo-liation	Crown class	Crown ratio	Age	D.b.h.	Height	
2	Simple r	-0.513**	0.248	0.336	0.012	-0.052	0.080	-0.073	-0.103	20
	Percent variation explained by model ($100R^2$)	26.3**	31.0**	35.5**	38.0**	38.8**	41.9**	44.6**	46.9**	

[1/] Variables were added in decreasing order of importance to regression model according to their contribution to R^2.

*, **, *** Significant at the 0.1-, 0.05-, and 0.01-levels, respectively.

In addition, percent defoliation was the third most important variable in determining early morning PMS (table 3). On the other hand, afternoon (maximum) PMS still exhibited a tendency towards an inverse relationship to defoliation (table 2).

Two Years Following Defoliation

The correlation between percent defoliation and afternoon (maximum) PMS in the 2d year following defoliation was insignificant (table 2). Although not statistically significant, there was a tendency for more heavily defoliated trees to have higher early morning (minimum) PMS measurements (table 3). The only significant correlation was between needle length and early morning PMS which indicated that trees with shorter needles had higher stress levels (table 3). There was also a strong negative interaction between percent defoliation and needle length ($r=-0.982$, $P<0.001$) on the Fox Prarie plot, suggesting that defoliation may have a more significant effect on early morning PMS than the analysis indicates.

Bark Beetle Attacks

All but one of the sample trees on the Fox Prairie plot received at least one *S. ventralis* attack by October 1, 1975, and of these, three died (table 4). Only heavily defoliated trees were successfully attacked, but there appeared to be no correlation between PMS and tree mortality, beetle attacks, or beetle survival.

Table 4--Plant moisture stress and *S. ventralis* attacks and survival in Douglas-fir tussock moth defoliated *A. grandis*

Tree	PMS				Attack success	Beetle data from killed trees		
	9-10 July 75		14 August 75			Attacks/ft^2	Emergence/ft^2	Emergence/attacks x 2
	AM	PM	AM	PM				
C1	4.2	12.2	6.3	15.7	unsuccessful	--	--	--
C2	4.8	11.3	4.8	16.8	unsuccessful	--	--	--
C3	3.8	10.3	4.5	17.0	unsuccessful	--	--	--
1	5.7	16.2	4.2	16.8	not attacked	--	--	--
2	6.5	17.5	6.0	17.3	unsuccessful	--	--	--
3	4.3	13.7	4.0	15.3	unsuccessful	--	--	--
4	4.2	12.0	5.8	15.5	unsuccessful	--	--	--
5	5.2	13.8	4.7	15.8	unsuccessful	--	--	--
6	6.5	11.7	5.7	11.8	successful	34.71	0	0
8	6.5	13.0	5.3	13.2	unsuccessful	--	--	--
9	5.2	11.5	4.5	11.7	unsuccessful	--	--	--
10	4.5	13.3	4.8	13.8	unsuccessful	--	--	--
11	5.8	10.7	4.0	13.8	unsuccessful	--	--	--
12	5.2	10.7	4.0	10.8	unsuccessful	--	--	--
13	5.0	7.0	dead	--	successful	6.09	1.02	0.084
15	1/	8.5	1/	5.0	successful	2.84	0	0
246 2/	15.5	13.5	1/	1/	successful	8.19	30.03	1.833

1/ Not measured.

2/ All trees from Fox Prairie plot except 246 which was from the Twin Buttes plot and was measured on July 23, 1974.

CONCLUSIONS

The most conclusive result of the present study is that defoliation reduced afternoon moisture stress in grand firs during the year that defoliation occurred, and in the area of the tree subject to defoliation. This result is hardly surprising because defoliation reduces the transpirational surface area and hence water loss from the crown. Conservation of water during the peak diurnal evapotranspiration period reduces moisture stress in the tree at this time.

Although the effects of defoliation were not statistically significant in the 2 years following foliage removal, there were some interesting trends. For example, defoliation appeared to play an important role in determining early morning PMS, being included in step three in the multiple regression analysis, and improving the coefficient of multiple determination by 12.8 and 4.5 percent in the 2 years, respectively (table 3). Above average precipitation in the winters and summers following defoliation[3] may have prevented a significant increase in early morning PMS. Although the hypothesis, that defoliation causes rootlet mortality (Redmond 1959) which results in moisture stress in the years following defoliation, could not definitely be established, the above observations suggest that there was a tendency toward increased PMS which may become pronounced under drought conditions.

An interesting interaction was discovered between PMS, needle length, and percent defoliation. Trees under high moisture stress had shorter needles, suggesting that needle length may be adapted to moisture conditions in the tree. In addition, needle length was inversely related to percent defoliation. The product of these two effects should be a strong direct effect of defoliation on PMS. That this was not observed indicates that the tree compensates for the effect of defoliation, perhaps by producing shorter needles so as to minimize evapotranspiration. A similar reduction in crown area in white fir infected with *Fomes annosus* root decay probably accounts for the finding that the trees showed no increased early morning PMS until more than 95 percent of the roots were decayed (Ferrell and Smith 1976).

The suspected relationship between defoliation, high PMS in the following years, and attack by the fir engraver beetle could not be demonstrated because PMS was not significantly increased by the effects of defoliation. Also, trees which were attacked and killed by the bark beetle were not noticeably higher in PMS than those that survived. The mechanism through which defoliated trees become susceptible to fir engraver attack has yet to be determined; however, we suspect that carbohydrate or oxygen deficits may be involved.

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[3] Climatological data for 1974, 1975 from U.S. Environmental Data Service, Meacham, Oreg.

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GPO 987-144

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LASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-324

November 1978

Foliar Essential Oils and Deer Browsing Preference of Douglas-fir Genotypes

by

M. A. Radwan, *Principal Plant Physiologist*

ABSTRACT

Yield and composition of essential oils were compared in foliage of Douglas-fir. Five clones with different susceptibilities to deer browsing were used; foliage was collected during the dormant season. There were no qualitative differences among the oils of the different clones, but the oils differed quantitatively in all variables measured. Eight variables appeared useful in separating resistant from susceptible clones. Only one compound, however, an unidentified chemical, seemed capable of distinguishing between all three deer browsing preference classes.

KEYWORDS: Essential oils chemistry, browse preference, genotypes, Douglas-fir, *Pseudotsuga menziesii*, deer (black-tailed).

INTRODUCTION

Feeding selection by black-tailed deer (*Odocoileus hemionus columbianus* Richardson) among Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) genotypes has been recently documented (Dimock et al. 1976). A universally accepted basis for such voluntary animal preferences, however, has yet to be established. Studies of factors affecting relative preference are necessary for a better understanding of plant-animal relationships and for devising methods of alleviating animal damage to forest trees.

Foliar essential oils and their terpenoid components have been prominent among the different chemical factors studied and have been postulated to influence feeding preference by deer (Radwan 1974). Important studies with Douglas-fir included determination of compositional changes in the oils during needle maturation (Maarse and Kepner 1970), evaluation of effects of the oils and their individual terpenes on deer rumen microbial activity *in vitro* (Oh et al. 1967, Oh et al. 1970, Radwan 1972), and determination of level and composition of volatile terpenes emitted from foliar essential oils (Radwan and Ellis 1975). There are no reports in the literature on relationships between content of whole essential oil or levels of its terpene components and selective deer browsing among foliage of different Douglas-fir trees.

In this study, therefore, I determined the yield and composition of the essential oils isolated from foliage of five different Douglas-fir clones previously ranked according to browsing preference by black-tailed deer. I compared clones by chemical component and attempted to identify the variables which were important in distinguishing between clones of the different deer browsing preference classes.

MATERIALS AND METHODS

PLANT MATERIAL

Test trees were from five different grafted clones (SD-8, SD-10, SD-13, SD-19, and SD-22) grown at the Olympic National Forest's Dennie Ahl Seed Orchard in western Washington. At time of sampling in 1974, the trees were 16 years old. Foliage from the clones had been ranked earlier into three preference classes according to browsing preference by captive deer--susceptible (SD-10 and SD-19), intermediate (SD-8), and resistant (SD-13 and SD-22) (Dimock et al. 1976).

Periodically, 100-g composite samples of foliage were collected from five trees of each clone in early morning during the dormant season. Each sample was obtained from current year's growth and consisted of 5-cm tips of secondary laterals cut from all sides of the trees at a height of about 1.5 m. Samples were individually sealed in precooled jars and brought to the laboratory in a portable cooler. There were 10 sample collections during the season.

CHEMICAL ANALYSES

In the laboratory, fresh foliage from each composite sample was chopped into small pieces. Subsamples were taken for moisture determination at 65°C, and isolation of essential oils.

Essential oils were obtained by blending tissue in minimum amounts of distilled water followed by steam-distillation for 4 hours in a Clevenger-type apparatus (Clevenger 1928) and collecting the oils in n-heptane. The oil solutions were diluted to a common volume with heptane after adding n-tetradecane as internal standard; they were then transferred to airtight vials equipped with Teflon® 1/ septa and stored at -15°C until analyzed by gas-liquid chromatography.

Separations of the oil components were carried out with a gas chromatograph equipped with flame ionization detectors and two open tubular, stainless steel columns. Columns were 61 m by 0.05 cm (inner diameter) coated with a mixture of 95-percent Carbowax 20M plus 5-percent Igepal CO-880. Operating conditions were: injection port, 250°C; detector, 250°C; column, isothermal at 70°C for the first 3 min, programed to 150°C at 2°C/min, and held at 150°C for 8 min; and N_2, H_2, and air flows of 4, 25, and 250 ml/min, respectively. Resolved peaks were identified by comparing relative retention times of unknowns on two columns (Carbowax 20M and SF-96(50)) and their infrared spectra with those of unknown compounds and by peak enrichment. Compounds were quantified by measuring peak areas with electronic integrator. Average yields per gram of tissue for the individual clones were calculated based on the 10 samples collected and two injections per sample.

RESULTS AND DISCUSSION

Yields of the essential oils of the five clones and their terpene components in both the monoterpene hydrocarbon and oxygenated monoterpene regions are shown in table 1. The oils contained over 40 compounds each, but many were consistently present in small or trace amounts. Compounds identified were similar to those found earlier in foliar oils of Douglas-fir (Maarse and Kepner 1970); and as expected, the oils were predominantly (78-86 percent) composed of monoterpene hydrocarbons. Most abundant components present in the oils were α- and β-pinene, sabinene, 3-carene, δ-terpinene, and terpinolene in the monoterpene hydrocarbon region, and terpinen-4-ol and α-terpineol in the oxygenated monoterpene region.

There were no qualitative differences among the oils of the different clones. In all collections, the same terpene components were detected in oils of the five clones.

Quantitative differences between clones were apparent in all terpenes comprising the oils, also in the sums of terpenes in the monoterpene hydrocarbon region, the sums of compounds in the oxygenated monoterpene region, and total yields of all terpenes. Levels of these variables, therefore, are characteristic of the different clones.

Comparisons of the different foliar oils indicated eight variables which appeared useful in distinguishing between clones of the different preference classes. These indicators of preference included the unknown compound represented by peak 30, β-phellandrene, linalool, citronellyl acetate, α-terpineol, geranyl acetate, the sum of terpenes in the monoterpene hydrocarbon region, and the total terpene yield. Level of the unknown compound (peak 30) was highest in the susceptible clones, intermediate in the oil of clone SD-8, and lowest in foliage of the two resistant genotypes. Remaining indicators, on the other hand, were higher in the resistant than in the susceptible clones, but not strictly intermediate in the foliage of the clone with the intermediate susceptibility to browsing

1/ Trade names mentioned do not constitute endorsement by the U.S. Department of Agriculture over similar products.

Table 1--*Composition and yield of foliar essential oils of different Douglas-fir clones*[1/]

Peak number	Component	Peak area (x 10^6)				
		Clone SD-10	Clone SD-19	Clone SD-8	Clone SD-13	Clone SD-22
	MONOTERPENE HYDROCARBON REGION					
2	α-pinene	17.14	25.38	20.88	27.16	31.60
3	Camphene	1.66	3.78	1.16	1.04	2.79
4	β-pinene	34.59	55.94	41.36	57.17	90.90
5	Sabinene	14.02	3.78	11.60	15.48	7.94
6	Δ-3-carene	13.43	3.56	9.12	8.80	8.94
7	Myrcene + α-phellandrene	4.77	2.96	3.38	4.28	5.23
9	α-terpinolene	7.51	1.40	5.34	5.72	2.87
10	Limonene	2.19	4.29	3.48	3.69	8.03
11	β-phellandrene	2.86	1.85	2.40	3.08	3.46
14	δ-terpinene + unknown	13.53	4.17	11.96	11.68	6.42
16	Terpinolene + p-cymeme	29.28	7.10	22.80	25.82	13.14
Total		140.98	114.21	133.48	163.92	181.32
	OXYGENATED MONOTERPENE REGION					
20	Cintronellal	0.08	0.09	0.09	0.06	0.48
21	Linalool	.33	.32	.16	1.31	.43
22	Unknown	1.11	.91	.72	.79	.92
25	Unknown	.75	2.28	.59	.50	1.01
27	Terpinen-4-ol	20.40	4.25	17.53	17.72	7.50
30	Unknown	1.72	1.15	.94	.84	.38
31	Citronellyl acetate	1.58	1.05	2.16	1.60	3.14
32	Unknown	1.59	1.40	.57	1.34	7.38
33	α-terpineol	4.19	3.70	5.45	5.32	5.38
35	Unknown	1.03	.89	.36	.71	1.45
37	Citronellol	.25	.28	.20	.24	.88
38	Geranyl acetate	.98	.40	.92	2.84	2.70
--	Other unknowns	5.09	2.38	2.51	4.04	3.61
Total		39.10	19.10	32.20	37.31	35.26
Total, both regions		180.08	133.31	165.68	201.23	216.58

[1/] Components measured in arbitrary units determined by electronic integrator and calculated per gram of foliage tissue. Values are means of 10 composite samples from five trees each. Susceptibility to deer browsing: SD-10 and SD-19 susceptible, SD-8 intermediate, SD-13 and SD-22 resistant.

(SD-8). The unknown compound, therefore, appeared to be the most sensitive indicator of deer browsing preference.

CONCLUSIONS

The five clones investigated in this study varied in yield and composition of the essential oils of their foliage. Clearly such characteristics of the foliar oils are among the chemical traits which show genetic variation in Douglas-fir, and their determination can be a valuable tool in identifying different genotypes.

Eight variables appeared useful in separating the resistant from the susceptible clones. Only one compound, however, an unidentified chemical, seemed capable of distinguishing between all three preference classes.

Expansion upon the findings of this study is needed. Most probably, measuring deer browsing preference by some continuous variable and increasing the number of clones studied would be desirable. This would permit use of sensitive statistical methods such as discriminant analysis (Rao 1952) to isolate terpenes and terpene ratios with the greatest discriminating ability among foliage of varying susceptibilities to deer browsing. Additionally, studies should be continued to evaluate other chemical compounds, such as chlorogenic acid, which have been shown to be positively associated with palatability of Douglas-fir (Radwan 1975, Tucker et al. 1976). Such biochemical research, coupled with use of advanced statistical methods, could ultimately lead to development of chemical indicators of resistance to browsing and to practical programs to alleviate deer browsing on Douglas-fir.

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SKYLINE YARDING COST ESTIMATING GUIDE

by

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Abstract

Reliable cost estimation is the key to good logging planning. Estimating costs is difficult when a variety of logging plans are being considered, new systems are introduced, or diverse conditions are encountered. An approach for estimating costs that provides insight into an assortment of logging situations is needed.

In this Note we present a breakdown of yarding cost and production elements and a straightforward procedure for determining and comparing the cost of alternative systems. Computation of production rates and costs is demonstrated in the appendix with detailed worksheets.

KEYWORDS: Skidding costs, logging operations analysis/design, skyline logging.

INTRODUCTION

Reliable cost estimates have always been an important part of careful timber harvest planning. For today's stringent silvicultural prescriptions and environmental standards, the preparation of accurate estimates is essential to insure economic production. Making comprehensive cost estimates is further complicated today by several factors that tend to make traditional data obsolete. Some of these factors are rapid advances in equipment design, reductions in average log size, and spiralling inflation.

In view of these influences, the conscientious planner cannot afford to rely solely on past cost records. A methodology must be at hand to structure the cost problem and thereby provide a framework for updating cost data to appropriately reflect today's economy and logging conditions. We also need a structure that furnishes insight into cost behavior to properly evaluate adjustments to cost or production parameters.

Good logging planning, like careful designing, is only achieved by selecting the optimal arrangement after a systematic evaluation of promising alternatives. Therefore, the best logging plan is the one that meets management goals and operational requirements for the least cost. Since cost is the final criterion for judging alternative yarding systems, a reliable method of estimation that can be readily adapted to a variety of situations is imperative. Ideally, the estimating procedure should be applicable to conceptual yarding plans where no hard data exist as well as to modified practices or diverse logging conditions.

PROBLEM FORMULATION

Yarding cost per unit volume, expressed in its simplest form, is the sum of owning costs and operating costs per unit of time divided by the production rate. Since these costs are made of several elements, it is necessary to break down the cost structure to observe the interrelationship of the elements and their influence on total yarding costs. The identification of cost factors of elements gives the insight needed to adjust the yarding plan to achieve minimal costs.

Axel Brandstrom, in his early study on logging costs, observed that the most significant variable affecting yarding cost and production is log size[1] (fig. 1). For small logs where production is inherently lower, yarding cost is highly sensitive to minor changes in the production rate (fig 2).

In evaluating yarding systems, it should be recognized that yarding is only one component of the total cost of a logging system. For example, today's roading costs increase faster than yarding costs, and minimal total logging costs may only be achieved by yarding longer distances. The importance of examining the total costs of each logging system is shown in the worksheets in the appendix that include costs of roading, felling, loading, and hauling. These additional costs should be considered in a comprehensive logging plan even though their analysis is beyond the scope of this estimating guide.

This guide presents a method of formulating yarding costs for a skyline system. It does not generate the numbers needed for cost estimation. Rather, this guide functions as the necessary first step in making accurate predictions by providing the foundation for cost development. It

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[1] Brandstrom, Axel J. F. 1933. Analysis of logging costs and operating methods in the Douglas fir region. 117 p., illus. West Coast Lumberman's Assoc.

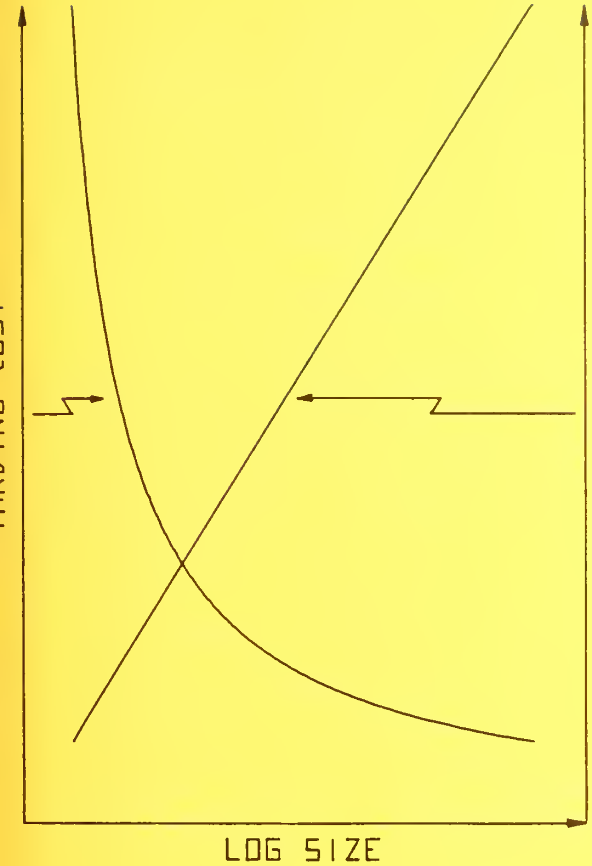

Figure 1.--Yarding cost and production rate versus log size.

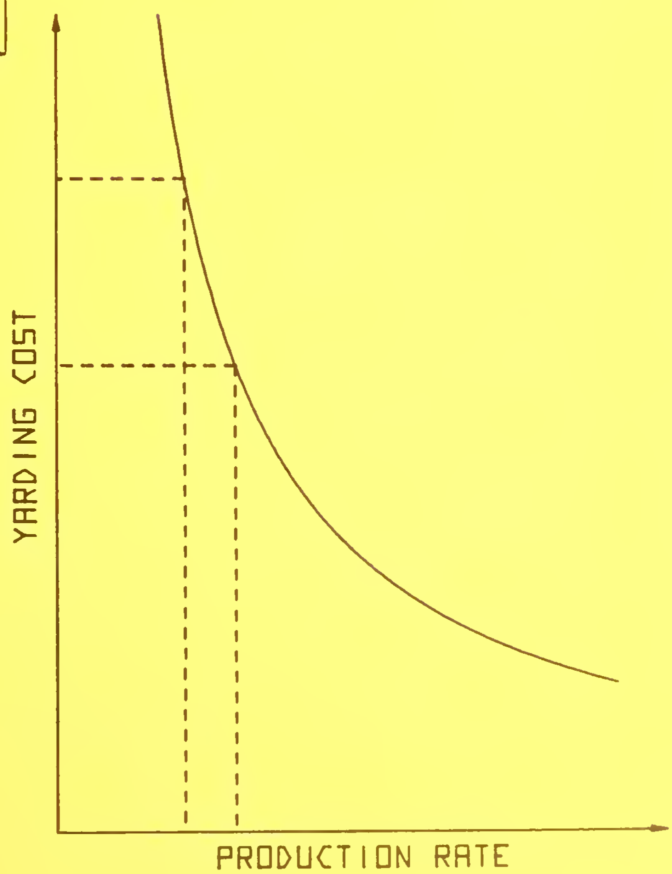

Figure 2.--Sensitivity analysis--yarding cost versus small log production rate.

serves to illuminate the yarding cost structure and to pinpoint sensitive areas where accurate data are required. The next logical step in cost estimation should be the acquisition of the following necessary data.

MACHINE RATE

"Machine rate" is a term commonly used in cost estimation to denote the total owning and operating costs per unit of time for any given equipment. Once the machine rate is established for a given yarder operation, it can generally be used with different production rates for a variety of yarding cost predictions. The machine rate must be recalculated to reflect any significant change in owning or operating costs.

A breakdown of the machine rate is shown in figure 3.

OWNERSHIP COSTS

Equipment Depreciation

For cost estimating purposes, it is generally preferable to use simple straight-line depreciation. This maintains a constant depreciation

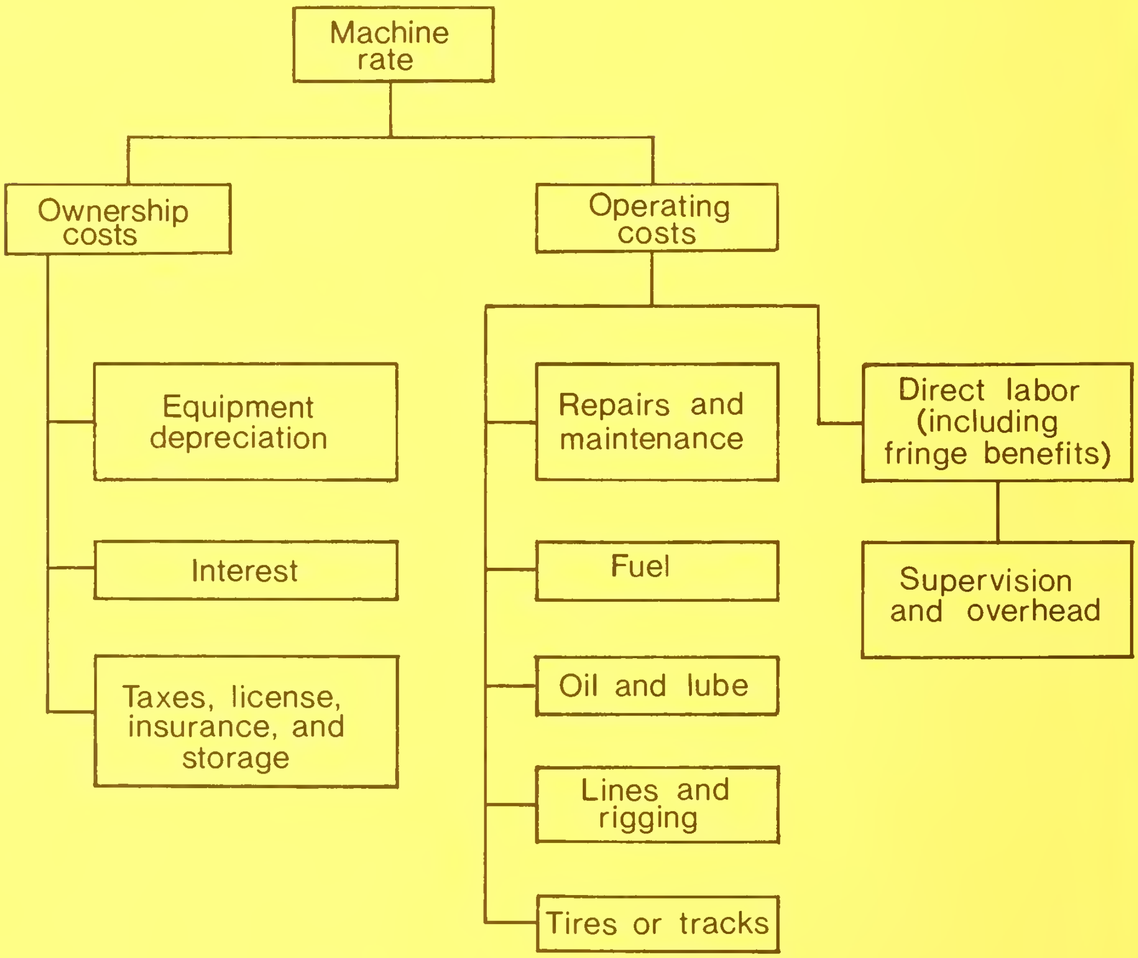

Figure 3.--Machine rate cost elements.

charge over the estimated economic life of the equipment. Residual (salvage) value is the estimated worth of the equipment at the end of the depreciation period. It may range from a high of 20 percent or more of initial cost to as low as the equipment's scrap value.

Interest

Interest may be computed as a uniform expense for the depreciation period of the equipment by applying the interest rate to the average annual investment. In today's economy, interest expense has become a very significant part of the cost of equipment ownership.

Taxes, License, Insurance, and Storage

Taken as a group, taxes, license, insurance, and storage costs can be estimated as a uniform expense based on a percentage of the average annual investment. This item may vary from 2 to 20 percent or more, depending on the type of equipment, location, etc.

OPERATING COSTS

Repairs and Maintenance

Although repairs and maintenance are related to equipment usage, the cost may be estimated as a percentage of equipment depreciation for convenience. Repairs and maintenance cost should account for repair parts and any outside labor. Crew costs related to repairs during operation are covered under delay time.

Fuel

An estimate of fuel consumption may be derived from rated engine horsepower and estimated load factor. The fuel consumption curves (fig. 4) for diesel engines are based on rated horsepower operating at average load factors ranging from 20 to 70 percent. The load factor is the percentage of full rated horsepower used during normal operation. Since cable yarders are not heavily loaded except during inhaul, their average factor usually runs under 50 percent.

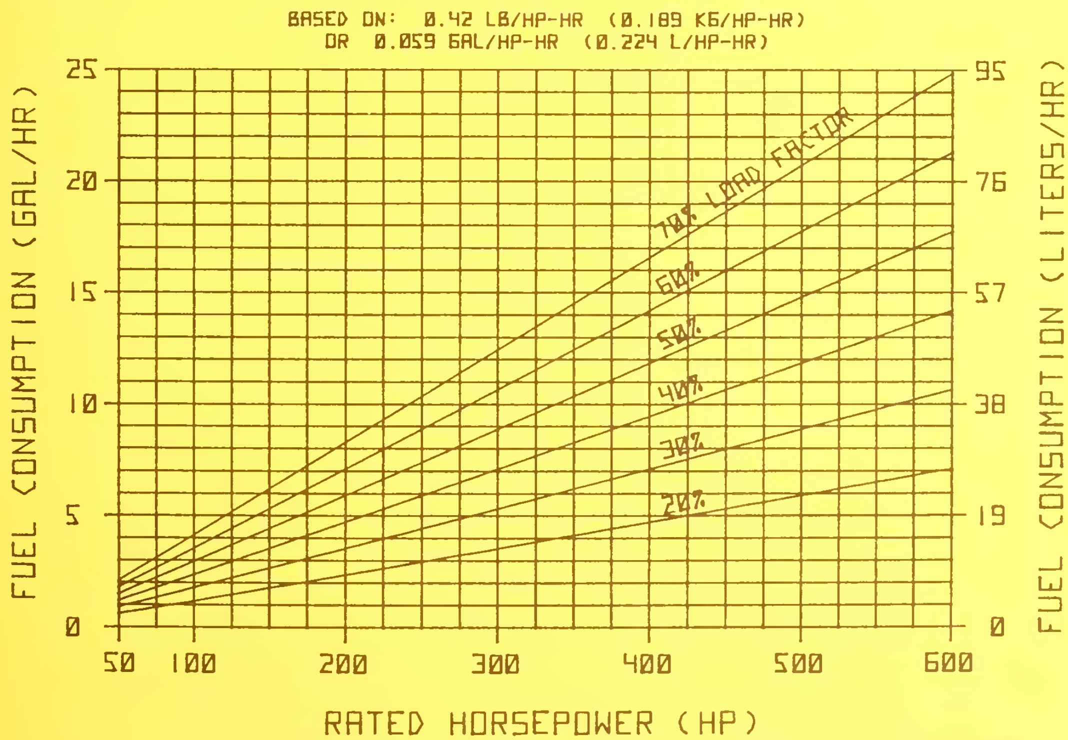

Figure 4.--Diesel engine fuel consumption chart.

Oil and Lubricants

A rule of thumb is that engine (crankcase) oil consumption equals about 1 percent of fuel consumed. Total oil requirements, including gear lube and hydraulic fluid, vary with the equipment design and may run to 5 percent of fuel consumption.

Lines and Rigging

The costs of operating lines and rigging may be charged as non-depreciable expenses. Line life and rigging life must be estimated to determine their costs on a unit-time basis. Often the life is expressed in volume of timber yarded rather than units of time. Line or rigging life must then be calculated by dividing the volume by the estimated average production rate. These assumed lives will in part determine whether the items are actually depreciated or not. For estimating costs, lines and rigging are generally considered expendable items rather than capital equipment if their estimated life is less than 2 years.

Tires or Tracks

The cost of tires or tracks is sometimes excluded from equipment value prior to depreciation. If the tire or track life is short enough to permit noncapitalization, the replacement cost may be treated as an operating expense. The useful life of tires or tracks must be estimated to arrive at the hourly cost.

Direct Labor

The full cost of direct labor includes the base wage plus fringe benefits and applicable travel pay. Fringe benefits cover such items as Workman's Compensation insurance, Social Security, unemployment insurance, sick leave, vacation, and paid holidays. Fringe benefits can be expressed as a percentage of the base wage rate.

Supervision and Overhead

Numerous indirect costs related to the operation add to the machine rate. Supervision and overhead are usually expressed as a percentage of the direct labor cost.

MACHINE RATE ESTIMATION

The worksheet shown in the appendix is furnished to facilitate the determination of machine rate. Costs may be computed on any unit-time basis, but the form is tailored to hourly costs for widest application.

YARDING PRODUCTION

Yarding production rate is the volume of timber brought to the landing per unit of time. Within a framework of scheduled operating time, the rate of production is dependent on the relative amounts of productive time and nonproductive time. These can be separated into smaller time elements, as shown in figure 5.

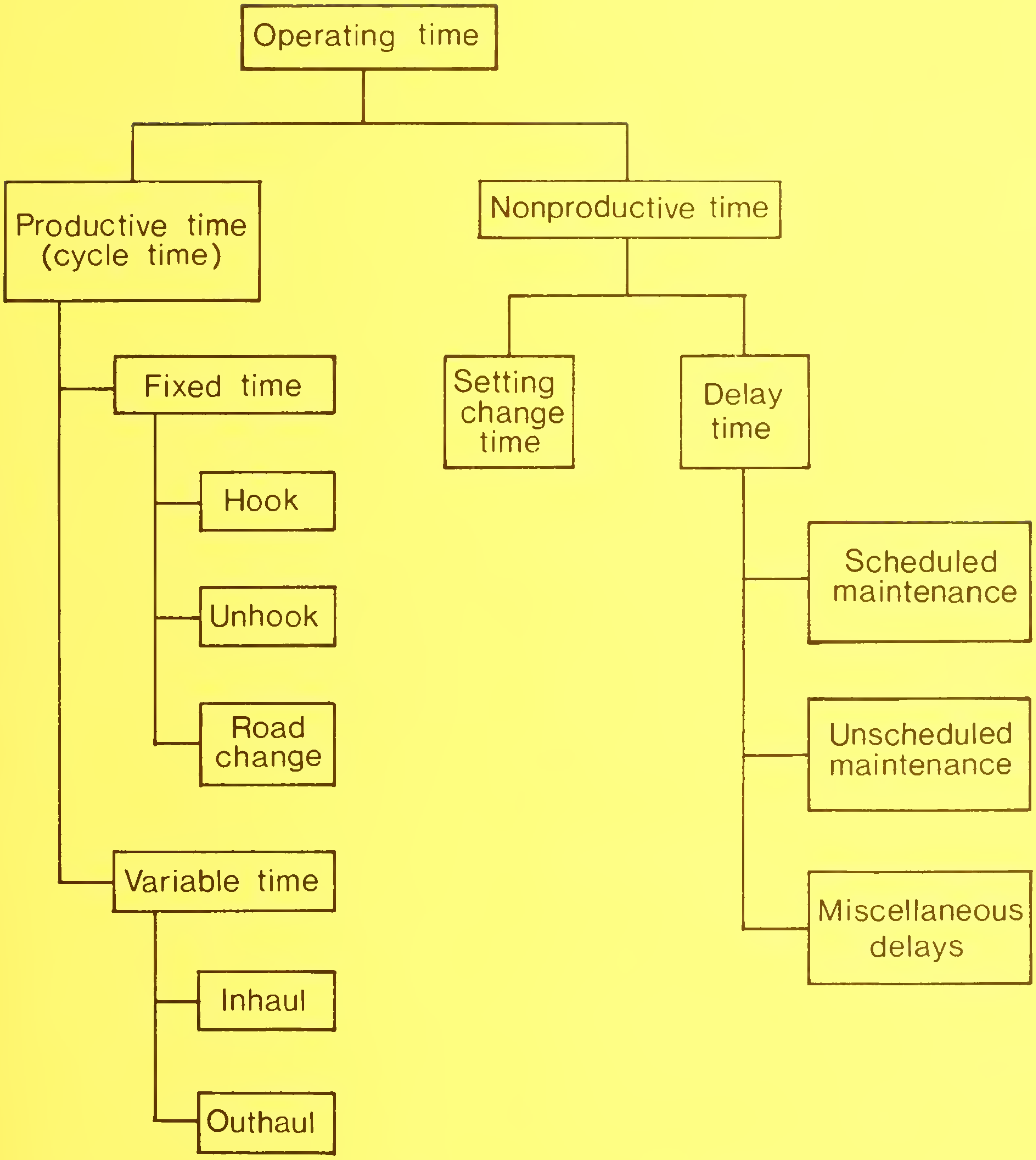

Figure 5.--Operating time elements.

PRODUCTIVE TIME (CYCLE TIME)

For convenience in estimating, the individual productive time elements are considered together as cycle time or turns per hour (turns per hour = 60/cycle time). Hook and unhook times may vary with size of pieces, pieces per turn, slope, ground or landing conditions, etc. Although their values may vary on a per turn basis, average values for settings will not change appreciably. Hook and unhook times are thus assumed to be fixed values, independent of yarding distance. The inhaul and outhaul elements are functions of yarding distance. Their relation to yarding distance may depend on numerous variables, such as carriage speed, slope, load size, etc.

Road change time may be prorated into the estimated cycle time. Road change refers to moving either the yarder or tailhold on fan-shaped settings. It should not be confused with a setting change. Road changes can frequently be accomplished with little interruption of yarding cycles. Although the time spent often cannot be identified as a discrete element, road change may represent a substantial proportion of cycle time on low volume settings.

The first step in making an estimate of cycle time is to determine the fixed time portion (fig. 6). On a per setting basis, this will normally be a constant value for most yarding systems. Generally, fixed time is also reasonably uniform among similar systems. An exception than can substantially reduce fixed time is the use of preset chokers.

The second step is to estimate turns per hour at a given average yarding distance. Average yarding distance is equal to the total distance yarded divided by the total number of turns. For rectangular and fan-shaped settings, the average yarding distance is one-half and two-thirds of the external yarding distance, respectively. The average yarding distance will vary with the size and shape of the setting and the yarding method.

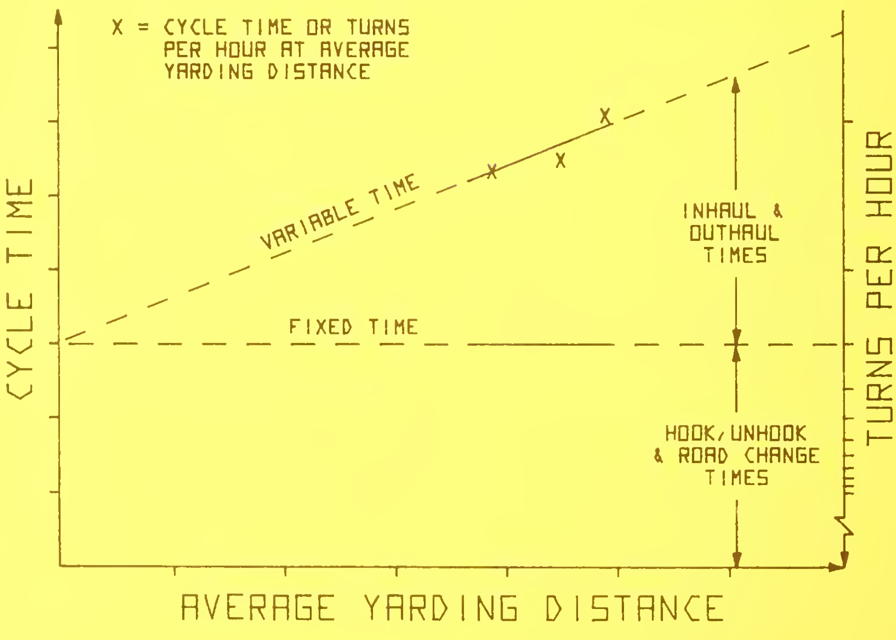

Figure 6.--Cycle time versus average yarding distance.

For cost estimation, there is no need to measure incremental elements of cycle time except to initially establish the value of fixed time. Also, yarding distance and cycle time are not required for every turn. Only the average values for the setting are needed for figuring costs.

The variable-time portion is directly related to yarding distance. One of the simplest ways of graphically representing this relationship is to plot the estimated or observed number of turns per hour at the known average yarding distance. Turns per hour can be figured by dividing the recorded number of turns for the setting by total yarding time for the setting. A single point is sufficient to initially establish the variable-time line. It must intersect the fixed-time value at zero average yarding distance. As more or better data become available, more points can be plotted and the line better fitted to the points for a closer approximation to the time-distance relation. Individual turns represent a wide range of yarding distances. Plotted points, representing average yarding distance, tend, however, to fall into a relatively narrow band where the variable-time line may be treated as linear. Cost estimation is concerned only with this band of values, indicated by the solid line portions in figure 6. A similar approach is to draw the linear variable-time line to correspond to an average value of inhaul plus outhaul in feet per minute. The variable-time line is drawn with this slope (feet per minute) starting at the intersection of the fixed-time line and zero average yarding distance; the steeper the slope, the slower the line speed of the yarder. The straight line relation depicted in figure 6 is typical of a skyline system.

Another way of determining this time-distance relationship is to plot the average cycle time versus average yarding distance for two, or preferably more, settings. When carefully plotted from reliable data, the intersection of the variable-time line with zero average yarding distance yields the predicted fixed time.

Minor operational delays--such as hangups, resetting or untangling chokers, dropping a log, etc.--can be considered normal components of cycle time. Since these delays are usually difficult to isolate and quantify as nonproductive time, they should be integrated into the value of cycle time.

Slope may influence cycle time under certain conditions, but its effect is difficult to predict. Where reliable slope correction data are available, they can be used to modify estimates of cycle time. The impact of uphill or downhill yarding and cutting treatment on the estimated cycle time should also be assessed.

NONPRODUCTIVE TIME

Setting Change Time

Moving both yarder and tailhold to a new setting is defined as a setting change. For example, setting changes are required between all parallel yarding corridors. For a well-planned cutting unit, setting change time can be estimated beforehand. Low-yield settings will increase the frequency of setting changes and result in higher production costs. Setting change time can be minimized by prerigging tailholds and anchors.

Delay Time

Delay time is difficult to estimate; type and condition of equipment, yarding conditions, and record of past down time must be taken into account. Delay time can be most easily expressed as a percentage of cycle time or turns per hour.

Scheduled maintenance covers regular servicing and replacement of parts, lines, and rigging. This maintenance is preferably performed during lengthy delays or outside the normal shift so that its impact is small.

Unscheduled maintenance refers to repair of equipment, line, or rigging after breakdown and is therefore unpredictable.

Miscellaneous delays are scheduling or other major operational delays including time lost because of inclement weather.

CALCULATION OF COST PER UNIT VOLUME

The worksheets in the appendix may be used to calculate the cost per unit volume of yarding a given unit. Average log volume for the stand can be obtained from timber cruise data. Judgment should be exercised in estimating a realistic volume per piece as bucked, since actual piece lengths may vary from the cruise data log length.

Similarly, cruise data can supply a figure for percent defect in the entire stand, but the percent defect will normally be lower in the pieces yarded.

The estimate for average number of logs per turn should consider any influencing factors, such as piece size, deflection, size and suitability of the landing, or distribution of pieces within the unit.

Move-in and move-out costs should cover all charges relating to preparation of equipment and transportation to and from the cutting unit.

Roading, felling, loading, and hauling costs are beyond the scope of this estimating procedure but should be included in the total logging system cost of any logging plan.

APPENDIX

Example Worksheets and Blank Copies for Reader's Use

Equipment Ownership Cost

Delivered equipment cost	$ 250,000
Less line and rigging cost	- $ 12,000
Less tire or track replacement cost	- $ N/A
Less residual (salvage) value	- $ 50,000
Depreciable value	$ 188,000

Equipment depreciation: $\frac{\text{(Depreciable value)}}{\text{(Depreciation period)}} = \frac{(\$\ 188{,}000\ )}{(\ 7\ \text{yr})}$ $ 26,857 /yr

Average annual investment: $\frac{\text{(Depreciable value)} \times \text{(Depreciation period + 1)}}{2 \times \text{(Depreciation period)}} + \text{(Residual value)}$

$$= \frac{(\$\ 188{,}000\ ) \times (\ 8\ )}{2 \times (\ 7\ )} + (\$\ 50{,}000\ ) = \$\ 157{,}429\ /\text{yr}$$

Interest expense: (Annual interest rate) x (Average annual investment) = (10 %) x ($ 157,429 /yr) + $ 15,743 /yr

Taxes, license, insurance & storage: 9 % of Average annual investment = (9 %) x ($ 157,429 /yr) + $ 14,169 /yr

Annual ownership cost: $ 56,769 /yr

Annual utilization: (200 days worked/yr) x (8 hours worked/day) = 1600 hr/yr

Ownership cost: $\frac{\text{(Annual ownership cost)}}{\text{(Annual utilization)}} = \frac{(\$\ 56{,}769\ /\text{yr})}{(\ 1600\ \text{hr/yr})}$ $ 35.48 /yr

Equipment Operating Cost

Repairs and maintenance: $\frac{50\ \%\ \text{of Equipment depreciation}}{\text{Annual utilization}} = \frac{(50\%) \times (\$\ 26,857\ /yr)}{(1600\ hr/yr)}$ $ 8.39 /hr

Fuel: (7 gal/hr) x ($ .45 /gal) + $ 3.15 /hr

Oil & lubricants: (4 % of fuel consumption) x (unit cost) = (4 %) x (7 gal/hr) x ($ 1.50 /gal) + $ .42 /hr

Lines: $\frac{\text{(Cost)}}{\text{(Estimated life)}} = \frac{(\$\ 9500\ )}{(800\ hr)}$ + $ 11.88 /hr

Rigging: $\frac{\text{(Cost)}}{\text{(Estimated life)}} = \frac{(\$\ 2500\ )}{(3200\ hr)}$ + $ .78 /hr

Tires or tracks: $\frac{\text{(Replacement cost)}}{\text{(Estimated life)}} = \frac{(\$\ \_\_\_\_\ )}{(\_\_\_\_\ hr)}$ + $ N/A /hr

Crew position: Yarder Engr. Rig. Slinger Chaser Chokersetter Chokersetter ______

Base wage: $ 9.60 /hr + $ 9.30 /hr + $ 8.20 /hr + $ 7.70 /hr + $ 7.70 /hr + $ ______ /hr

Total crew wage: $ 42.50 /hr

Direct labor cost: (Total crew wage) x $\left[\frac{(100 + \%\ \text{fringe benefits})}{100} + \frac{\text{(travel time/day)}}{\text{(operating time/day)}}\right]$

$= (\$\ 42.50\ /hr) \times \left[\frac{(100 + 30\ \%)}{100} + \frac{(.5\ hr/day)}{(8\ hr/day)}\right]$ + $ 57.91 /hr

Supervision and overhead: 15 % of direct labor cost = (15 %) x ($ 57.91 /hr) + $ 8.69 /hr

Operating cost: $ 91.22 /hr

Machine rate: (Ownership cost) + (Operating cost) = ($ 35.48 /hr) + ($ 91.22 /hr) $ 126.70 /hr

Cruise Data

Area of unit: A = 35 acres

Yield per acre : V = 40 MbF / acre

Gross unit volume: V_T = (V) x (A) = (40 MbF / acre) x (35 acres) = 1400 MbF

Average volume per log as cruised = .21 MbF

Average volume per piece as bucked: v = .25 MbF

Percent defect in stand as cruised = 10 %

Percent defect in pieces as yarded: D = 6 %

Engineering Data

Number of settings in cutting unit: N = 8

Average yarding distance = 480 ft.

Estimates

Average number of pieces per turn: n = 3.2

Average volume per turn: v_t = (v) x (n) = (.25 MbF) x (3.2) = .8 MbF

Average turns per hour: C = 12.5

Delay as a percentage of turns per hour: d = 15 %

Adjusted turns per hour: c = (C) x $\frac{(100 - d)}{100}$ = (12.5) x $\frac{(100 - 15\ \%)}{100}$ = 10.6

Time per setting change: t_s = .67 hours

Total setting change time: T_s = (t_s) x (N - 1) = (.67 hr) x (7) = 4.7 hours

Move-in and move-out cost, M: $ 2000

Calculations

Number of turns: $\frac{\text{(Gross volume, } V_T)}{\text{(Volume per turn, } v_t)} = \frac{(1400 \text{ MbF})}{(.8 \text{ MbF})} = 1750$

Operating time: $\frac{\text{(Number of turns)}}{\text{(Adjusted turns per hour, c)}}$ + Total setting change time

$= \frac{(1750)}{(10.6)} + 4.7 \text{ hr} = 169.8 \text{ hours}$

Yarding cost: (Machine rate) x (Operating time) = ($ 126.70 /hr) x (169.8 hr) = $ 21,513.66

Add move-in and move-out cost, M: + $ 2000

Total yarding cost: $ 23,513.66

Yarding cost per gross unit volume: $\frac{\text{(Yarding cost)}}{\text{(Gross volume, } V_T)} = \frac{(\$ 23{,}513.66)}{(1400 \text{ MbF})} =$ $ 16.80 / MbF

Net volume: (Gross volume, V_T) x $\frac{(100 - \%\text{ defect, D})}{100}$ = (1400 MbF) x $\frac{(100 - 6 \%)}{100}$ = 1316 MbF

Yarding cost per net unit volume: $\frac{\text{(Yarding cost)}}{\text{(Net volume)}} = \frac{(\$ 23{,}513.66)}{(1316 \text{ MbF})} =$ $ 17.87 / MbF

For total logging system cost, add:

Roading cost per net unit volume = + $______/______

Felling cost per net unit volume = + $______/______

Loading cost per net unit volume = + $______/______

Hauling cost per net unit volume = + $______/______

Total logging cost per net unit volume = $______/______

Equipment Ownership Cost

Delivered equipment cost	$______	
Less line and rigging cost	- $______	
Less tire or track replacement cost	- $______	
Less residual (salvage) value	- $______	
Depreciable value	$______	

Equipment depreciation: $\frac{\text{(Depreciable value)}}{\text{(Depreciation period)}} = \frac{(\$\_\_\_\_\_\_)}{(\_\_\_\_ \text{yr})}$ $______/yr

Average annual investment: $\frac{\text{(Depreciable value)} \times \text{(Depreciation period + 1)}}{2 \times \text{(Depreciation period)}}$ + (Residual value)

$= \frac{(\$\_\_\_\_\_\_) \times (\_\_\_\_)}{2 \times (\_\_\_\_)} + (\$\_\_\_\_\_\_) = \$\_\_\_\_\_\_/\text{yr}$

Interest expense: (Annual interest rate) x (Average annual investment) = (____%) x ($______/yr) + $______/yr

Taxes, license, insurance & storage: ____% of Average annual investment = (____%) x ($______/yr) + $______/yr

Annual ownership cost: $______/yr

Annual utilization: (______days worked/yr) x (____hours worked/day) = ______hr/yr

Ownership cost: $\frac{\text{(Annual ownership cost)}}{\text{(Annual utilization)}} = \frac{(\$\_\_\_\_\_\_/\text{yr})}{(\_\_\_\_\_\_ \text{hr/yr})}$ $______/yr

Equipment Operating Cost

Repairs and maintenance: $\frac{\text{\_\_ \% of Equipment depreciation}}{\text{Annual utilization}} = \frac{(\text{\_\_\%}) \times (\$\text{\_\_\_\_/yr})}{(\text{\_\_\_\_ hr/yr})}$ $______/hr

Fuel: (______gal/hr) x ($______/gal) + $______/hr

Oil & lubricants: (____% of fuel consumption) x (unit cost) = (____%) x (_____gal/hr) x ($______/gal) + $______/hr

Lines: $\frac{\text{(Cost)}}{\text{(Estimated life)}} = \frac{(\$\text{\_\_\_\_\_})}{(\text{\_\_\_\_\_ hr})}$ + $______/hr

Rigging: $\frac{\text{(Cost)}}{\text{(Estimated life)}} = \frac{(\$\text{\_\_\_\_\_})}{(\text{\_\_\_\_\_ hr})}$ + $______/hr

Tires or tracks: $\frac{\text{(Replacement cost)}}{\text{(Estimated life)}} = \frac{(\$\text{\_\_\_\_\_})}{(\text{\_\_\_\_\_ hr})}$ + $______/hr

Crew position: ________ ________ ________ ________ ________ ________

Base wage: $______/hr + $______/hr + $______/hr + $______/hr + $______/hr + $______/hr

Total crew wage: $______/hr

Direct labor cost: (Total crew wage) x $\left[\frac{\text{(100 + \% fringe benefits)}}{100} + \frac{\text{(travel time/day)}}{\text{(operating time/day)}}\right]$

= ($______/hr) x $\left[\frac{(100 + \text{\_\_\_\%})}{100} + \frac{(\text{\_\_\_\_ hr/day})}{(\text{\_\_\_\_ hr/day})}\right]$ + $______/hr

Supervision and overhead: _____% of direct labor cost = (_____%) x ($______/hr) + $______/hr

Operating cost: $______/hr

Machine rate: (Ownership cost) + (Operating cost) = ($______/hr) + ($______/hr) $______/hr

Cruise Data

Area of unit: A = ____________

Yield per __________: V = ____________/________

Gross unit volume: $V_T = (V) \times (A)$ = (__________/________) x (____________) = ____________

Average volume per log as cruised = __________

Percent defect in stand as cruised = _____%

Average volume per piece as bucked: v = ____________

Percent defect in pieces as yarded: D = _____%

Engineering Data

Number of settings in cutting unit: N = ______

Average yarding distance = __________

Estimates

Average number of pieces per turn: n = ______

Average volume per turn: $v_t = (v) \times (n)$ = (_________) x (_________) = __________

Average turns per hour: C = ________

Delay as a percentage of turns per hour: d = _____%

Adjusted turns per hour: $c = (C) \times \frac{(100 - d)}{100}$ = (________) x $\frac{(100 - \_\_\_\_\%)}{100}$ = __________

Time per setting change: t_s = ________hours

Total setting change time: $T_s = (t_s) \times (N - 1)$ = (_______hr) x (______) = ________hours

Move-in and move-out cost, M: $__________

Calculations

Number of turns: $\dfrac{\text{(Gross volume, } V_T)}{\text{(Volume per turn, } v_t)} = \dfrac{(\qquad\qquad)}{(\qquad\qquad)} =$ ________

Operating time: $\dfrac{\text{(Number of turns)}}{\text{(Adjusted turns per hour, c)}}$ + Total setting change time

$= \dfrac{(\qquad)}{(\qquad)} +$ ______hr = __________hours

Yarding cost: (Machine rate) x (Operating time) = ($________/hr) x (________hr) = $__________

Add move-in and move-out cost, M: + $__________

Total yarding cost: $__________

Yarding cost per gross unit volume: $\dfrac{\text{(Ysrding cost)}}{\text{(Gross volume, } V_T)} = \dfrac{(\$\qquad\qquad)}{(\qquad\qquad)} =$ $________/______

Net volume: (Gross volume, V_T) x $\dfrac{\text{(100 - \% defect, D)}}{100}$ = (__________) x $\dfrac{(100 - \quad \%)}{100}$ = __________

Yarding cost per net unit volume: $\dfrac{\text{(Yarding cost)}}{\text{(Net volume)}} = \dfrac{(\$\qquad\qquad)}{(\qquad\qquad)} =$ $________/______

For total logging system cost, add:

Roading cost per net unit volume = + $________/______

Felling cost per net unit volume = + $________/______

Loading cost per net unit volume = + $________/______

Hauling cost per net unit volume = + $________/______

Total logging cost per net unit volume = $________/______

GPO 987-079

ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-326 December 1978

Effects of Defoliation by Douglas-fir Tussock Moth on Timing and Quantity of Streamflow

usda douglas-fir tussock moth • research & development program •

by

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ABSTRACT

Streamflow data from three watersheds in the Blue Mountains of Oregon were tested for changes in annual runoff, summer runoff, and peak discharge following the defoliation in 1972 and 1973 caused by the Douglas-fir tussock moth. Annual runoff from the Umatilla River watershed in 1974 was 13.2 cm greater than the predicted value and 2.5 cm greater than the end point 95-percent confidence band for the baseline data. No changes in runoff were detected on the North or South Fork of the Walla Walla River. Defoliation was more extensive on the Umatilla drainage.

KEYWORDS: Runoff -)vegetation, insect damage (-forest, defoliation damage, Douglas-fir tussock moth, *Orgyia pseudotsuga*.

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FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE - PORTLAND, OREGON

INTRODUCTION

The purpose of the research reported in this paper was to determine the effect of defoliation by the Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) on annual runoff, seasonal runoff, and peak discharge from major drainage systems. This information is necessary for a complete evaluation of the moth outbreak on the affected ecosystems. If discharge rates during spring runoff increase substantially, culverts and bridges could be destroyed and stream habitat damaged for aquatic life. On the other hand, an increase in flow during late summer could enhance aquatic habitat and provide more water for irrigation agriculture, provided water quality remains acceptable.

The water balance of a drainage basin can be expressed mathematically as:

$$R = P - (T + I + E) \pm S$$

where R is runoff, P is precipitation, T is transpiration, I is interception, E is evaporation from land surfaces, and S is soil moisture storage. The units are depth over the drainage area and the time period usually is a year or a season.

It is generally agreed that vegetation reduction has no measurable effect on precipitation amounts (McDonald 1960), but transpiration and interception losses are reduced. Evaporation losses increase somewhat because of increased soil exposure to solar energy. Soil moisture storage increases and remains at a higher level than before vegetation reduction. The net effect of complete vegetation removal, whether by natural causes or by forest harvest, is an increase in annual runoff. A partial reduction may or may not produce an increase in runoff, depending on several factors including the percentage of vegetation reduction and the balance between soil moisture storage and energy available for evaporation. A more detailed discussion of the soil moisture-energy-runoff relationships as they apply to this study will be presented later.

PREVIOUS WORK (NATURAL DEFORESTATION)

One of the most extensive insect outbreaks in this country occurred in Colorado between 1941 and 1946. The Engelmann spruce beetle (*Dendroctonus rufipennis* (Kirby)) killed practically all of the Engelmann spruce and lodgepole pine growing on 585 km^2 within the White River watershed (Love 1955). Love's analysis of annual water yield changes indicated that about 5 cm of extra water per unit area were produced by the White River drainage after the insect attack. A later analysis by Bethlahmy (1975) indicated that even 25 years after the attack, runoff was still about 10 percent greater than the natural values. Apparently the denuded forest was extremely slow in recovering.

Tropical storms sometimes travel along the eastern part of North America and cause considerable damage to forested areas. A hurricane in 1938 was one of the most destructive on record as far as the forest is concerned. It uprooted and broke off vast numbers of trees in two New England watersheds. Patric (1974) analyzed historical flow records and concluded that annual runoff increased about 12.5 cm per unit area during the first year after the hurricane. Because of the rapid recovery of hardwood forests, runoff returned to normal after only 5 years.

Wildfire is perhaps responsible for destroying more vegetation in western forests than any other natural cause. In 1970, about 485 km^2 of forested land in north central Washington were blackened by wildfire. Helvey (1972) reported average water yield increases of 8.4 cm per unit area (50 percent) and water temperature increases of 5.5° C on the Entiat Experimental watersheds during the 1st year after the fire. Klock (1972) found that water in the soil profile was 11.5 cm greater in September 1971 than in September 1970, indicating that a large part of the transpiration savings were retained in the soil profile. Water yield increases in later years were even greater (Helvey 1973), but record precipitation amounts prevented an accurate determination of the effect of vegetation reduction alone. The burned areas became extremely sensitive to precipitation input, and runoff rates were much higher than before the fire. Debris flows were common during the second postfire year.

THE STUDY AREA

The study area, located in northeastern Oregon and southeastern Washington, is part of the Blue Mountains. Topography of the Blue Mountains varies from undulating plateaus to steep rugged mountains reaching to 2 500 m elevation. Vegetation varies with elevation i.e., big sagebrush (*Artemisia tridentata* Nutt.) occupies the lowest levels; and as elevation increases, vegetation changes to ponderosa pine (*Pinus ponderosa* Laws.), to Douglas-fir (*Pseudotsuga mensiesii* (Mirb.) Franco), to subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and finally to vegetation typical of above timberline conditions (Hall 1973).

Precipitation is primarily a cool season phenomenon. Maritime storms cross the mountains from west to east in the fall and winter. Orographic lifting cools the moist air and causes precipitation to fall. Average annual precipitation is 38 cm at the lowest elevations; over 138 cm at the upper slopes. Approximately 80 percent of the total annual precipitation falls between October 1 and May 31. At the upper slopes, a snowpack usually begins to form by late November. It increases in depth and water content until late March or early April. Snowmelt begins on lower slopes with south exposure in February, and the snow line advances to upper elevations. Complete snowmelt varies from year to year depending on maximum snow accumulation and air temperature in the early Spring months. The last snow usually is melted by early June.

Runoff patterns are typical of areas where snow is the dominate form of precipitation. Figure 1 illustrates average monthly flow rate for the Umatilla River. Runoff increases during the fall months because of increased rainfall at the lower elevations. Rapid snowmelt in March, April, and May produces maximum discharge rates during these months. Flow rates decrease during summer months because evapotranspiration demand greatly exceeds rainfall input.

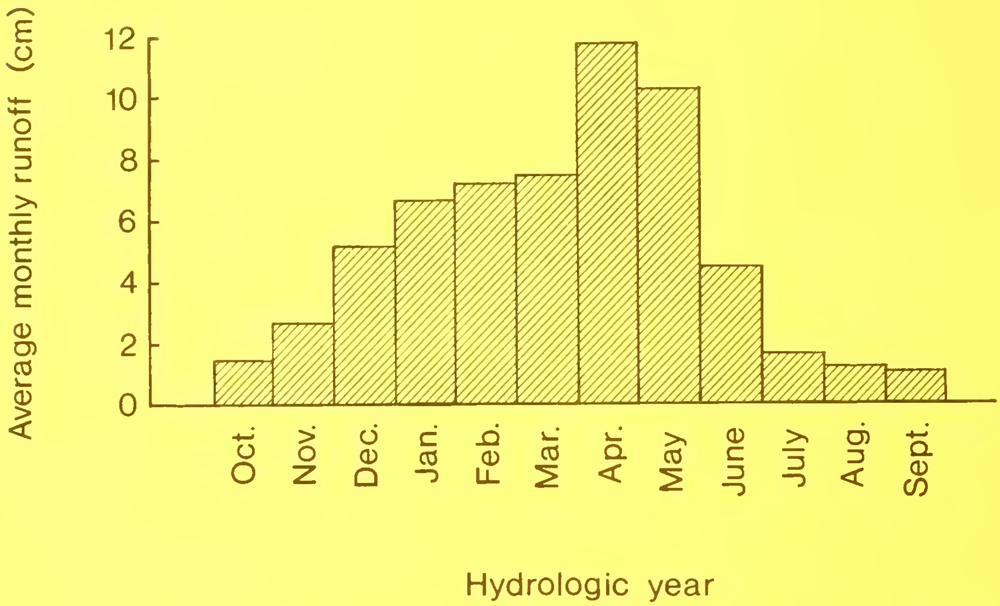

Figure 1.--Average monthly runoff from the Umatilla River.

METHODS

Runoff changes caused by vegetation reduction usually are determined by the paired watershed technique. That is, runoff from two or more watersheds is measured during a 3- to 10-year calibration period while the watersheds remain undisturbed. The watersheds are purposely chosen for their similarity in vegetation, soils, and geomorphology. One watershed is designated the control, and regression equations are developed during calibration so that runoff from each watershed can be accurately predicted from values measured on the control unit. After the watersheds are satisfactorily calibrated, the vegetation on one or more units is reduced by a predetermined amount while the control unit remains undisturbed. Runoff changes due to vegetation reduction are calculated by subtracting the value predicted by the calibration regression from the measured value. If this absolute difference is significantly greater than zero at the accepted level of probability, the change is attributed to reduced vegetation levels.

A variation of the paired watershed technique was used in this study. Instead of the typical experimental watershed of 40-400 hectares, watersheds used in this study range up to 340 km^2. Although small drainages would have been more desirable, no watersheds within the defoliated area had been monitored for runoff before defoliation began. The only alternative was to choose watersheds within the defoliated area for which the U.S. Geological Survey had collected and published discharge records.

A map indicating areas of tussock moth defoliation in the Blue Mountains was supplied by the Umatilla National Forest. Insect damage was identified on this map as heavy mortality in 1972, heavy mortality in 1973, top killing in 1973, and light defoliation in 1973. There is some indication that the damage was not as severe as the initial survey indicated. After the insects were killed with chemical spray, some trees, which at first appeared to be heavily damaged, put out a new set of needles and fully recovered.

Three watersheds which were partially defoliated and which have been gaged by the Geological Survey were chosen for study (fig. 2).

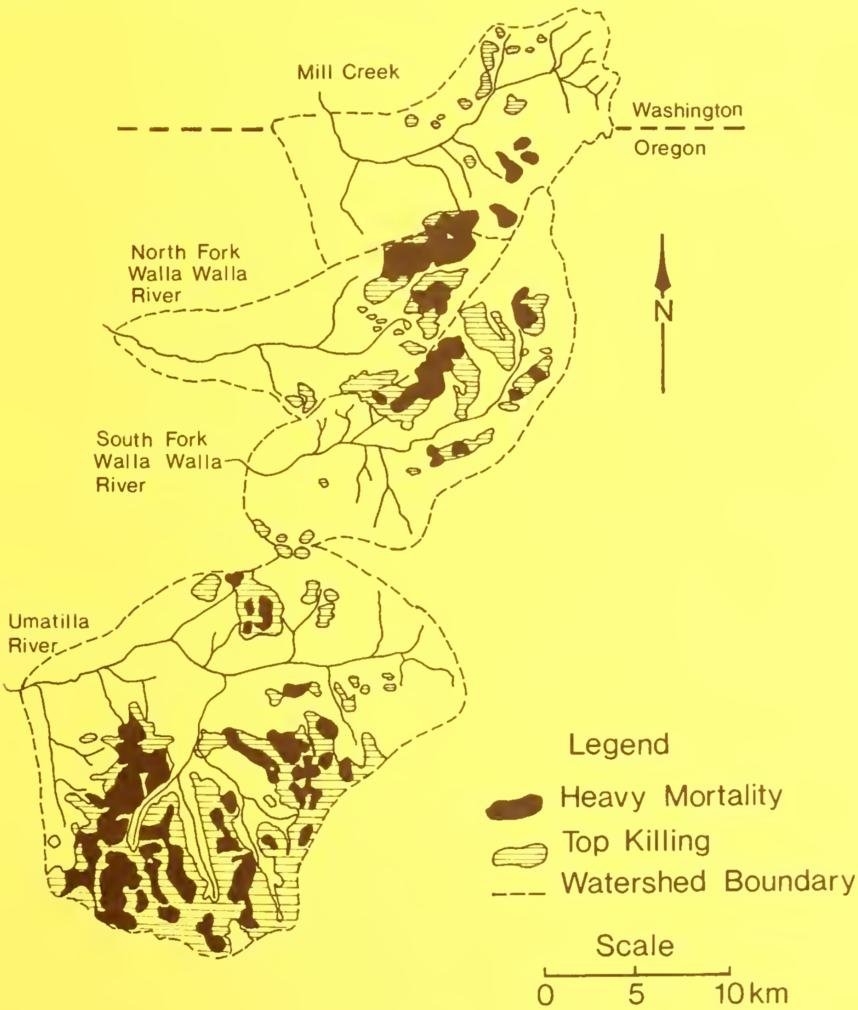

Figure 2.--The study watersheds: Mill Creek, North Fork Walla Walla River, South Fork Walla Walla River, and the Umatilla River.

These are (1) the North Fork of the Walla Walla River (113 km^2), the South Fork of the Walla Walla River (169 km^2), and the Umatilla River (352 km^2). Runoff from Mill Creek (160 km^2), was used as control data since defoliation was slight on this drainage (Hicks 1977). A dot grid was used to estimate the percentage of total watershed area in each defoliation category listed above.

The analytical procedure used here is illustrated by the following example: (1) Annual runoff volume from the Umatilla River and Mill Creek was tabulated for each year between 1950-1971. (2) A scatter diagram was plotted in which runoff from the Umatilla Basin (partially defoliated) was the dependent variable (Y) and runoff from Mill Creek was the independent variable (X). (3) A linear regression was computed and the least squares line drawn on the scatter diagram. (4) The location of several points on the 95-percent confidence limits was calculated for the individual points on the scatter diagram using the equation:

$$\hat{Y} \pm t \sqrt{(\text{Residual MS}) \left\{(1 + \frac{1}{N} + \frac{(Xo - \bar{X})^2}{\Sigma x^2}\right\}}$$

(The interested reader is referred to Freese (1967) for a discussion of the computation and interpretation of the confidence limits.) (5) A smooth curve was constructed through the confidence limit points. (6) Measured runoff from the Umatilla River during each year after defoliation was plotted on the scatter diagram as a function of concurrently measured runoff from Mill Creek. If a value after defoliation was inside the confidence bands, we concluded that runoff during that year was not significantly different from predefoliation values. If the value was outside the confidence bands, we concluded that runoff was different from the relationship before defoliation; and we speculated on the cause of the difference.

The same steps as outlined above were followed for annual runoff, seasonal runoff (April-June, July-September, and September-November), and peak discharge from each of the partially defoliated basins.

Personnel in National Forest Administration were contacted for information on past insect outbreaks and for timber harvest records. According to these records, there has been no serious insect defoliation in any of the drainages in recent times; but timber harvest has proceeded on each watershed since 1950. There is no evidence to indicate that logging on one drainage was enough greater than on the others to cause measurable changes in water yield. Thus, runoff differences between watersheds before the tussock moth outbreak are the result of natural factors and not man's activity. The control watershed (Mill Creek) serves as a municipal watershed for the city of Walla Walla, Washington. The city diverts about 0.62 m^3/sec at a point 4 miles above the gaging station for municipal use (U.S. Geological Survey 1975). No correction of the records was attempted for this diversion--it was considered a constant value from year to year. No logging is permitted on the headwaters of Mill Creek.

RESULTS AND DISCUSSION

Table 1 lists the estimated area percentages affected by the insect in 1972 and 1973. It appears from this tabulation that the Umatilla drainage was more severely defoliated than the other two. If we assume that top killing removes about half of the transpiring surface of a tree and heavy mortality removes all surfaces, the Umatilla drainage suffered a 25-percent reduction in transpiring surfaces in 1972 and 1973 combined. The North Fork of Walla Walla River lost about 16 percent of its foliage surfaces and the South Fork about 13 percent. Light defoliation in 1973 was about the same on all three watersheds at 20 percent. The most severe damage occurred along ridgetops and upper slopes where soil moisture usually is more limiting than on lower slopes. This is an important factor because vegetation removal from upper slopes would be expected to influence runoff less than an equal reduction on lower slopes. The reason for this conclusion will be discussed later.

Table 1--*Douglas-fir Tussock Moth Area-Activity in three drainages of the Blue Mountains of Oregon*

Activity	North Fork Walla Walla	South Fork Walla Walla	Umatilla
		Percent	
Heavy mortality in 1972	8	4	1
Heavy mortality in 1973	1	2	10
Top killing in 1973	14	14	30
Light defoliation in 1973	20	21	20

Annual runoff from the Umatilla River is plotted in figure 3 as a function of annual runoff from Mill Creek. Ninety-five-percent confidence bands are included, as recommended by Freese (1967), to illustrate variability in the data before insect defoliation began. Data points after defoliation are identified on the figure by the year of measurement.

Our statistical analysis indicated no effect of defoliation on runoff in 1972 when the insect outbreak began, nor in 1973 when annual precipitation was extremely low. In 1974, however, when about 25 percent of the transpiring surface was removed and annual precipitation was near the maximum ever recorded for the study area, annual runoff was 13.2 cm greater than the predicted value (fig. 3). Although this value is 2.5 cm greater than the upper end point of the confidence band, it should be interpreted with caution because the measured value on Mill Creek in 1974 was 22 cm greater than the largest value in the calibration data. One basic assumption of regression analysis is that

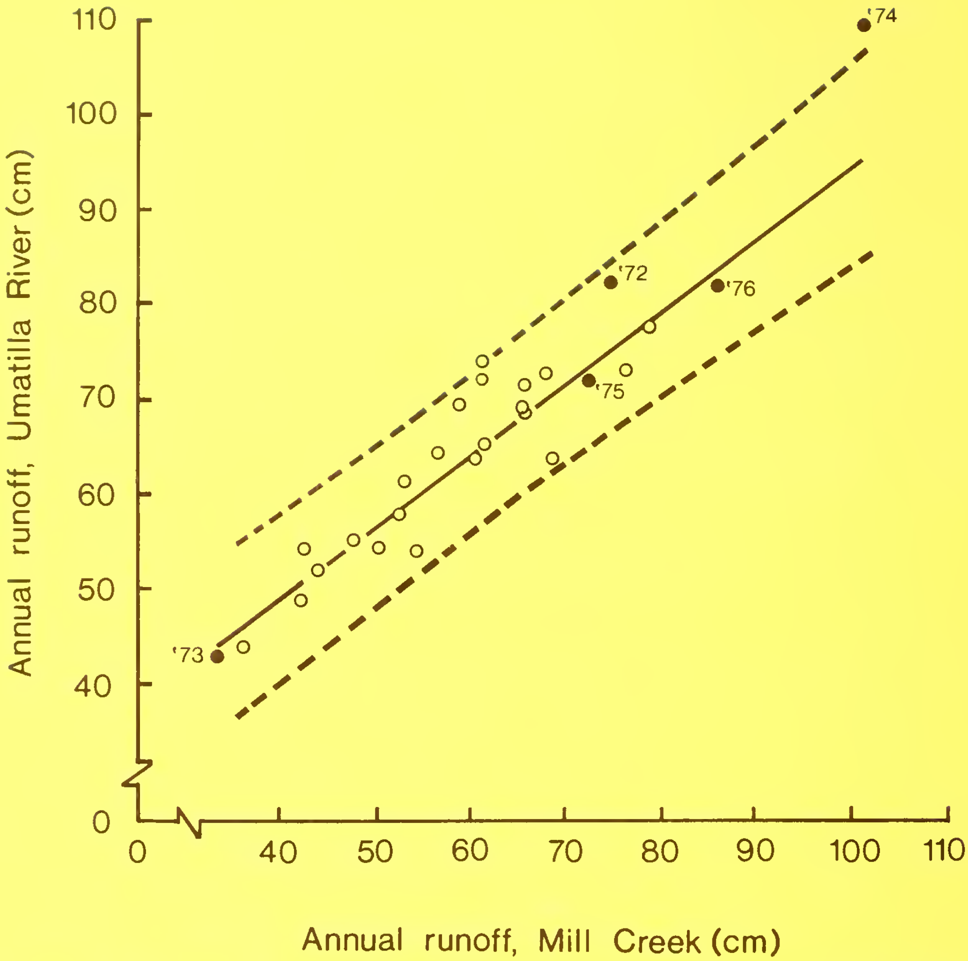

Figure 3.--Annual runoff from the Umatilla River compared to annual runoff from Mill Creek. The number beside each solid dot is the year of measurement for that point.

prediction should be restricted to the range of data used to compute the regression. Although runoff in 1974 was greater than the upper end point of the 95-percent confidence band, the uncertainty associated with the confidence band location prevents a definitive statement about the effects of defoliation on runoff in 1974.

In 1975 and 1976 when precipitation was slightly above average, runoff from the Umatilla River was near the predicted value. If the increase in 1974 was due to decreased evapotranspiration resulting from defoliation, it seems that increased runoff would have continued into 1975 and 1976. It could be that tree recovery from the initial defoliation (greenup) was sufficient to restore transpiration losses to a level which approximated natural conditions.

The next step in the analysis was to test for seasonal changes in runoff from the Umatilla River associated with the defoliation. Tests were made on peak discharge, and total runoff during snowmelt (April-June), during summer months (July-September), and during the autumn months (September-November). The test indicated no significant change during snowmelt or the summer months. Runoff during the autumn months of water year 1974, however, was significantly greater than the predicted value. Actual runoff during these months was 23.6 compared to the predicted value of 17.8 cm. This was about 1.3 cm greater than the upper end point of the confidence band (95-percent level) for the baseline data.

Peak discharge data were highly variable, and no change could be detected. This result was expected because even on small watershed studies where runoff is measured much more accurately than is possible on rivers, complete clearcutting produces only small increases in peak flow rates (Harr 1976).

Plottings of annual runoff for the North Fork and the South Fork of the Walla Walla River revealed no detectable change in runoff after the defoliation (figs. 4 and 5).

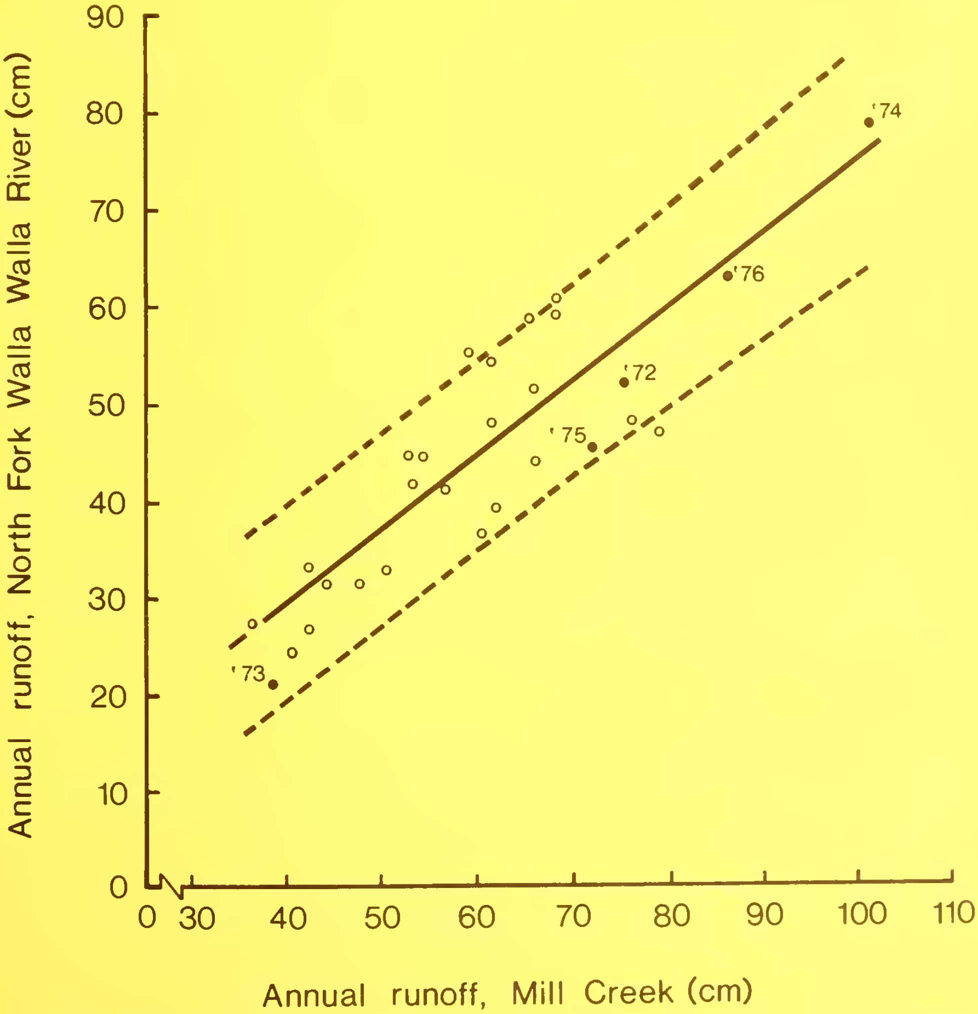

Figure 4.--Annual runoff from the North Fork of Walla Walla River compared to annual runoff from Mill Creek. The number beside each solid dot is the year of measurement for that point.

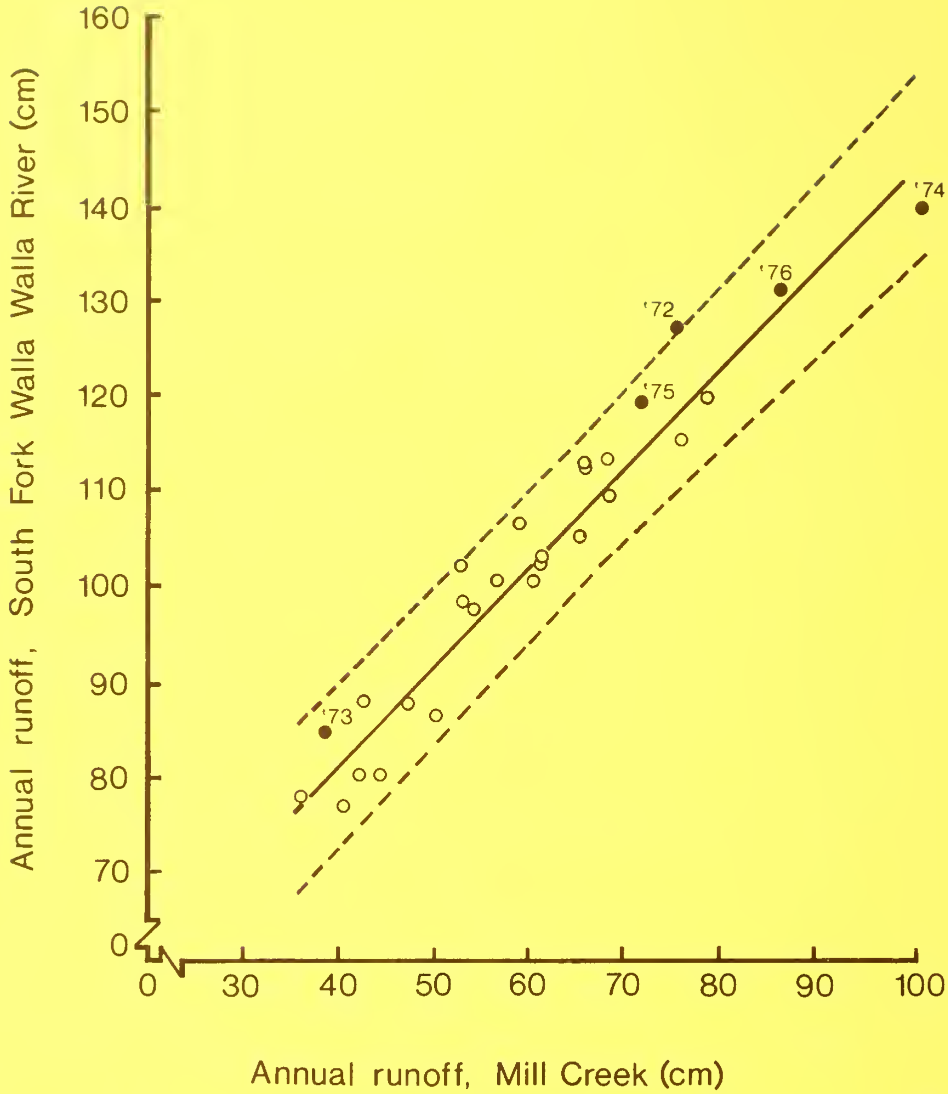

Figure 5.--Annual runoff from the South Fork of Walla Walla River compared to annual runoff from Mill Creek. The number beside each solid dot is the year of measurement for that point.

From these and previously published results, it appears that at least three factors are involved in determining the amount of annual runoff increase following vegetation reduction. These are (1) percent of the total drainage area deforested, (2) location of the deforested area with respect to the stream channel, and (3) current annual precipitation as a percent of the longterm mean value. Hibbert (1965) concluded from his world wide literature survey that at least 20 percent of a basin must be deforested before runoff significantly increases. Hibbert gave two reasons for this result: First, removing a smaller percentage of vegetation, such as thinnings, allows remaining trees to increase their water use rates, especially in areas such as eastern

Oregon where potential evapotranspiration in late summer usually exceeds available water supplies. Second, an increase must be larger than the experimental error associated with the baseline data before a statistically significant change is indicated. Accuracy of the runoff data used in this analysis is rated "good" by the U.S. Geological Survey. This means that about 95 percent of the daily discharge values are within 10 percent of the true value. Therefore, an increase smaller than 10 percent in this study cannot be detected.

In areas where potential evapotranspiration exceeds available soil moisture supplies, removing riparian vegetation has a larger effect on runoff than an equal area of cutting on upper slopes. For example, Rowe (1963) reported an increase in flow equal to 35 cm over the area treated when riparian vegetation was removed from a drainage in southern California. On the other hand, the riparian effect could not be demonstrated in western North Carolina where precipitation during all seasons exceeded potential evapotranspiration (Helvey and Hewlett 1962).

Bethlahmy (1974) showed that increases in runoff after deforestation are directly related to current annual precipitation, i.e., increases were much larger during wet than during dry years. Therefore, the indicated runoff increase in 1974 from the Umatilla River probably was caused by insect defoliation because this was the year of maximum defoliation and an ample moisture supply.

SUMMARY

The trees on 16 percent of the North Fork of Walla Walla River Basin, 13 percent of the South Fork of Walla Walla River Basin, and 25 percent of the Umatilla Basin were defoliated by Douglas-fir tussock moth between 1972 and 1974. The integrated effects of this natural activity on the water balance were determined by regression analysis of runoff data. Runoff records from an adjacent basin (Mill Creek) which received only minor activity, served as control data.

Because of the great variability in runoff data before defoliation began, a rigorous test of runoff changes caused by insect activity could not be made. Annual runoff from the Umatilla River in 1974, however, was 13.2 cm greater than the predicted value and 2.5 cm greater than the upper end point of the 95-percent confidence band for the baseline data.

No changes in annual runoff were detected from the lightly defoliated basins, and no effect of defoliation on peak discharge was detected on any of the watersheds.

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USDA FOREST SERVICE RESEARCH NOTE

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USING PHOTOGRAPHY FOR RECREATION RESEARCH

by

Mack L. Hogans

ABSTRACT

A photographic technique was developed and tested. The test showed that 35-mm color slides were better than black and white prints and 8-mm color movie formats for recording and identifying information about recreationists driving forest roads. Black and white prints proved to be more reliable for this purpose than 8-mm color movies. None of the formats allowed reliable identification of all the information obtained through direct observations and conversations with recreationists. The formats permitted reliable identification of only the number and type of vehicles using forest roads. Recreation equipment could be identified only slightly over 50 percent of the time. Number of people, group composition of parties, age, and recreation activity were the variables most difficult to identify (2 to 44 percent of the time depending on which of the three formats was used). There was little variation in scores generated by three groups of photo coders--(1) university students, (2) Forest Service managers, and (3) recreation researchers.

KEYWORDS: Survey methods/planning, photography, data recording methods, recreation surveys, recreation.

INTRODUCTION

Land managers, planners, and researchers constantly seek to devise field measures to efficiently and reliably monitor recreation use on forest lands. They now use questionnaires, interviews, direct observations, and self registration techniques to obtain recreation use information about forest visitors. Several recent developments suggest that photography can be a useful field instrument in the production of reliable data on recreationists. For example, relatively simple and economical photographic techniques have been developed which permit more effective use of man-hours and in some cases can produce more reliable information than is usually obtainable with conventional data collection methods (Baker 1974). In addition these techniques use equipment that is readily available (Marnell 1977). Perhaps the most important advantage photography holds for recreational research is its potential for increased confidence in research results, permitting as it does the use of tests for intercoder reliability. Despite its great potential, photography has not been used to obtain selected social data on recreationists useful in social research analysis and recreation planning.

The purpose of this paper is to describe a 1975 study designed to assess the potential of photography as a reliable field technique for producing selected social data on recreationists in motorized vehicles entering National Forests. The threefold objective of this study was to: (1) test three inexpensive camera systems under identical conditions to determine their individual effectiveness for recording social data about recreationists driving forest roads; (2) compare the quality of these photographic data with identical baseline social data obtained through direct observation and conversation with recreationists and; (3) develop techniques for coding, recording, and analyzing visitor use information identifiable from 35-mm color slides, 5-x7-inch black and white prints and 8-mm color movie frames. Specifically, the variables on which data were obtained through the use of these camera systems included: (a) type of vehicle, (b) number in party, (c) group composition, (d) equipment used, (e) age, i.e., child, teen, adult, senior citizen, (f) license number--place of origin, and (g) recreation activities pursued.

METHODOLOGY

Data for this study were collected through direct observation and conversations with recreationists and by photographing these parties with selected camera systems.

Three cameras were used in the study. Camera #1 was a 35-mm still, single lens reflex (through the lens light metering system). Its lens was standard size with a focal length of 49 mm, Fl. 4. Kodachrome color slide film, with an ASA value of 64, was used. Camera #2 was also a 35-mm still, single lens reflex through the lens metering system. Its lens was standard size with a focal length of 58 mm, Fl. 4. Plus-X black and white film, with an ASA value of 125, was used. Camera #3 was an 8-mm color movie camera with automatic aperture setting and capable of producing single-frame exposures. It had a telephoto zoom lens with a focal length of 50 mm, Fl. 8. Ektachrome 160, type G Super 8 color movie film was used.

The testing of the camera systems took place on two selected road systems: the Clackamas Highway on the Clackamas Ranger District, Mt. Hood National Forest in western Oregon, and the Greenwater Road System on the White River Ranger District, Mt. Baker-Snoqualmie National Forest in western Washington. The two areas were chosen because they are typical of dispersed road recreation settings in the Pacific Northwest and had been selected previously for recreation studies because they fit selected criteria (Hendee, Hogans, Koch 1976).

At the time of the study, all visitors to National Forests in the Pacific Northwest Region were required to stop for a fire prevention check before entering. During this required stop, field technicians in the study areas obtained the criterion baseline data through direct observation and conversations with selected recreation parties. At the same time, the recreationists' permission to take the photographs was solicited and granted by all parties. The fire prevention check point was designated Station No. 1.

The photographic data were obtained at designated Station 2, 100 feet from Station 1. The three cameras were located 40 feet from the center of the road on individual tripods adjacent to one another and turned at a 45-degree angle to the road. They were focused to infinity and aimed at a large red marker positioned along the opposite side of the road 45 feet away. Each camera system was operated independently by a field technician. Figure 1 and 2 illustrate the relationship between the two Stations.

The vehicles passing Station 2 were traveling at less than 25 miles per hour, because they did not have time to gain speed after departing Station 1. Once the vehicle approached the red marker, they were photographed by camera operators and assigned unique numbers on special forms corresponding to the camera frame number.

The test films were processed for average resolution by commercial photo finishers. Prints (5-x7-inch) were made from the exposed black and white negatives; color slides were mounted in 2-x2-inch slide mounts for screen viewing; 8-mm color movie films were placed on standard movie reels for viewing with a single frame movie projector.

Data Analysis

Once the films were processed, photographs were selected for analysis and coded for review by photo coders. Photo coders were then selected, shown the photographs, and their responses were recorded and evaluated.

A total of 50 subjects were photographed by each of the camera systems. From this total, 15 subjects, each photographed by a different camera system, were randomly selected for analysis. The 15 color slides of the subjects represented Treatment No. 1; the fifteen 5-x7-inch black and white prints represented Treatment No. 2; and the fifteen 8-mm color movie frames constituted Treatment No. 3. All three treatments were of the same subjects but in different formats.

Figure 1.--Baseline information being gathered from recreationists at Station 1.

Figure 2.--Photographic information being gathered on recreationists at Station 2 by camera operators after vehicle departed Station 1.

A score sheet was developed on which photo coders could check the relevant variables identified in their perception of the 45 photographs. Raw scores derived from the photo coders were determined by giving a score of "one" for each correctly identified variable.

From 3 different groups, 15 volunteer photo coders were selected to review the 3 treatments. Group 1 was composed of five undergraduate students (seniors) majoring in outdoor recreation at the University of Washington's College of Forest Resources. This group represented potential seasonal or technical staff that an agency like the U.S. Forest Service might hire to review photo data if camera applications were adopted.

Group 2 included five professional staff members of the Mt. Baker Snoqualmie National Forest Supervisor's Office in Seattle. This group represented the administrative staff, which would be responsible for the planning and training of technical staff to install cameras and review data if camera applications were adopted.

Group 3 was composed of five professional and technical staff members from the Forest Service's Recreation Research Project in Seattle. This group represented a mixture of Groups 1 and 2, i.e., technical staff, which would review and summarize the photo data, and administrative staff to plan and train technical staff for camera applications and data analysis.

The three groups of coders were separately exposed to three photo treatments. The order of exposure to the treatments was rotated for each group as shown below.

	Treatment sequence		
Group number	1st	2d	3d
1	Color slides	Black and white prints	8-mm movies
2	Black and white prints	8-mm movies	Color slides
3	8-mm movies	Color slides	Black and white prints

The purpose of this rotation procedure was to distribute equally and cancel out any bias that may have resulted from coders becoming fatigued during the testing.

Just before they were shown the photographs, each group was given a brief verbal explanation of the study and specific instructions. They were then given a blank score sheet containing the relevant variables. These variables were explained and defined to each group in the same manner. Each coder put his or her name on the score sheets and began the evaluation.

Treatment Presentations

Fifteen color slides were projected one at a time on a screen. Each slide remained on the screen for 60 seconds, after which the screen was darkened for 5 seconds. Then another slide was projected. The process was repeated until all 15 slides had been reviewed.

Individual packets of fifteen 5-x7-inch, black and white glossy prints were given to each photo coder for review. These were photographs of the same subjects in Treatment 1, but in reverse order to cancel out any bias resulting from coders "learning" during the test. Each print had numbered codes on the back, which the group was instructed to put in a special column on the score sheet next to their evaluations. Coders were allowed to view each print for 60 seconds, after which a blank page was viewed for 5 seconds; and the process was repeated until all 15 prints had been reviewed.

For each group, fifteen 8-mm color movie frames were individually projected onto a screen. These 15 frames were of the same subjects as in Treatments 1 and 2 but in a different order. Each frame remained on the screen for 60 seconds after which the screen was darkened for 5 seconds; then another treatment frame was projected and the process repeated until all 15 frames had been reviewed and evaluated by coders.

RESULTS

Photo Coding is Reliable

The greatest variation in coders' scores was between photograph formats and not between groups. For the most part, none of the three groups of photo coders had any advantage in identifying variables from the photographs (table 1). There was only 2 percentage points difference between

Table 1--*Percentage of baseline variables correctly identified from color slides, black and white prints, and 8-mm movie photograph formats by the three photo-coder groups*

Photo coder group	Photograph format		
	Color slides	Black and white prints	8-mm color movies
	- - - - - - - - - - Percent - - - - - - - - - -		
Group 1	38	35	33
Group 2	38	33	31
Group 3	36	33	30

the group scores on color slides (36-38 percent), 2 percentage points difference on black and white prints (33-35 percent), and 3 percentage points difference on 8-mm movie frames (30-33).

The groups of photo coders did not increase their accuracy as they progressed from Treatment 1 to Treatment 3. This suggests that the coders did not carry their perception of one photograph format into another, nor did they become fatigued as they went through the treatment sequence. The variation in scores from one format to the next for all three groups' treatment sequence indicates that scores were more a function of individual format than any other extraneous factor (table 2, 3, 4). Table 2, for example, shows that Group 1 scores decreased from a high of 38 percent correct for color slides (Treatment 1) to 33 percent correct for 8-mm movies (Treatment 3). Conversely, the average score for Group 2 (table 3) increased from 33 percent correct for black and white prints (Treatment 1) to 38 percent correct for color slides (Treatment 3). Table 4 shows that Group 3 scores increased from 30 percent correct for 8-mm movies (Treatment 1) to 36 percent correct for color slides (Treatment 2), then decreased to 33 percent correct for black and white prints (Treatment 3).

Table 2--*Distribution of scores for individual photograph formats by GROUP 1 in the sequence they were exposed to each*

Photo format and sequence	Baseline variables							
	Vehicle type	Number of people	Group composition	Recreation equipment	Age	License	Activity	Average total
	Percent							
(1) Color slides	100	46	19	51	20	1	28	38
(2) Black and white prints	100	31	8	57	15	0	32	35
(3) 8-mm color movies	100	27	7	51	12	0	32	33
Average total	100	35	11	53	16	0	31	35

In general there was little variation in coders' raw scores for individual variables. The widest variation in scores among intracoder groups was in the 8-mm color movie format for variables such as number of people and age. No coder variable was identified to account for the wide variation in scores from the 8-mm color movie format. This, however, suggests that 8-mm color movies are less reliable than the other two formats for identifying detailed recreation use data.

Color Slides Superior Over Other Formats

Color slides permitted greater identification of all the social baseline variables than either the black and white prints or 8-mm color movie frames (table 5). On the average the most variables were identified from

Table 3--*Distribution of scores for individual photograph format by GROUP 2 in the sequence they were exposed to each*

Photo format and sequence	Baseline variables							
	Vehicle type	Number of people	Group composition	Recreation equipment	Age	License	Activity	Average total
	- - - - - - - -	- - - - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -	- - - - - -	- - - - - -
(1) Black and white prints	100	37	7	46	10	0	33	33
(2) 8-mm color movies	100	33	0	38	6	0	37	31
(3) Color slides	100	46	16	56	11	0	38	38
Average total	100	39	8	47	9	0	36	34

Table 4--*Distribution of scores for individual photograph format by GROUP 3 in the sequence they were exposed to each*

Photo format and sequence	Baseline variables							
	Vehicle type	Number of people	Group composition	Recreation equipment	Age	License	Activity	Average total
	- - - - - - - -	- - - - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -	- - - - - -	- - - - - -
(1) 8-mm color movies	100	27	0	46	6	0	33	30
(2) Color slides	100	40	13	55	11	0	32	36
(3) Black and white prints	100	35	4	50	7	0	35	33
Average total	100	34	6	50	8	0	33	33

Table 5--*Percentage of baseline variables correctly identified from color slides, black and white prints, and 8-mm movie photograph formats by the three photo-coder groups*

Photo format	Baseline variables							
	Vehicle type	Number of people	Group composition	Recreation equipment	Age	License	Activity	Average total
Color slides	100	44	16	54	14	0	33	37
Black and white prints	100	34	6	51	11	0	33	34
8-mm color movies	100	29	2	45	8	0	34	31

35-mm color slides (37-percent correct) followed by 5-x7-inch black and white prints (34-percent correct) and 8-mm movies (31-percent correct). Only one variable, type of vehicle, was correctly identified (100 percent) on all photograph formats by all three groups of coders.

Except for number of people, the overall difference between color slides and black and white prints was small.

Some of the differences between the three formats seem small enough to be the result of chance variation, while other differences are probably too large to have been created solely by chance. The consistent patterns of results across various dependent variables, however, suggests that the differences are not a result of chance. This suggests that color slides are better than 8-mm movies and black and white prints for providing social data on recreationists.

The overall superiority of color slides in this test was underscored by the fact that recreation equipment was identified from slides on the average 9 percentage points greater (54-percent correct) than 8-mm movie film (45-percent correct) and 3 percentage points greater than black and white prints (51-percent correct). Color slide scores for number of people (44-percent correct) were 15 percentage points better than 8-mm movies (29-percent correct) and 10 percentage points better than black and white prints (34-percent correct). For the other variables, color slide scores were better or as good as the other formats. Recreation activity was identified on the average 3 out of 10 times (33-percent correct) from the slides, which was equal to black and white prints (33-percent correct) and 1 percentage point lower than 8-mm movies (34-percent correct). Other scores for color slides were: group composition 16 percent, and age 14 percent. Only one license number was correctly identified from the slides.

Even though the three groups on the average identified the correct number of people in a vehicle only 44 percent of the time from the color slides, they identified the correct number of people in parties of three or less 63 percent of the time. Scores for all groups decreased as the number of people in each party increased from three as user images became indistinguishable. This could not be done in the other film formats. The three photo coder groups also correctly identified 54 percent of all recreation equipment from color slides. They were, however, able to correctly identify 88 percent of all equipment located on the outside of the principal transportation vehicle, such as wood-hauling trailers, motorbikes, rafts, boats, and fishing gear.

Black and White Prints Superior Over 8-mm Color Movies

Even though black and white prints proved to be less reliable than color slides for producing social data, they are somewhat better than 8-mm color movies (table 5). Overall, black and white print scores (34 percent) were 3 percentage points better than 8-mm color movies (31 percent). Black and white prints, however, were substantially better than 8-mm movies for variables such as number of people and recreation equipment.

Photography is Limited in Producing Social Data

Photography in this test proved less reliable than direct observation and personal contacts in producing selected social data about recreationists driving forest roads (table 6). Photographs at best permitted identification of all social baseline data--obtained through personal contact and direct observations--only 37 percent of the time. This suggests the superiority of human observations and conversation over photographic systems of the type tested here for obtaining selected social data. Group composition, age, license, and activity were the most difficult variables to identify through photography. They could only be identified from 0 to 38 percent of the time.

Table 6--*A comparison between three photograph formats and observation techniques for identifying variables and answering questions about recreation use in roaded areas of forest environs*

Variables sought and questions to be answered	Percentage of questions answered by coders from the three photo formats and through human means			
	35-mm color slides	5"x7" black and white prints	8-mm color movie	Conversations and direct observations
1. How many and what type of vehicles are recreationists using?	100	100	100	100
2. How many recreationists are using areas?	44	34	29	100
3. What is the group composition of recreation parties?	16	6	2	100
4. What kind and how much recreation equipment do recreationists bring into the area?	54	51	45	100
5. What are the approximate ages of the recreationists using the area?	14	11	8	100
6. What is the license number of the recreationists using the area so origin can be determined?	0	0	0	100
7. What kind of activities do recreationists pursue in this area?	33	33	34	100

CONCLUSIONS

The following conclusions were drawn from the foregone data and apply only to photography systems and conditions experienced in this test.

1. Despite its great potential, photography proved less reliable than direct observation and conversations--under field conditions--in producing selected social data on recreationists driving forest roads.

2. It is possible to reliably identify the number and type of recreation vehicles using forest roads from photography.

3. Photography cannot reliably identify recreation user characteristics, such as number of people, age, group composition, recreation activity, and equipment, and will consistently underestimate the frequency of these variables.

4. Large projection format 35-mm color slides proved more suitable for identifying social data on recreationists than either black and white prints or 8-mm color movie formats. Black and white prints are better for this purpose than 8-mm color movies.

5. Photo coding among individuals in this test proved reliable. Undergraduate students proved as adept as Forest Service managers at identifying recreation use information from photographs.

RECOMMENDATIONS

Although it is not possible to prescribe for all conceivable circumstances from the results of one study, the following recommendations seem warranted until additional experience and research results are available.

1. Land managers, planners, and recreation researchers should not rely solely on photography to produce reliable user-characteristic information on recreationists driving forest roads until further research on this problem is completed, or until the technology is further advanced.

2. Future research should investigate ways to advance the art of measuring and analyzing social data on recreationists from photographs.

3. Further testing of photo-technology application to recreation use measurements should continue with additional evaluation of (a) camera systems variables, (b) camera site location and placement variables, and (c) recreation user variables. These variables are the critical elements in a successful photography program for gathering reliable information on recreation use.

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OCCURRENCE OF CALCIUM OXALATE AND OXALATE-UTILIZING BACTERIA IN *ECHINODONTIUM TINCTORIUM* DECAY ZONES IN *ABIES CONCOLOR* [1] [2]

by

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[2]Chemical analyses were performed by the Cooperative Analytical Laboratory under the joint direction of Elly Holcombe and Joanne Kristaponis by Agreement Supplement No. 99 to the Master Memorandum of Understanding between the U.S. Forest Service and Oregon State University.

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ABSTRACT

Concentrations of Ca and oxalate were measured separately in both apparently sound and decayed *Abies concolor* wood. *Echinodontium tinctorium*, the fungus causing the decay, is capable of producing oxalate *in vitro*. Although not statistically significant, highest concentrations of both Ca and oxalate occurred in incipient and advanced decay zones. The average ratio of Ca to oxalate in these zones was 1:1.85, close to the ratio of 1:2.2 in pure Ca oxalate. Bacteria capable of utilizing Ca oxalate were isolated from decay zones of two trees infected with *E. tinctorium* and from the uninfected control tree. It is postulated that recycling of Ca and other cations by degradation of oxalates by bacteria may play an important role in decay of wood by fungi, however, additional studies are needed to demonstrate this hypothesis. An additional hypothesis we propose is that production of oxalic acid may enhance the rate of pectin decomposition by *E. tinctorium*.

KEYWORDS: Heart rot, white fir, decay process, discoloration, Indian paint fungus, deterioration.

INTRODUCTION

The Indian paint fungus, *Echinodontium tinctorium* Ell. and Ev. is responsible for the greatest decay losses in true firs and hemlocks in western North America (Boyce 1961). Recent studies indicate an interrelated community of microorganisms is associated with hymenomycetous fungi that cause decay (Shigo 1967). Many microorganisms, including bacteria, have been consistently isolated from decay caused by *E. tinctorium* (Aho 1976, Hudson 1972). The roles of bacteria in the decay process, though relatively unknown, may be mutualistic (Cosenza et al. 1970). For example, Aho et al. (1972) isolated bacteria capable of fixing atmospheric nitrogen from decay associated with *E. tinctorium* and other fungi in white fir (*Abies concolor* (Gord. and Glen.) Lindl.). Bacterial fixation of nitrogen may be a source of nitrogen needed by fungi to decay wood, a substrate of high C/N ratio (Merrill and Cowling 1966).

Fungi, in a variety of natural habitats, produce oxalic and other organic acids as a part of carbohydrate metabolism (Foster 1949). Production of oxalic acid by *Sclerotium rolfsii* (Sacc.) facilitates cell wall decomposition by precipitating calcium from cell wall pectates and facilitating polygalacturonase activity (Bateman and Beer 1965). Bacteria capable of utilizing relatively insoluble oxalates, such as calcium oxalate, have been isolated from earthworms, various types of soils, and dungs (Chandra and Shethna 1975). Such bacteria, however, have not been isolated from decomposing wood.

The objectives of this exploratory study were to determine the concentrations of oxalate and calcium in sapwood and heartwood and various decay zones caused by *E. tinctorium* in white fir, to isolate bacteria capable of utilizing calcium oxalate as an energy source from the wood and decay zones, and to determine whether or not *E. tinctorium* produces oxalic acid in pure culture. An additional objective was to determine whether or not oxalate-utilizing bacteria are present in decay caused by other fungi in western hemlock and Sitka spruce in a coastal Oregon forest

METHODS AND MATERIALS

Field Collections

Wood samples were collected from two white firs bearing *E. tinctorium* sporophores and from one tree without decay located near Porcupine Ridge (elevation 1 200 m) in the Butte Falls Ranger District, Rogue River National Forest. Two samples, 60 cm in length, were cut from the bole of each tree. The samples were taken from the trees at heights of approximately 4.5 m and 10.5 m above ground. The wood sections were placed in individual plastic bags and taken to Corvallis on the same day. They were stored approximately 60 h at $2^{o}C$ before being used in the experiments.

Advantage was taken of an unrelated study made at the Cascade Head Experimental Forest, near Otis, Oregon to test for presence of calcium oxalate decomposing bacteria in wood decayed by fungi other than *E. tinctorium.* Discolored and decayed wood blocks (7.5 cm^3) were removed from 53 western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and 99 Sitka spruce (*Picea sitchensis* (Bong.) Carr.) boles bearing 15-year-old injuries, 12.5 cm wide by 50 cm long. Wounds had not been treated with chemicals, and one wound was sampled per tree.

Sample blocks were obtained from the wood behind the face of the bottom, middle, and top of each wound. They were placed in individual plastic bags and taken to a field laboratory at Cascade Head Experimental Forest where isolations were made. Two isolations were taken from each block.

Laboratory Tests

The bark was removed from the 60-cm white fir sections, and a 7.5-cm-long disk was cut from the center of each. We attempted to isolate bacteria and decay fungi and to determine calcium and oxalate concentrations in sapwood, early, incipient, and advanced decayed wood of the two infected trees and in sound sapwood and heartwood zones of the uninfected control tree.

Echinodontium tinctorium isolates from decayed wood in white fir were tested for their ability to produce oxalate in pure culture on an artifical medium. Mycelia of *E. tinctorium* were put on a nylon mesh (Nitex 276) applied to the malt agar surface and incubated at $18^{o}C$ for 2 weeks. Mycelial mats were collected from the nylon mesh, lyophilized, and introduced into 100- X 16-mm I.D. glass tubes with teflon-lined screw caps. Three ml of 5 percent HCI-methanol solution were added to each tube. Oxalate concentration was measured using the gas chromatographic method of Mee and Stanley (1973).

Isolation of bacteria and fungi.--Two methods were used to isolate calcium oxalate-utilizing bacteria. First, wood plugs (7.5 cm long by 1.2 cm diam) were removed aseptically from each wood and decay zone with a tubular chisel, placed in sterile rubber tubing, and subjected to 200 to 350 Kg/cm^2 of pressure in a hydraulic press (Aho et al. 1974, Knutson 1970). One ml of expressed sap was immediately diluted in 9 ml of sterile distilled water and serially diluted to 1/1000. One-tenth ml of sap and of each dilution (1/10, 1/100, 1/1000) from each wood and decay zone was pipetted into each of three plates containing a calcium oxalate medium modified slightly from that reported by Jayasuriya (1955). Yeast extract concentration was reduced from 0.1 percent to 0.01 percent (v/v) and 3 percent agar (Difco) was substituted for Davis New Zealand agar. The inoculum was spread over the surface of the medium with a sterile glass rod. The plates were incubated at $25^{o}C$ and checked periodically for growth. A clear zone developed around bacteria capable of utilizing calcium oxalate (Jayasuriya 1955).

Second, when it was not possible to squeeze sap from various white fir wood and decay zones, small wood chips (about 3 mm^3) were removed aseptically from freshly exposed surfaces (Aho et al. 1974), placed on the calcium oxalate medium in petri plates, and incubated at 25°C. The same technique was used to isolate decay fungi except that the small wood chips were placed on 2.5 percent malt agar (Difco) in culture tubes and incubated at 20°C.

The discolored and decayed wood samples behind injuries in western hemlock and Sitka spruce trees were treated similarly. Each was carefully split to expose fresh surfaces. Six wood chips (two each from the blocks taken from the bottom, middle, and top of the scar) were plated on the calcium oxalate medium and incubated at 25°C. Two chips from each sample block were also placed on malt agar slants.

Concentration of oxalic acid.--Pieces of wood from each decay zone, weighing at least 10 g, were carefully removed from the white fir disks, lyophilized, and ground in a Wiley mill to pass a 40-mesh screen. Concentration of oxalate present in each sample was determined by the gas chromatographic method of Mee and Stanley (1973). Calcium oxalate is solubilized with IN HCI which also catalyzes a reaction between methanol and oxalate forming dimethyl oxalate. Concentration of oxalate is determined by comparison with standard concentrations of dimethyl oxalate.

Concentration of calcium.--The remaining portions of each white fir disk were carefully separated by stage of decay, oven-dried to constant weight at 65°C, and ground in a Wiley mill to pass a 40-mesh screen. Samples were ashed at 500°C, ash was taken up in HCI, and calcium concentration determined by spark emission spectroscopy (Chapman and Dickson 1974).

Statistical Analyses

Mean and standard error of the mean were calculated for calcium and oxalate concentrations for sound and decayed wood in each of the three trees by pooling the observations for samples at two heights.

RESULTS AND DISCUSSION

Isolation of Bacteria and Fungi

Bacteria capable of utilizing calcium oxalate as an energy source were isolated from all three white fir study trees. None were found in the sapwood or advanced decay zones but were isolated from: (1) early and incipient decay in both sections from tree 1, (2) incipient decay at 10.5 m in tree 2, and (3) the inner heartwood zone of tree 3 at 10.5 m. The latter heartwood zone was not visibly decayed, but was slightly discolored. No fungi could be isolated from it. The only decay fungus isolated from decayed wood in trees 1 and 2 was *E. tinctorium.* Bacteria and black non-hymenomycetous fungi were also isolated from decay zones in these trees.

Due to the low numbers of calcium oxalate-utilizing or other bacteria found in this study, it was not possible to make an accurate population estimate. We attribut this result to time of year (winter), low moisture content of the wood, and most importantly, to the high concentrations of phenolic compounds present in sap expressed from *E. tinctorium* decay (Aho et al. 1974).

Conclusive evidence that these bacteria are commonly associated with discolored and decayed wood in living trees was obtained by isolations from wounded western hemlock and Sitka spruce. Calcium oxalate-utilizing bacteria were isolated from at least one of six chips from 62 percent of the wood samples behind scars on 53 hemlock and nearly 60 percent of the 99 wounds on spruce. These data indicate that calcium oxalate-decomposing bacteria are present in decayed wood other than that caused by *E. tinctorium*. To the best of our knowledge this is the first report of the presence of calcium oxalate-utilizing bacteria in living trees. No attempt was made to identify these bacteria from white fir, western hemlock, or Sitka spruce, but all were gram-negative rods.

Concentrations of Calcium and Oxalate

Oxalate was found in all *E. tinctorium* isolates tested. Concentrations in two cultures were 0.8 and 0.5 percent of freeze-dried weight. This confirms, at least *in vitro*, that the white rot fungus *E. tinctorium* has a physiological capability to produce oxalate and in concentrations similar to that found in rhizomorphs produced by *Fomitopsis pinicola* Swarz. & Franz in decayed Douglas-fir heartwood (Cromack et al. 1977). Other researchers have shown that both white and brown rot fungi produce relatively large amounts of oxalate (Henningsson 1965, Milova 1973, Nord and Vitucci 1947).

Oxalate was detected in all wood and decay zones tested (table 1). Concentrations of oxalate were higher, though not statistically significant, in the incipient

Table 1--Concentrations of oxalate and calcium in sound wood and *Echinodontium tinctorium* decay zones in white fir

Tree number	Wood or decay zone	Oxalate[1]		Calcium[1]	
		Concentration (% dry wt.)	Standard error	Concentration (% dry wt.)	Standard error
1	Sapwood	0.146	0.011	0.09	0.010
	Early decay	.124	.011	.10	.005
	Incipient decay	.807	.020	.46	.005
	Advanced decay	.382	.180	.32	.150
2	Sapwood	.421	.010	.13	.030
	Early decay	.471	.050	.18	.010
	Incipient decay	.571	.025	.27	.070
	Advanced decay	.521[2]	--	.23[2]	--
3	Sapwood	.068	.022	.08	.005
	Outer heartwood	.113	.022	.26	.040
	Inner heartwood	.068	.022	.17	.090

[1] Average of two measurements made at different heights (4.5- and 10.5-m) in each tree.

[2] Advanced decay stage present only in the 4.5-m sample in tree 2.

and advanced decay zones of the two infected trees than in sound sapwood or heartwood zones of the uninfected control tree. Calcium concentrations corresponded to those of oxalate, also being nonsignificantly higher in the incipient and advanced decay zones (table 1). The average ratio of Ca to oxalate in incipient and advanced decay stages was 1:1.85 (0.25 S.E., n = 7 samples); whereas, in pure Ca oxalate it is 1:2.2. The average calcium concentrations in the incipient and advanced decayed wood are in excess of those needed to form a precipitate with all of the oxalate anion present. Due to the limited sample size, it is quite possible that in some locations within individual trees, adequate Ca is not present to precipitate all the oxalate anion present. Other studies have shown that calcium is concentrated in decayed wood by fungi (Johansson and Theander 1974, Rennerfelt and Tamm 1962, Safford et al. 1974, Tatter et al. 1971), including *E. tinctorium* (Ellis 1956) suggesting that oxalate can be accumulated by wood decay fungi.

Concentration trends of calcium and oxalate in sapwood and inner and outer heartwood (Tree 3) were similar. Highest concentrations of calcium occurred in wood containing the highest levels of oxalate (table 1). The presence of oxalate in sound woody tissue should not be considered unusual since it is known that trees also naturally produce this compound (Esau 1967). Bacteria have been isolated from apparently healthy woody tissues (Aho and Hutchins 1977), including sapwood (Knutson 1973, Shortle and Cowling 1978). Conceivably, oxalate produced by a tree could be a substrate for some of these bacteria.

We suggest that the high concentrations of calcium and oxalate in incipient and advanced decayed wood, and the presence of bacteria capable of utilizing calcium oxalate as a source of energy aid microorganisms attacking cellulose and lignin components of wood by recycling cations. Decay fungi, such as *E. tinctorium*, or associated non-hymenomycetous fungi, produce oxalic acid in the degradation of wood. Calcium and oxalate precipitate to form a sparingly soluble compound; other cations form complexes with oxalate anions. Neutralization of free oxalic acid by formation of calcium oxalate or by formation of complexes with other cations such as Fe or Al would maintain a higher pH in decayed wood than would free oxalic acid thus favoring fungal growth. Decomposition of Ca oxalate by bacteria would tend to increase microsite pH, with formation of soluble Ca $(HCO_3)_2^-$. Jayasuriya (1955) found pH to increase from 7 to 9.5 with bacterial decomposition of K oxalate. The Ca $(HCO_3)_2^-$ can react with cation exchange sites or with the oxalate anion to form additional Ca oxalate, thus completing a cycling of Ca. Calcium cycling within the three decay zones may be analogous to recycling of Ca within soil profiles, where both fungal production of the oxalate anion and bacterial decomposition of oxalates may considerably influence the weathering rates of cations, causing release of P from Fe and Al hydroxy phosphates (Graustein et al. 1977).

In the process of wood decay, oxalic acid production by *E. tinctorium* may enhance pectinase activity by the same chemical mechanism suggested by Bateman and Beer (1965); *E. tinctorium* is known to produce oxalic acid (this study) and pectinase *in vitro* (Mayers 1932).

We hope the results of this study will stimulate additional research to define and clearly demonstrate the roles of fungi and bacteria in accumulation and utilization of oxalate and calcium (and other cations), respectively, in the decay process.

Answers to the following questions will help in our understanding of the process of wood decay in living trees:

1. What is the role of Ca oxalate utilizing bacteria in the wood decay process by *E. tinctorium* and other decay fungi, including effects on pH and cation exchange processes?
2. What role does oxalic acid production by *E. tinctorium* and other decay fungi have in regulating rate of pectin decomposition?
3. Can nitrogen-fixing bacteria, commonly found in decaying wood, also utilize Ca oxalate?
4. Is atmospheric nitrogen fixed by bacteria utilized by fungi decayed wood? Is rate of decay increased by presence of nitrogen-fixing and Ca oxalate utilizing bacteria?

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EFFECTS OF SOIL AND FOLIAR APPLICATIONS OF NITROGEN FERTILIZERS ON A 20-YEAR-OLD DOUGLAS-FIR STAND

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ABSTRACT

We compared growth and cone production of Douglas-fir treated 4 years earlier with 150 pounds N per acre applied as urea prill by hand and as a 32-percent N solution applied by helicopter. Nitrogen fertilization increased growth by 88 ft^3 per acre during the 4 years after treatment; this 35-percent gain was similar for both soil (prill) and foliar (solution) applications. Although cone production on the prill-treated plots averaged twofold to fourfold greater than on the control plots, these differences were not statistically significant.

KEYWORDS: Nitrogen fertilizer response, fertilizer applications, cone production, Douglas-fir, *Pseudotsuga menziesii*.

INTRODUCTION

Although application of urea to the soil is the most common method of fertilizing Douglas-fir forests in the Pacific Northwest, application of concentrated N solutions to the foliage is an alternative method (Miller and Young 1976). Concentrated salt solutions are more likely to damage foliage or shoots and thus reduce the beneficial effects of fertilization or even reduce growth below that of unfertilized trees. Moreover, fertilizing Douglas-fir forests with a 32-percent N solution applied as a foliar spray has been more expensive than fertilizing with urea prill. For example, in large-scale operations, total costs per pound of N applied as a 32-percent N solution averaged 21 percent more than for urea fertilization (Miller and Young 1976).

We report the 4-year results of a field trial comparing the effects of soil and foliar application in a recently thinned, 20-year-old stand of Douglas-fir. We wanted to answer the following questions: To what extent can growth in height and total cubic volume and production of cones be increased by application of 150 lb of N per acre as urea prill and as concentrated urea-ammonium nitrate solution (32-percent N)?

MATERIALS AND METHODS

Study Area

The study area lies 7 miles southeast of Canyonville, Oregon, on a northeast aspect (fig. 1). Elevation of the nine 0.2-acre plots in the study area ranges between 2,500 and 2,850 ft; slopes range between 20 and 45 percent. Annual precipitation at Riddle, which is located about 14 miles to the northwest, averages 36.6 in with 6.0 in falling from April 1 through September 30.[1]

Soils in the study area are well-drained and are developing from a highly fractured metamorphic shale. Eight of the nine plots are located on the McGinnis series (Typic Haploxerult, clayey-skeletal, mixed, mesic). This soil has a dark brown, clay loam surface with a red, gravelly clay subsoil. The McGinnis soil is less than 40 in deep and contains 35 to 50 percent of highly weathered shale fragments. Site index among the eight plots in this soil series averaged 112 and ranged between 103 and 116 ft (100-year index age).

The remaining plot is on the Pollard series (Typic Haploxerult clayey, mixed, mesic) which is deeper and more productive. Although the surface soil is also dark brown and clay loam in texture, the subsoil is red clay with less than 20 percent of shale fragments. This soil is deeper than 40 in and has more water-holding capacity than McGinnis soils. Site index on plot 10 was 140.

The Stand

Our 20-year-old stand originated after a seed tree cut and broadcast burning in 1951. Prior to precommercial thinning in August and September 1972, the young stand contained 340 to 880 Douglas-fir per acre that were 1.6-in d.b.h. and larger; these Douglas-fir represented 88 to 100 percent of the total basal area (table 1). Madrone was initially present in all but one plot; chinkapin, red alder, and willow were present on some plots. The thinning removed 32 to 68 percent of the initial basal area of Douglas-fir and reduced density to 140 to 225 Douglas-fir stems and 0 to 85 hardwood stems per acre (table 1); all residual Douglas-fir were less than 8-in d.b.h. (table 2). The three plots sampling each treatment spanned the range of the initial and final stand conditions (table 1).

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[1]Unpublished data filed at the Douglas County Water Master's Office, Roseburg, Oregon.

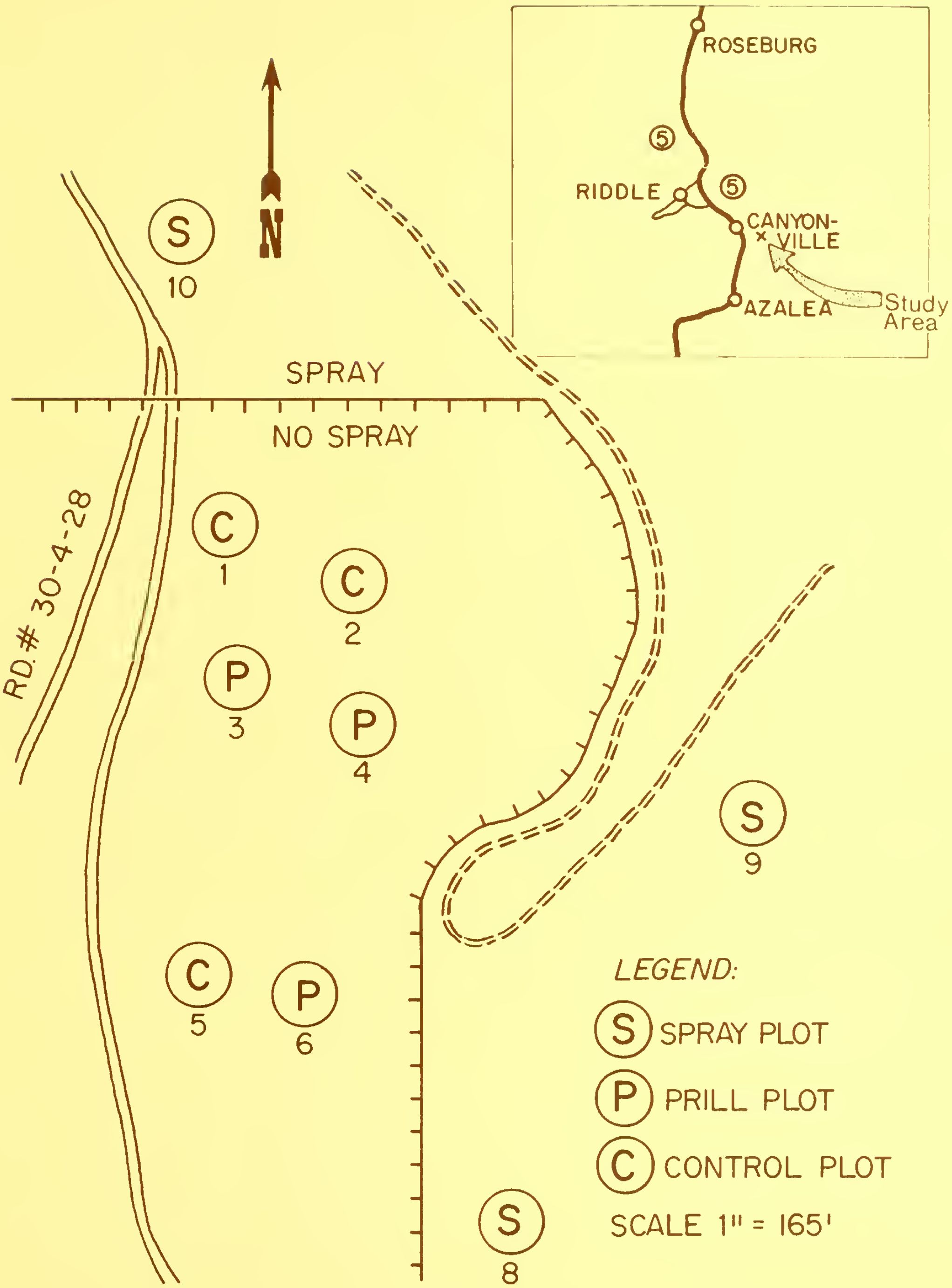

Figure 1.--Vicinity and schematic map at the study area.

Table 1--Stand statistics before and after thinning, per acre basis[1]

Fertilizer status	Plot No.		Douglas-fir D.b.h.	Douglas-fir Stems	Douglas-fir Basal area	Hardwoods[2] D.b.h.	Hardwoods[2] Stems	Hardwoods[2] Basal area
			Inches	Number	Square feet	Inches	Number	Square feet
None	2	Before		340	19.2		45	1.8
		After	4.0	150	13.0	2.8	35	1.6
	[illegible]	Before		590	26.9		45	1.0
		After	3.7	180	13.5	2.0	45	1.0
	5	Before		790	41.3		0	0
		After	4.1	225	20.8	--	0	0
Prill	6	Before		500	24.8		105	2.8
		After	3.8	160	12.4	2.3	95	2.2
	4	Before		585	28.7		20	.5
		After	4.2	160	15.3	2.1	20	.5
	3	Before		880	40.7		10	.3
		After	3.9	180	14.8	2.4	10	.3
Spray	8	Before		555	22.4		65	1.9
		After	3.2	140	7.8	2.2	50	1.3
	10	Before		765	45.5		235	6.0
		After	4.4	180	18.5	2.2	50	1.2
	9	Before		805	25.0		80	4.4
		After	3.4	180	11.1	1.9	20	.4

[1]Plots are arrayed within treatment by increasing number of Douglas-fir in the original stand.

[2]Includes madrone on all but one plot; chinkapin and incense-cedar on some plots.

Table 2--Diameter distribution of residual Douglas-fir, per acre basis

Fertilizer	D.b.h. class, inches: 2	3	4	5	6	7	All
	Average number of trees						
None	30	42	70	33	7	3	185
Prill	25	45	52	32	13	0	167
Spray	33	58	45	23	5	1	167
	Average cumulative percent						
None	100	84	61	23	5	2	
Prill	100	85	58	27	8	0	
Spray	100	80	46	19	5	2	

Plot Installation and Tree Measurement

We established nine 0.2-acre, circular plots in this stand before the 1973 growing season. We located three plots in an area designated for foliar fertilization by helicopter. We placed the remaining six in an abutting 14-acre, non-spray area and randomly selected three of these plots for hand fertilization with urea prill; the other three were control plots (fig. 1). Thus, our spray-treated plots were adjacent, but not randomly intermingled with the other plots.

We measured diameters of all trees 1.6 inches and larger and heights of 15 trees per plot at 2-year intervals; two-thirds of these 15 height trees initially exceeded the quadratic mean d.b.h. of their respective plot. To reconstruct information about the stand before thinning, we determined species, number, and d.o.b. of all stumps exceeding 1.9 in. We estimated d.b.h. of these cut trees by using regression equations of d.b.h. and stump d.o.b. for 8 to 18 live trees measured on each plot.

Statistical Analysis

The non-random location of the spray-treated plots theoretically precludes valid statistical analysis of the effects of foliar fertilization, because some effects of this treatment could be due to site or stand differences associated with the spray-treated plots being 300 to 400 ft away from the nearest control or prill-treated plots. We assume the treatments equally sampled a fairly homogeneous stand and therefore, think this theoretical confounding has little influence on our conclusions.

We tested differences among treatment means by either analysis of variance or by analysis of covariance when a suitable covariate was available. We separated significant differences among the three means by the orthogonal comparisons: control *versus* fertilized, and soil *versus* foliar fertilization. We used the 10-percent probability level ($P<0.10$) to judge differences as real or statistically significant.

Fertilization

Urea prill.--Our original plan was to apply both fertilizers prior to the 1973 growing season; however, the foliar application by helicopter was inadvertently delayed. On March 24, 1973, when the Douglas-fir buds were still tight, we fertilized plots 3, 4, and 6 with 150 lb N per acre using agricultural grade prill. We uniformly broadcast the prill by hand within 0.4-acre circular areas concentric with the 0.2-acre measurement plots. Volatilization losses were unlikely, because the soil was moisture saturated at fertilization and rain fell the next day; the weather station at Riddle reported 0.72 in of precipitation in the 7 days after fertilization.

Foliar spray.--After an unplanned delay until June 9, we applied a commercial, 32-percent N solution by helicopter over the 55-acre spray area. Diameter growth had started and buds had burst; most trees had completed 10 to 25 percent of their twig growth.

Our target dosage was 150 lb of N per acre. To enhance spreading of the solution over the foliage, we added 0.5 weight percent of "Plyac", a commercial spreader-sticker.[2] Subsequently, we found that this surfactant was ineffective, because it coagulates rather than disperses in this concentrated salt solution. We surmise that the ineffectiveness of this surfactant had little impact on our results.

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[2]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

We controlled and measured the distribution of the foliar spray. To insure accurate flight lines, we marked the boundaries of the spray area with yellow flagging, aluminum foil, and helium-filled balloons. To sample the actual dosage on each spray plot and the amount of drift to prill-treated and control plots, we placed 1-ft-square sampling papers near 10 randomly selected trees per plot. We fixed these papers on boards either placed atop a pole raised to tree height or on the ground in a nearby opening (fig. 2). In the three spray-treated plots, we used five raised targets and five on the ground. On the six other plots within the non-spray area, we used three raised targets and seven on the ground. We collected these paper targets after fertilization and stored them in an iced container before analysis for nitrogen contents.[3]

Figure 2.--Spray dosage at canopy level was measured on elevated sampling papers. Note also the extent of twig extension when the liquid fertilizer was applied.

RESULTS AND DISCUSSION

Measured Spray Dosage

Average N dosages measured on the three helicopter-treated plots varied widely and were consistently less than the prescribed 150 lb of N per acre. Average N dosages and their 95-percent confidence limits on the sprayed plots were 64±8, 100±13, and 123±22 lb per acre. Dosage on individual sampling papers ranged between 52 and 165 lb of N per acre.

Drift onto the remaining six plots within the non-spray area was minimal and the average N dosages and 95-percent confidence limits for individual plots ranged between 0±0 and 3.5±1.2 lb per acre. Maximum dosage on any paper in the non-spray area was 5.9 lb N per acre, even though some sample papers were within 300 ft of the spray-treated plots.

[3]Nitrate-N analyses of these sampling papers were kindly provided by Dr. Donald C. Young, Research Chemist, Union Oil Co., Brea, Calif. Total N was computed on the basis of the percentage of nitrate in the fertilizer.

Our measured dosage estimates the actual dosage received by the trees. This dosage for each spray-treated plot was consistently less than our target dosage of 150 lb N per acre. We offer two explanations. First, some decrease in dosage may be characteristic of helicopter applications of nitrogen solutions. For example, small droplets of spray could be lost to the atmosphere. If so, then one would have to increase a desired dosage to compensate for assumed losses. Second, fewer than 150 lb N per acre could have been released from the helicopter, presumably because the pilot avoided the spray/non-spray boundary to minimize drift into the non-spray area. By monitoring spray dosage, however, we were reasonably assured that growth on the control and prill-treated plots was negligibly affected by the spray fertilization and that the spray-treated plots received less nitrogen per acre than did the prill-treated plots.

Spray Injury

To foliage.--Visual estimates after the first growing season showed that as average dosage per plot increased, more of the trees had injured needles and a larger percentage of the needles on these trees were injured (table 3). On plot 8, which received an average of 123 lb of nitrogen per acre, 93 percent of the Douglas-fir had some needle injury; however, only 4 percent of the trees had as much as 30 percent of their foliage surface injured. In this heavily thinned stand, severity of foliar burning was not related to crown class (table 3). The combined data from all spray plots showed that 56 percent of the trees had 10 to 20 percent of their needle surface burned, but only 1 percent of the trees had 30 or more percent burned. We observed more severe crown burning in other portions of the sprayed area which probably received heavier dosages of spray, e.g., near the edge of the stand where the helicopter pivoted to change direction.

According to previous investigations, negative effects of injury to Douglas-fir foliage began to offset benefits of fertilizing when more than 30 percent of the needle surface of a tree was injured (Miller and Young 1976). Assuming the ineffective surfactant had little influence on spray injury, we concluded that our target dosage of 150 lb of N per acre was probably close to the maximum safe dosage for the weather and tree conditions at time of treatment.

To leaders.--After the first growing season, 10 percent of the trees on the sprayed plots had curled or dead leaders compared to 8 percent broken or dead leaders on the prill-treated and 18 percent on control plots. These differences were not statistically different and indicate the ferti-

Table 3--Injury to Douglas-fir foliage after spray application of a 32-percent N solution

N per acre	Crown class	Number per acre	Injury class[1]			
			0	10	20	30
Pounds			- - - - Percent of trees - - - -			
64	Dominant	125	68	28	4	0
	Codominant	50	60	40	0	0
	Intermediate	5	100	0	0	0
	All	180	67	31	3	0
100	Dominant	115	48	52	0	0
	Codominant	60	50	33	17	0
	Intermediate	5	0	100	0	0
	All	180	47	47	6	0
123	Dominant	85	0	76	24	0
	Codominant	55	18	55	18	9
	Intermediate	0	--	--	--	--
	All	140	7	68	21	4
[2]96	All	167	43	47	9	1

[1]The estimated percent of needle surface on the tree that appeared discolored or burned.

[2]Average of the three spray plots.

lizer treatments did not increase the incidence of misformed leaders.

Height Growth

Annual height growth in nearly all plots during the 4 years after treatment averaged about 10 percent less than that during the 2 years before treatment (table 4). Although this reduction probably indicates that the rate of height growth peaked prior to treatment, it could show that heavy thinning temporarily reduced height growth as previously observed in low-site quality Douglas-fir (Staebler 1956, Miller and Reukema 1976).

Although average height growth on fertilized plots was slightly greater than control growth, this difference was not significantly different ($P<0.38$) after adjustment for the greater height growth on the fertilized plots prior to treatment. Therefore, contrary to our expectations, neither soil- nor foliar-applied nitrogen had any measurable effect on height growth.

Cubic Volume Growth

Volume growth on individual plots during the subsequent 4-year period was closely related to growing stock after thinning (fig. 3). We reduced the effects of these initial differences in growing stock by using covariance analysis to adjust average growth for each treatment to a common starting volume.

This adjusted volume growth on the prill-treated plots exceeded that on the control plots by 37 percent or 92 ft^3 during the 4-year period (table 5). Likewise, the adjusted volume growth of the spray-treated plots averaged 80 ft^3 more than that of the unfertilized plots for the 4-year period or 12 ft^3 less than that of the prill-treated plots. Orthogonal comparisons indicated a signifi-

Table 4--Average initial height and annual height growth before and after fertilization

Fertilizer	N per acre	Plot[1]	Initial height	Annual height growth 1971-72	Annual height growth 1973-76	Ratio 1973-76 / 1971-72
	Pounds		- - - - - - Feet	- - - - - - -		
None	0	2	26.8	2.4	2.2	0.91
	0	1	29.1	2.5	1.9	.75
	0	5	31.3	2.4	2.2	.96
	0	Average	29.1	2.4	2.1	.90
Prill	150	6	29.0	2.4	2.4	1.00
	150	4	29.2	2.8	2.6	.93
	150	5	31.0	2.8	2.3	.85
	150	Average	29.7	2.7	2.4	.93
Spray	123	8	24.6	2.3	2.2	.93
	100	[2]10	33.8	2.9	2.7	.94
	64	9	26.3	2.4	1.9	.78
	96	Average	28.2	2.5	2.3	.88

[1]Plots are arrayed within treatment by increasing number of Douglas-fir in the original stand.

[2]Pollard soil series. The other plots are on the McGinnis series.

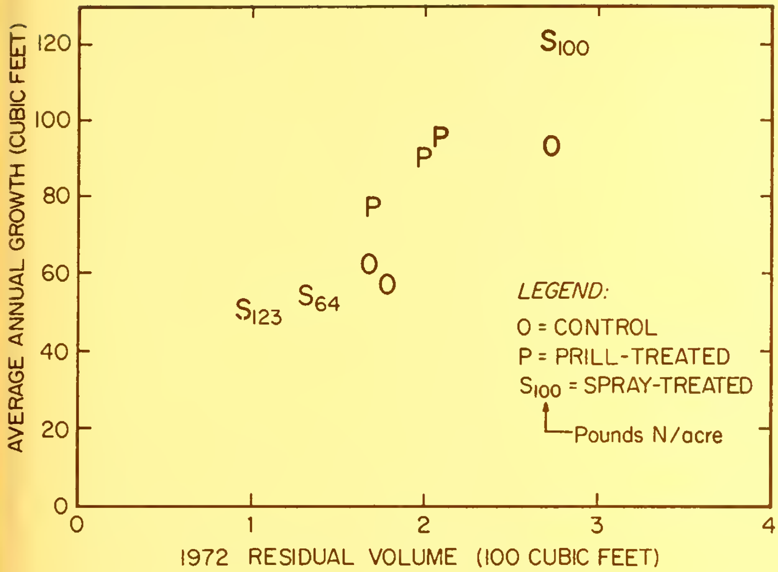

Figure 3.--Average annual gross volume growth during 4 years after treatment, all species, trees 1.6 in and larger, per acre basis.

cant difference between the fertilized plots and the control plots ($P<0.01$), but no significant difference between the prill and the spray-treated plots ($P<0.58$). Acknowledging the non-random allocation of the spray plots, we speculate that the response to foliar spray was comparable to that of prill.

One could argue that to compare the effectiveness of soil and foliar application, we should adjust volume response to foliar fertilization for the shorter period of time after treatment (3.9 to 3.75 versus 4.0 growing seasons) and for the lower N dosage evidently received on the spray-treated plots (96 versus 150 lb N per acre). Although such adjustments are logical, estimating their magnitude is speculative. For example, we don't know how closely our measured N dosage corresponds to the dosage actually released by the helicopter. If we assume (1) the helicopter sprayed an average of 96 lb of N per acre, and (2) a linear response surface between 0 and 150 lb of N per acre, then average growth on the spray-treated plots would be increased by 56 percent. Although we considered both assumptions reasonable, we chose the conservative approach: we assumed that 150 lb of N per acre were applied by the helicopter to the spray-treated plots

Table 5--Average initial volume and gross volume growth of all trees 1.6 in d.b.h. and larger, per acre basis

Fertilizer	N per acre	Volume after thinning	Periodic annual growth		4-year gain[1]	
			Unadjusted	Adjusted[1]	Absolute	Relative
	Pounds	Cubic feet				Percent
None	0	204	69	62	--	--
Prill	150	190	86	85	92	37
Spray	96	166	74	82	80	32

[1]Growth adjusted for initial differences in stand volume.

and concluded that fertilizer efficiency of both methods of supplying nitrogen was comparable during the first 4 years after treatment.

Longer-term measurement at this and other study areas[4] will provide more definitive comparisons of these two methods of fertilization. We know that application of concentrated nitrogen solutions requires reduced N dosage and more uniform distribution than does application of urea prill, because growth after foliar fertilization more strongly reflects the net effect of fertilizing, i.e., improved nutritional status minus negative effects of chemical burning. If, for example, spray dosages on our plots had greatly exceeded our highest dosage of 123 lb of N per acre, foliar or terminal damage may have been increased and volume response been reduced. The N dosage that can be applied to Douglas-fir stands without causing excessive needle damage depends on numerous factors including N source, additives, season of year, stage of tree growth, spray volume relative to amount of foliage, and uniformity of spray application (Miller and Young 1976). We believe that in most Douglas-fir stands, however, dosage of at least 100 lb N per acre can be applied with little concern for foliage injury.

[4]Unpublished data on file at the Forestry Sciences Laboratory, Olympia, Washington.

Cone Production

We were interested in cone production for at least two reasons: (1) to know if commercial fertilizers increased cone production and (2) to learn if increased cone production could have reduced gains in volume production.

In the second and fourth growing seasons after fertilization of our 20-year-old stand, cone production by 15 sample trees per plot was highest in prill-treated plots, much lower in the control plots, and lowest in the spray-treated plots (table 6). Method

Table 6--Cone production in the 2d and 4th years after treatment, 15 trees per plot

Fertilizer	N per acre	Plot	Trees with cones 1974	Trees with cones 1976	Cones per tree[1] 1974	Cones per tree[1] 1976
	Pounds					
None	0	2	2.0	5.0	8.7	9.9
	0	1	0	1.0	0	.5
	0	5	1.0	7.0	.3	3.3
		Average	1.0	4.3	3.0	4.6
Prill	150	6	5.0	6.0	8.5	11.5
	150	4	6.0	9.0	34.3	11.3
	150	3	3.0	9.0	3.3	13.1
		Average	4.7	8.0	15.4	12.0
Spray	123	8	0	4.0	0	5.0
	100	10	0	3.0	0	1.3
	64	9	0	2.0	0	.9
		Average	0	3.0	0	2.4

[1]Equals total cones ÷ 15 sample trees.

of fertilization influenced the number of trees that bore cones as well as the average number of cones per sample tree (total cones ÷ 15 trees). In the second growing season, foliar fertilization clearly reduced cone production. Our orthogonal comparisons could not compare cone production on prill-treated and control plots. A separate test of these treatment means, however, showed that urea prill significantly increased the number of trees with cones ($P<0.02$). The total cones per plot (or average number of cones per tree), however, was not significantly different from that on the control plots ($P<0.28$), despite an apparent fivefold increase in production.

In the fourth growing season, cone production on the spray-treated plots increased, but remained less than that on the control plots. Cone production did not differ significantly between the control and all fertilized plots ($P<0.30$), however, cone production on the prill-treated plots was more than fivefold greater than on the spray-treated plots; ($P<0.02$) and 2.5 fold greater than on the control plots ($P<0.06$).

These results indicate that the large increases in cone production in the 2d and 4th years after fertilization with urea prill was probably a true effect in the 4th year. Moreover, the absence of cone production in the second growing season after foliar fertilization was also an effect of that treatment.

To determine if diameter growth of prill-fertilized trees was depressed by increased cone production, we regressed basal area growth and cone production of individual trees. The absence of a significant slope to the regression line for each of the prill-treated plots indicated that these levels of increased cone production had no measurement effect on diameter and probably on volume growth.

Others[5] have reported that N fertilization of Douglas-fir near time of bud burst increased cone production in the following year (Stoate et al. 1961, Ebell and McMullan 1970). Timing of fertilization is generally considered critical to its effectiveness. For example, Stoate et al. (1961) reported that fertilization 2 weeks before or after bud burst did not stimulate cone production. Since our application of urea prill was at least 4 weeks before bud burst and that of N solution was several weeks after bud burst, both methods might have been more effective if applied closer to bud burst.

Although fertilization is a commonly used means for inducing cone crops in conifers (Puritch 1972), fertilization has been relatively ineffective in years of cone failure (Steinbrenner et al. 1960). Regional cone production was generally poor in 1974 and 1976 when we observed our trees, so our observed differences between fertilized and control trees may have been reduced.

Ebell and McMullan (1970) demonstrated that the nitrate form of nitrogen is more effective than the ammonium form for producing cones in Douglas-fir. Thus, our urea-ammonium nitrate solution should have been more effective than urea prill. We could not test this, because our application of the nitrate-containing fertilizer solution was made after twig growth was 10 to 25 percent completed. Application after bud burst, coupled with the likelihood that the solution could have damaged bud tissue in the expanding twigs, may explain the absence of cone production in the year following foliar fertilization.

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[5]Ebell, L. F. 1962. Growth and cone production responses of Douglas-fir to chemical fertilization. Report on Project B.C. 1, Can. Dep. For. B.C. District, 41 p. Victoria, B.C. Mimeo.

CONCLUSIONS

1. Our target dosage of 150 lb of N per acre as a 32-percent N solution without an effective surfactant was probably close to the maximum safe dosage for the weather and tree conditions. Only 4 percent of the trees had as much as 30 percent of their foliage surface injured on the plot receiving 123 lb of N per acre.

2. The incidence of terminal or leader injury was not increased by foliar or soil fertilization.

3. Neither foliar- nor soil-applied N had any measurable effect on height growth during the first 4 years after treatment.

4. Assumptions had to be made about the amount of foliar-applied nitrogen. Although target dosage was 150 lb N per acre, the measured dosage averaged 96 lb.

5. Nitrogen fertilization increased growth in this recently thinned stand by 22 ft^3 per year or 88 ft^3 during the 4-year period. This 35-percent improvement in growth was about the same for both soil and foliar applications despite the likelihood that much less N was applied in the foliar application.

6. Foliar fertilization decreased cone production in the second growing season after treatment and urea prill increased cone production in the fourth growing season by 2.5 fold.

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Metric Conversion Factors

1 pound/acre	= 1.121 kilograms/hectare
1 acre	= 0.405 hectare
1 foot	= 0.3048 meter
1 inch	= 2.54 centimeters
1 ft^2/acre	= 0.2296 m^2/ha
1 ft^3/acre	= 0.06997 m^2/ha
1 tree/acre	= 2.47 trees/ha
1 mile	= 1.61 kilometers

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PNW-330

March 1979

RESPONSE TO UREA AND AMMONIUM NITRATE FERTILIZATION IN AN 80-YEAR-OLD DOUGLAS-FIR STAND

by Richard E. Miller, Principal Soil Scientist

and Constance A. Harrington, Research Forester

Abstract

Volume growth response to 200 lb of nitrogen per acre applied as urea or ammonium nitrate was monitored for 4 yr in an 80-yr-old, site I, Douglas-fir stand. Fertilization increased gross total cubic growth by 20 percent over the controls. Response to urea and to ammonium nitrate was similar. The rapid volume growth on the control plots, 342 ft^3 per acre per year, plus the substantial increase in growth on the fertilized plots, indicate the desirability of delaying final harvest of this stand.

KEYWORDS: Nitrogen fertilizer response, increment (volume), urea, ammonium nitrate, silviculture, Douglas-fir, *Pseudotsuga menziesii*.

INTRODUCTION

Silvicultural treatments that increase growth in mature stands can be attractive financial investments because the initial costs and carrying charges can be quickly recovered from early harvest of high value products. In this Research Note, we present the initial results of a trial in which nitrogen fertilization increased volume growth of an 80-yr-old, site I, Douglas-fir stand. We also compare the effects of urea with those of ammonium nitrate on volume growth.

THE STUDY AREA AND TREATMENT

The study area was an unthinned, nearly pure Douglas-fir stand in the McCleary Experimental Forest[1] in western Washington (fig. 1). Basal area stocking averaged 111 percent of normal (McArdle et al. 1961) and site index (100-yr base) averaged 193 or low site I. The soil is Tebo gravelly loam; annual precipitation averages 66 inches.

We used 12 circular, 1/5-acre plots to compare three treatments: 200 lb of nitrogen per acre as urea, 200 lb of nitrogen per acre as ammonium nitrate, and no nitrogen (control). We randomly assigned four plots to each treatment. Most stand characteristics were similar among treatments (table 1).

We applied the fertilizers by hand on April 13, 1973, to 1/2-acre plots centered on the 1/5-acre measurement plots; this provided a 30-ft-wide buffer. The weather during application was cloudy and cool; about an inch of rain fell during the 3 days following treatment. Thus nitrogen losses by volatilization were probably minimized.

[1]Maintained by the Pacific Northwest Forest and Range Experiment Station in cooperation with Simpson Timber Company.

Figure 1.--A portion of the 80-yr-old, unthinned stand in the McCleary Experimental Forest.

Table 1--Initial stand characteristics of study plots in the McCleary Experimental Forest, per acre basis

Characteristic	Treatment			
	Control	Urea	Ammonium nitrate	Average
Age (years)	80	78	80	79
Site index (100-year base)	190	198	191	193
Stems (number)	159	121	135	138
Average diameter[1/] (inches)	19.3	21.3	21.0	20.5
Basal area (square feet)	324	298	324	315
Volume (cubic feet)	18,952	17,566	18,760	18,426
Percent Douglas-fir	99	98	99	99

[1/] D.b.h. of the tree of mean basal area.

MEASUREMENTS AND ANALYSES

Our 12 study plots were some of the control plots of a thinning experiment that began in 1949 (Reukema and Pienaar 1973); consequently, we had prefertilization growth data. We remeasured the trees immediately before fertilization and 4 yr after fertilization. We measured diameter at breast height (d.b.h.) of all trees 1.6 in and larger and recorded their crown class and condition. We also determined the heights of nine trees on each plot; two-thirds of these trees had diameters greater than average d.b.h. Based on these height trees, we calculated an average tarif number and thus a volume equation to estimate total stem volume for each plot in each measurement year.

We examined the effect of treatment on 4-yr volume growth and mortality. Because growth and mortality prior to fertilization varied among the plots, we used covariance analysis to adjust for these differences. We tested two variables as covariates: cubic-foot volume at the begining of the study and periodic annual increment (p.a.i.) in basal area during a 14-yr period prior to fertilization. Insufficient height data during the prefertilization period precluded our using pretreatment volume growth as a covariate. The analyses using p.a.i. in basal area (pretreatment) as the covariate were more effective in reducing the effects of pretreatment differences among the plots. In the results of these analyses which follow, we used the 10-percent probability level ($P<0.10$) to judge differences as real or statistically significant. The orthogonal comparisons, control vs. fertilized and urea vs. ammonium nitrate, were used to separate treatment means.

RESULTS AND DISCUSSION

Response to nitrogen fertilization was significant ($P<0.04$).

When treatment means were adjusted for differences in pretreatment growth rates, volume growth on the fertilized plots averaged 20 percent greater than that on the control plots (table 2). This equaled an average 4-yr increase of 280 ft^3 per acre. There was no significant differences between response to urea and response to ammonium nitrate. Volume loss to mortality during the 4-yr period after fertilization varied greatly among the plots and treatments (table 2). Due to this variability, mortality losses were not significantly affected by treatment ($P<0.68$).

This response to fertilization was somewhat lower than that measured in an earlier study of fertilization of individual trees in a thinned portion of the same stand (Miller and Reukema 1974). The six fertilizer treatments in that study increased average basal area growth 31 percent over the controls during a 5-year period after fertilization. Ammonium nitrate (300 lb of nitrogen per acre) increased basal area growth 53 percent, while urea (300 and 600 lb of nitrogen per acre) increased growth 31 and 22 percent. Due to the variability in response, however, only the ammonium nitrate treatment differed significantly from the control.

The difference in fertilizer response measured in the two studies could be explained by a number of factors. For example the individual tree study used six codominants for each treatment, whereas our study used 1/5-acre plots and thus had both greater tree numbers and crown class representation. The earlier study also used higher rates of nitrogen per acre. In addition, response to fertilization by individual trees is likely to be greater in a thinned stand than in an unthinned stand, because light is more likely to limit growth in an unthinned stand (Brix 1971).

Volume growth measured in this 80-yr-old stand was surprisingly large. Gross periodic annual growth on the four control plots averaged 342 ft^3 per acre compared with reported estimates of 263 (Staebler 1955) and 287 (Curtis 1967) ft^3 per acre for normal stands of the same site index and age. Having checked our procedures and calculations, we have no reason to doubt the accuracy of our growth estimates. Moreover, our estimates of stand volume and growth are supported by previous estimates (Reukema

Table 2--Mean annual volume growth and mortality in an 80-year-old, Douglas-fir stand during a 4-yr period after treatment, per acre basis[1/]

Treatment	Volume growth[2/]		Mortality[2/]
	Cubic feet	Percent	Cubic feet
Control	342	100	75
Urea	409	119	140
Ammonium nitrate	415	121	65

[1/] Cubic volume of the total stem of trees 1.6-in d.b.h. and larger.

[2/] Means adjusted by covariance analysis.

and Pienaar 1973). For example, earlier periodic annual growth for these and other unthinned plots in this stand progressed from 263 ft^3 per acre at age 56 to 285 ft^3 at age 71. This trend of increasing volume growth over time indicates that gross growth in this stand has not yet culminated. Thus, delaying the final harvest of this stand is an attractive management option.

CONCLUSIONS

In this 80-yr-old stand of Douglas-fir:

1. Urea or ammonium nitrate applied at 200 lb of nitrogen per acre increased gross volume growth 20 percent over the controls during the first 4 years following treatment. This was an average increase 280 ft^3 per acre.
2. Ammonium nitrate and urea provided the same gain in volume growth.
3. Fertilization did not significantly change the volume lost to mortality.
4. Gross volume growth of the control plots has not peaked; therefore, delaying final harvest should be evaluated.

Based on the results at this location and others,[2] we believe nitrogen fertilization is an efficient means for increasing total yields in mature Douglas-fir stands.

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Metric Equivalents

1 square foot/acre = 0.2296 square meters/hectare
1 cubic foot/acre = 0.06997 cubic meters/hectare
1 stem/acre = 2.471 stems/hectare
1 inch = 2.54 centimeters

[2]Unpublished data on file at the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Olympia, Washington.

GPO 987-934

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

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PNW-331 March 1979

WHAT PROGRAM MANAGERS AND PROJECT LEADERS SHOULD KNOW ABOUT PUBLICATIONS BUT USUALLY LEARN THE HARD WAY [1/]

by

George M. Hansen, *Supervisory Technical Publication Editor*

Abstract

Responsibilities of Program Managers and Project Leaders in Forest Service Research are listed and discussed. The focus is on publication of research results.

KEYWORDS: Communications, technology transfer, research.

INTRODUCTION

First, you should understand how I feel as an editor of research publications. For research I feel that there is no permanent value until the study findings have been documented in a publication. The objective of publishing research results is to disseminate the findings to the users. This is another way of saying "technology transfer." The procedures reported in this Note reflect the publication policy of the Pacific Northwest Forest and Range Experiment Station (PNW). Other Stations may have more or less minor differences.

[1/] Presented to Project Management Training Task Groups, Phoenix, Arizona, March 26-30, 1979. An in-Service meeting conducted by U.S. Department of Agriculture, Forest Service, Washington, D.C.

Perhaps we should establish what a publication is because often there are misunderstandings. In general terms, a publication is printed or duplicated material that is distributed to meet specific needs of the general public, other agencies, and cooperators, as well as the needs of the USDA Forest Service. Exhibit 1 is the definition according to the Forest Service Manual[2/] (paragraph 1630.51). Visuals, mentioned last, will be addressed in more detail later.

Exhibit 1

Publications. For purposes of control and management in the Forest Service, the term, publications, generally refers to printed or duplicated informational material that is distributed to meet specific needs of the general public, other agencies and departments, and cooperators, as well as the needs of the Service. The term does not apply to the Forest Service directive system (FSM 1105).

1. Materials considered publications are:

a. Reports, booklets, bibliographies, leaflets, folders, pamphlets, and brochures issued in established series or as miscellaneous items by Regions, Stations, Areas, the Washington Office, or the Department.

b. Folders that include maps or charts and text other than legends (commonly called Forest visitor maps and wilderness maps).

c. Newsletters, instructor's aids, field guides, and training texts.

d. Articles in Service or Department periodicals, such as "Fire Management Notes" and "Tree Planters Notes."

e. Official articles, abstracts, chapters, or sections (FSM 1633) for publication in non-Government periodicals, books, encyclopedias, and proceedings.

f. Articles, leaflets, pamphlets, brochures, and books usually prepared cooperatively with State agencies, foundations, industrial associations, conservation organizations, or academic institutions.

g. Annual reports required by statute.

2. Materials not considered publications are:

a. News media releases and background materials for media use (FSM 1650).

b. Speeches, except those to be issued after the event in a published proceedings, and book reviews.

[2/] U.S. Department of Agriculture, Forest Service. 1978. Forest Service Manual, Amend. 53.

c. Directives, regulatory and administrative announcements, financial advice, hearing and appeal notices, specifications and bid notices, and administrative reports issued to meet Forest Service statutory responsibilities.

d. Forms, schedules, agendas, and routing slips.

e. Preliminary drafts of publications reproduced in limited quantity for review. These should be clearly marked "Review Draft - Not for Publication."

f. Posters, signs, tags, and posted notices to the public.

g. Maps and charts without accompanying text.

h. Visual and lecture notes for filmstrips and slides (FSM 1640).

GENERAL PROCEDURES

The first step in preparing for sound, efficient research should be a study plan. After a study plan has been approved by line management, the research is conducted from which data are assembled, analyzed, and conclusions drawn for publication. At that point, the author may feel ready to start writing the report.

At the PNW Station, the author writes his own report. He should begin with a carefully organized outline, then write and rewrite until the product is the very best that the researcher is able to produce.

At that time the Program Manager or Project Leader and the author should decide what technical review process will be followed. The technical reviewers for some Stations have to include outside scientists in the same field as well as others at the home Station. Most of the Stations require biometric reviews of statistical analysis, and some scientific journals require it.

The Department of Agriculture requires that any mention of pesticides must be reviewed by the Pesticide Monitor of a Station who decides whether the mention or the recommendation of pesticides conforms with policy and law. Exhibit 2 is an official definition of pesticides.[3/]

Exhibit 2

Pesticides are synonymous with "Economic Poisons" as defined in the Federal Insecticide, Fungicide and Rodenticide Act and include those materials plus nematicides, herbicides, plant regulators, plant defoliants, plant desiccants, and bird, animal, and reptile repellents or poisons. Wood preservatives are also included, but not fire retardants.

Another part of the review process is the arithmetical and mathematical check. It is not done by a biometrician. If complex, the check requires a

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[3/] Correspondence from E. Bacon, USDA Forest Service, Washington, D.C., dated March 9, 1970.

mathematician; if not complex, this might be done by somebody in the author's own unit who can check the additions, subtractions, and totals as they might appear in tables or in the text itself.

Another important check or review is of literature citations. Readers may need to check on the source of certain statements made in the report, so citations must be accurate, down to the spelling of the author names, titles just as published, and properly documenting the outlet in which they appear.

After full review and resulting revisions, the manuscript should be ready for approvals by Project Leader and Assistant Director (Program Manager and Deputy Director) and forwarding to the Editor. Figures should not be prepared in final form before editing because often preliminary figures may have incorrect legends or misspelled labels.

After editing and approval by the author and the Program Manager or Project Leader, further approvals are usually required by the Assistant Director or (Deputy Director), and the Director, the order according to the practices of each Station. The edited manuscript is then returned to the Editor who prepares it for printing. At the PNW Station, final preparation, including artwork, is usually handled by the Editor's shop then approved by the author. Afterwards the manuscript goes to the printer.

The printing is negotiated by the Publications Control Officer. At the PNW Station this responsibility is delegated from the Director to the Editor who also decides whether the outlet is appropriate, whether it would be more appropriate in a journal or in the Station series (usually decided when editing). When the report is printed, the Distribution Control Officer enters into the process.

Now that these have been mentioned in general, I'll deal with them from a different perspective.

RESPONSIBILITIES OF THE PROGRAM MANAGER OR PROJECT LEADER FOR PUBLICATIONS

The Program Manager or Project Leader is the first line officer required to approve an author's manuscript. Responsibility includes supervision--overseeing the quality of research which leads to the publication, and approving the technical soundness of the research, which means there must be adequate technical and statistical review. They are also responsible for the organization, quality, and completeness of the paper. In addition, they are responsible for reviewing revisions of the manuscript, and must also look at and review the comments made by the technical reviewers to decide whether the author has properly dealt with the valid comments of the reviewers. In some cases, they may have to arbitrate between the author and the technical reviewers. When satisfied, the Program Manager or Project Leader forwards the manuscript to the next level of approval which is the Assistant Director or Deputy Director. In some Stations the next step might be the Editor.

ESTABLISHMENT OF PRIORITIES

The Editor is responsible for following any valid priorities that may be given to a manuscript. The PNW Station's editors will process a manuscript chronologically as received if no priority designation has been given. For top priority, an Editor may need from a week to perhaps 60 days, depending on length, before the manuscript would be ready for the printer. When real deadlines require priority, it's usually the Assistant Director or the Deputy Director who assigns the priority for the Editors' attention. If there is a conflict between the different programs and projects or different Assistant Director's on the Editors' time, then the Director might make the final decision for designating priority.

One might ask why there have to be priorities. These come about when a scientist gets a "short notice" invitation to present a paper at a meeting or to submit a report to a journal. It might be that the subject of the report is very timely and needs to be published as soon as possible, or that the publication be ready in time for a panel evaluation of a scientist or for other reports. All of these needs for priority are aggravated by procrastination. It is unfair to expect the Editor's shop to meet deadlines which are not theirs.

FINANCIAL CONSTRAINTS

The Program Manager or Project Leader should be aware of some financial constraints, although not having to make the final decision. The author should use only figures and photos that are actually needed in the report. The author should avoid verbosity and repetition. Some journals will reject articles that are too long or charge for excess pages over what they consider is their normal accepted manuscript. When printing must be rushed to meet a deadline, it is going to cost more. Printers are not used to printing any faster than they want to; and when they have to hurry, they charge more.

Authors and their supervisors should ask for color illustrations only if essential. Use of color is usually approved only to illustrate fire, disease, identification, or on maps. Such approval is requested by the Station Editor and is granted by the Washington Office.[4] Exhibit 3 gives more detail (see footnote 2, paragraph 1630.12).

Exhibit 3

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PERSONAL WRITING

Another consideration in preparing articles will involve whether the article is personal writing, defined here as those works not covered in the study plan, and whether it is writing on official time and about official work.

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[4] Washington Office refers to administrative headquarters of USDA Forest Service, Washington, D.C.

If the article is written on the author's own time about official work, he will need the Director's approval whether or not he's paid for the article. If there are royalties involved, these royalties are the author's property only if his agency has approved. He can assign copyrights to the publisher. Exhibit 4 is from the Employees Handbook[5] and explains more fully.

Exhibit 4

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(i) Employees may not accept honorariums for written articles, speaking engagements, or addresses on radio or television or other appearances performed as part of their official duties... .

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[5] USDA Administrative Regulations 3, AR18 and 19, and Code of Federal Regulations 7 CFR0.735-13.

> All manuscripts submitted to private copyrighted journals or magazines must be declared to be in the public domain with the following statement:
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The new Copyright Law,[6/] which came into effect January 1978, is essentially just like its predecessor; however, unlike the former law, the 1978 law is being strictly enforced.

REPRINTS AND RERUNS

The Publications Control Officer is responsible for reprinting and rerunning. The expense of an official publication is paid from the General Assessment budget by Research Support Services.[7/] This includes journal page charges, general handling expense, journal surcharges for color or for excessive length or number of figures, and Government Printing Office charges.

Another consideration in publications is what to do when the supply for reprints becomes exhausted. The expense of journal reruns for Station publications can be handled in different ways. Either the project pays for them or in some cases Research Support Services pays for them. Some Stations will not reprint journal articles after 2 years and will not reprint Station publications after 5 years. There are exceptions to these instances that can be granted by the Deputy Director or Assistant Director or perhaps only by the Director.

The author can usually obtain all the reprints he wants, the rest being available to the public as well as available for in-Service distribution. Expense of publication is usually for the life of a publication, and this will vary by Station policy. The National Technical Information Service photocopies publications that have been put into their system, and they charge a high fee for a photocopy. Libraries have copies available in bound volumes--especially the large libraries. Superintendent of Documents may sell a Station publication if the proper procedures have been followed.

PUBLICATION DISTRIBUTION

Distribution of publications is usually controlled by the Station Publication Control Officer. At the PNW Station, this position is delegated by the Director. The research programs and projects may have distribution plans which should be made known to the Publication Control Officer. In-Service distribution, which I will mention only briefly, includes distribution to other Research Stations, Regional Offices, and the Washington Office. Forestry libraries usually get copies as do National Forest Supervisors, the Station's own staff and its field units. The number needed for public requests must be estimated, and experience determines what this number should be.

[6/] U.S. Laws, Statutes etc. 1976. Copyright Law. An act for the general revision of Title 17 of the United States Code, Public Law 94-553, 90 Stat. 2541, effective January 1, 1978.

[7/] Research Support Services is an administrative unit in USDA, Forest Service Research.

VISUAL DISPLAYS, POSTER PRESENTATIONS, TALKS

Earlier I mentioned visuals or displays, poster presentations, and talks, as they are not called publications in the Forest Service Manual (see footnote 2). These may be reviewed and edited by some Stations just like a report to be published. Identifying audience is very important because, as the Forest Service Manual states, regional, national, and international audience presentations must have the Director's policy approval.

CONCLUSION

Titles of supervisors may change, the mechanical processes may change, but the dissemination of research results in publications of highest possible quality will remain the high-priority objective of Forest Service Research.

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PNW RESEARCH NOTE

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

PNW-332

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PRELIMINARY RESULTS OF EXPERIMENTAL FIRES IN THE BLACK SPRUCE TYPE OF INTERIOR ALASKA

by

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Abstract

Four units totaling 1 hectare in area were burned during the summer of 1976 in the Washington Creek experimental fire site near Fairbanks, Alaska. Original vegetation on the site consisted of an unevenly spaced stand of black spruce approximately 70 years old, with an understory of ericaceous shrubs and a nearly continuous cover of moss and lichen. One plot was burned on July 22 and the remainder on August 26 during two periods in the summer when the limits of the burning conditions were met. Measurements taken during the fire showed a difference of fire intensity among the four plots, which was also reflected in the percentage of area in each of five forest floor fire severity classes. Effects of the fires on vegetation, thickness of the organic layer, soil temperatures, phosphorus content of the forest floor, and the amounts of fuel are discussed. Seed fall from black spruce and revegetation of permanent plots during the 1976 season are given. Although the units were small, the burning under different weather conditions and with extra fuels placed on two of the plots resulted in a wide variation in the severity of burns and simulated conditions of a moderately severe wildfire.

KEYWORDS: Fire effects, fire use, black spruce, *Picea mariana*, Alaska (interior), taiga.

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INTRODUCTION

Land managers need to understand the effects of fires of varying intensities on the major taiga ecosystems. Recognizing that black spruce (*Picea mariana* (Mill.) B.S.P.) is the most widespread forest type in interior Alaska and also the type with the highest frequency of fire, the Institute of Northern Forestry (INF), the University of Alaska, and the U.S. Department of the Interior, Bureau of Land Managment (BLM) have worked together toward the establishment of the Washington Creek Fire Study and Training Area where basic research on the black spruce type, as well as experiments on prescribed burning in the black spruce type, can be conducted.

In 1976, through cooperation of INF, BLM, and the University of Alaska, the successful burning of four units within the Washington Creek experimental fire site marked the first carefully measured experimental fire in interior Alaska. It is the first of a planned series of studies on experimental burning in interior Alaska.

The fires were planned with two overall objectives:

1. To measure fire behavior under controlled burning conditions in the black spruce type in interior Alaska.
2. To determine the effects of fires of different intensities on the vegetation, surface organic layer, and soil.

A study plan was developed by INF scientists and a burning plan by BLM fire management personnel. The study plan called for collection of data before, during, and after the fire for information on prefire vegetation, fuels, and weather, fire behavior and intensity, and postfire changes in vegetation, fuels, soil nutrients, soil organic layers, and tree seed dispersal.

The experimental fire site occupies an area of about 1 ha (English equivalents are listed on page 28) on a ridgetop, between the drainages of Cushman Creek and Washington Creek at an elevation of 520 m. The area slopes to the southeast into the Washington Creek drainage. The soil at the site is shallow Fairplay silt loam with a shattered bedrock and stones at a depth of 20 to 50 cm. No permafrost was encountered; if it is present, it is well within the bedrock zone. The Washington Creek experimental fire site is located about 40 km north of Fairbanks.

The area was divided into five units (fig. 1). After the firelines were constructed, the undisturbed units ranged in size from 0.09 to 0.15 ha. Four of the units were burned and the fifth was left unburned for a control. An aerial view of the location and layout of the units and surrounding firelines is shown in figure 2.

METHODS

Unit Layout

The units were roughly diamond shaped (fig. 1). Two parallel transects, 8 m apart, were established along the long axis of each unit.

At 8-m intervals along each transect, five vegetation plots were established and permanently marked. Each of these 10 plots consisted of a 1-m^2 quadrat for sampling ground vegetation and low shrubs and a 4-m^2 circular area for sampling tall shrubs. Trees were sampled in a 4-m-wide belt centered on each of the transects (256 m^2 for each unit).

The percentage of cover in each species, stem counts by diameter class, and number of seedlings were recorded. Trees were counted and tallied by diameter class.

To facilitate observations of the rate of spread and to aid in relocating plots after the fire, we staked each unit into a grid. The location of the stakes is shown in figure 1.

Fuel Loading and Measurements

Because of the small size of the units we thought that they might not burn with the intensity of a severe wildfire. Therefore, to possibly increase the intensity of the fires, we loaded two of the units (1L and 4L) with additional fuels--black spruce cut from the firelines laid in rows within the units. We recorded the diameter of each tree at the time it was placed in the unit so we could determine biomass.

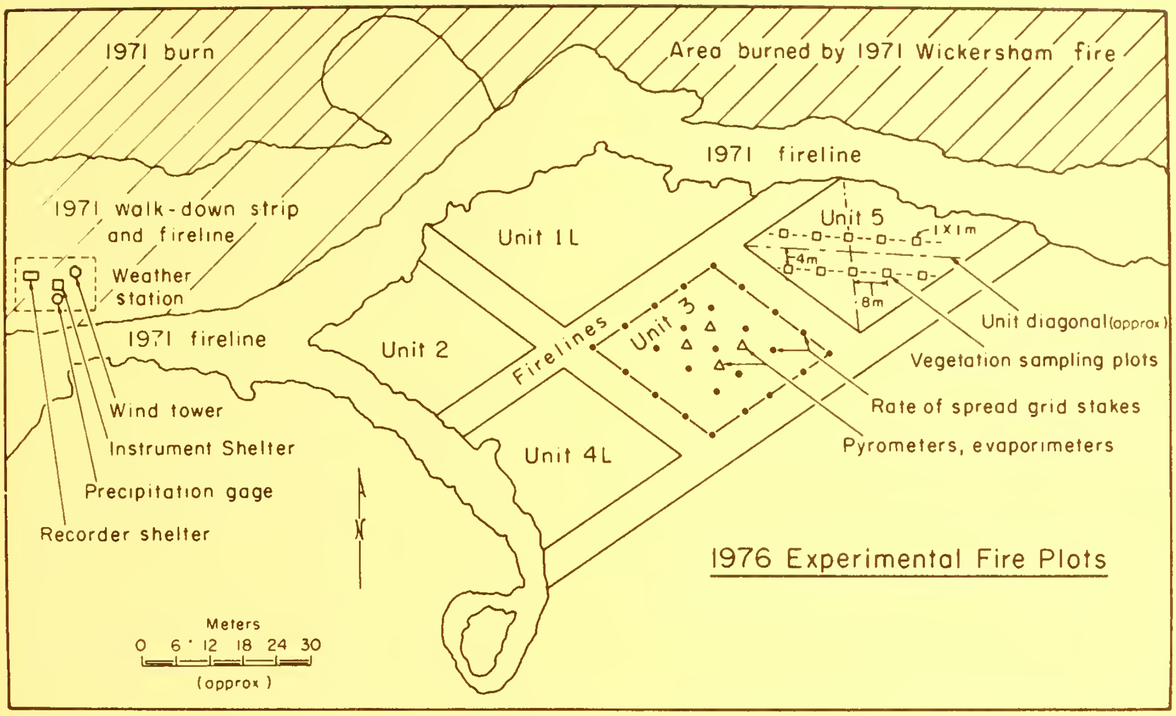

Figure 1.--Layout of the five units and the location of the weather station and firelines, Washington Creek experimental fire site. Unit 2 was burned on July 22, 1976; the other units on August 26, 1976. Unit 5 is the unburned control.

Figure 2.--Aerial view of 1976 experimental fire site. Old fire pattern of 70-year-old burn in the black spruce can be seen in the foreground. Area behind the site is the area burned by the 1971 Wickersham fire. Firelines along the ridge and in the foreground are from the 1971 fire. The walk-down strip diagonal to the left was put in in 1975 as part of suppression activities for the Alps fire in upper Washington Creek.

Fuel measurements were taken on permanently marked 10-m transects by the method developed by Brown (1971) and Brown and Roussopoulos (1974). This technique involves intersections of woody pieces with vertical sampling planes. Twenty randomly located, 10-m-long transects were sampled in each unit before the fire, and 10 were resampled after the fire. The loaded units were measured before and after the fuel was added.

Measurements of Fire Temperature

One of the more difficult aspects of this project was to categorize the intensity of each fire and describe its behavior and to assign some relative intensity to each. To obtain some idea of the actual heat intensity, we used several measuring devices.

1. Four pyrometer tiers were systematically located within each unit to be burned. Each tier consisted of three 7.5- by 12.5-cm pyrometers, one in the upper part of the organic layer, one from the air-organic material interface to 12 cm above the surface, and one 30 cm above the litter surface.
The pyrometers were adapted from the design of Fenner and Bentley (1960) and used chemicals fusible at 66°, 121°, 288°, 454°, and 660°C, painted in strips. The lowest temperature is about the lethal temperature for plant tissues; the upper is about flame temperature.

2. Energy release was measured indirectly through water loss in four simple evaporimeters. The devices consisted of No. 10 cans with 250 ml of water. The evaporimeters were located adjacent to the pyrometers; they were set out just before the fire and were retrieved and measured soon afterward.

3. Near the center of each unit a single pyrometer was installed with heat sensitive paint on aluminum strips at 50-cm vertical intervals to a height of 2.75 m.

4. Heat sensitive pellets with a range from 43° to 83°C were placed on the moss surface and at 5- and 10-cm depth in the organic layer.

Percent Moisture in the Organic Layer

In each unit moisture in the organic layer was determined immediately before the fire at one to four locations, depending on time available. The samples were taken every 2 cm to a depth of 10 cm and the remaining organic sample was used as the last sample.

Thickness of the Organic Layer

To assess effects of fire, we measured the thickness of the forest floor both before and after burning. Measurements were taken at 1/2-m intervals along the two vegetation transects on each unit. Along each transect 63 observations of forest floor thickness were made, for a total of 126 per unit. Measurements were made with a steel probe with graduated 1-cm intervals.

In addition, degree of burning of the ground vegetation was estimated by five forest floor fire severity classes. These were:

1. Heavily burned: deep ash layer present, organic material in the soil consumed or nearly so to mineral soil, no discernible plant parts remaining.
2. Moderately burned: organic layer partially consumed, shallow ash layer present, parts of woody twigs remaining.
3. Lightly burned: plants charred but original form of mosses and twigs visible.
4. Scorched: moss and other plants brown or yellow but species usually identifiable.
5. Unburned: plant parts green and unchanged.

This information was recorded for each of the 10 vegetation plots and along the 10 randomly located 10-m-long fuel transects within each unit.

Soil Nutrients

Immediately after the fire, five samples of the forest floor were attained in a systematic fashion from each unit, including the unburned control. Samples were taken at the approximate center of each unit and halfway between the center and each corner. A 15-cm-diameter core of the forest floor was obtained from a zone judged to represent the average degree of combustion of the forest floor in each location. Samples were immediately transferred to plastic bags, care was taken to avoid contamination of lower portions of cores by ash from the burned surface. The cores were separated into genetic horizons in the laboratory. Layer thickness, fresh weight, and ovendry (65°C) moisture content were estimated for subsequent bulk density calculations. Separated layers were frozen until analyzed. The acid fluoride soluble phosphorus was determined for each sample.

CONDITIONS PRIOR TO AND DURING BURNING

Vegetation

Vegetation of the area consisted of an unevenly spaced stand of black spruce approximately 70 years old, with an understory of shrubs, herbs mosses, and lichens. Vegetation data are given in tables 1 and 2.

Numbers of trees over 2.5-cm d.b.h. in the four units varied from 2,226 to 5,468 per hectare. Average diameters ranged from 4.3 to 4.9 cm, but the largest trees in the plots had diameters in the 9- to 10-cm class and heights of 6.5 m. Trees as large as 15-cm d.b.h. and 10 m in height were cleared from the fireline. A few paper birch *(Betula papyrifera)*, alder (*Alnus crispa*), and willow (*Salix* spp.) were scattered in the units. The trees were unevenly distributed so that there were small open areas between the tree clumps. In these small clearings the low shrubs--lingenberry (*Vaccinium vitis-idaea*), blueberry (*V. uliginosum*), and Labrador tea (*Ledum groenlandicum*)--were common; and these were the main areas for the lichen mats. Mosses were abundant throughout the stand; cover values ranged from 72 to 85 percent in the different units.

Fuel Load

Using regression equations developed by Van Cleve and Hunt[4] for black spruce at a nearby study site at Washington Creek, we determined the biomass of the fuels loaded on units 1L and 4L (table 3). Unit 1L was more heavily loaded than unit 4L, the total being 26 500 kg/ha for 1L and 15 600 kg/ha for 4L.

The units were loaded in June 1975; burning was planned for that summer. Therefore, although most of the needles had fallen from the trees by the summer of 1976, the fine fuels had an additional summer to cure.

Limits of the Burning Conditions and the Weather Preceding the Fires

The limits of the burning conditions were written by Roy Percival, Bureau of Land Management, with the anticipation that the fire would duplicate a moderately intense wildfire, in spite of the small size of the units. The foremost consideration in formulating the prescription was to obtain burning within safe control limits. The conditions necessary for the fire were the following:

1. Fuel moisture sticks (range)	5 to 20 percent
2. Humidity (range)	20 to 45 percent
3. Speed and direction of wind	0-4.5 m/s (0 to 10 mi/h) from S.W. to S.E.
4. Type of fire	Head, strip
5. Time of day	1400 to 1800 hours
6. Buildup index[5]	10 or above
7. Temperature	10° to 27°C (50° to 80°F)

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[4] Progress report and proposed research for the continuation proposal dealing with "The structure and function of a black spruce (*Picea mariana* (Mill.) B.S.P) forest in relation to other fire affected taiga ecosystems"; K. Van Cleve and C. T. Dyrness co-principal investigators. March 1977. On file at Department of Forest Soils, University of Alaska, Fairbanks. 205 p.

[5] A number expressing the cumulative effects of daily drying factors and precipitation in fuels with a 10-day timelag constant.

Table 1--Percent cover of vegetation and number of stems per hectare of tall shrubs and tree seedlings before burning, Washington Creek 1976 experimental fire site[1]/

Vegetation	Unit 1L	Unit 2	Unit 3	Unit 4L
	PERCENT COVER (NUMBER OF STEMS PER HECTARE)			
Tree seedlings:				
Picea mariana (Mill.) B.S.P.	2+0.6 (4,250+1,760)	2+2.5 (4,500+1,760)	2+0.6 (5,750+2,658)	1+0.4 (3,000+1,090)
Betula papyrifera Marsh.				1+.2 (1,250+990)
Populus tremuloides Michx.				1+.1 (250+250)
Tall shrubs:				
Alnus crispa (Ait.) Pursh	2+1.2 (1,750+1,730)	4+.3 (3,500+2,335)	8+4.8 (7,500+4,166)	
Salix scouleriana Barratt	5+2.5 (3,750+1,730)	4+2.3 (3,000+1,796)	2+1.5 (3,000+1,976)	10+5.2 (15,000+8,090)
Salix alaxensis (Anderss.) Cov.	1+.5 (1,500+1,480)			
	PERCENT COVER			
Low shrubs:				
Empetrum nigrum L.	3+1.1	5+1.3		5+1.5
Ledum groenlandicum Oeder	3+1.5	3+.3	4+.3	4+1.9
Vaccinium uliginosum L.	18+3.7	25+3.9	18+6.8	18+3.9
Vaccinium vitis-idaea L.	8+1.9	11+2.2	6+.9	12+1.9
Herbs:				
Calamagrostis canadensis (Michx.) Beauv.	1+.2	1+.2	1+.2	
Cornus canadensis L.	1+.4		1+.3	
Geocaulon lividum (Richards.) Fern.	1+.3	1+.4	5+1.2	4+1.1
Lycopodium complanatum L.	1+.3	1+.3		.1+.1
Mosses:				
Aulacomnium palustre (Hedw.) Schwaeger.				1+.1
Dicranum undulatum Brid.		1+.9	1+.3	2+1.0
Hylocomium splendens (Hedw.) B.S.G.	20+5.0	18+5.3	31+7.7	23+5.8
Ptilium crista-castrensis (Hedw.) DeNot	3+2.0			2+1.1
Pleurozium schreberi (Brid.) Mitt.	61+9.6	62+6.4	43+6.4	45+7.9
Polytrichum commune Hedw.	1+.6	.5+.3	1+.5	3+1.4

Table 1--Continued

Vegetation	Unit			
	1L	2	3	4L
	PERCENT COVER			
Lichens:				
Cetraria cucullata (Bell.) Ach.				1±.2
Cladonia gracilis (L.) Willd.				1±.5
Cladonia rangiferina (L.) Web.	1±1.7	5±2.9		4±2.0
Cladonia sylvatica (L.) Hoffm.			1±.2	4±3.0
Cladonia spp.		.7±.5	1±.2	1±.5
Nephroma arcticum (L.) Torss.	5±10.9	4±1.5	1±.1	3±1.7
Peltigera aphthosa (L.) Willd.	1±3.1	2±1.1	1±.2	7±3.8
Peltigera canina (L.) Willd.			1±.3	1±.5
Stereocaulon paschale (L.) Hoffm.				1±.1
Total cover:				
Trees	19±5.6	12±4.0	28±6.6	8±3.0
Tall shrubs	9±2.6	7±1.8	3±4.5	14±5.3
Low shrubs	32±4.9	44±5.7	28±7.5	38±5.4
Herbs	3±.4	2±.5	6±1.3	4±1.1
Mosses	85±6.1	82±6.0	78±8.2	72±7.3
Lichens	9±3.9	12±4.8	3±.5	22±7.0
Deadwood	12±2.1	10±2.6	16±1.2	14±2.1
Litter	22±3.7	20±4.4	30±6.5	22±4.3

[1] Measurements were taken in 1975. ± = standard error.

Table 2--Density, height, diameter, and biomass of trees before burning, Washington Creek 1976 experimental fire site[1]

Item	Unit 1L	Unit 2	Unit 3	Unit 4L
Density (stems per hectare):[2]				
Black spruce trees	3,398±497	5,468±1,878	4,179±2,707	2,226±939
Paper birch trees	0	741±497	78±110	117±55
Black spruce saplings[3]	1,490±432	1,953±1,761	8,758±1,933	1,874±111
Paper birch saplings[3]	0	78±110	0	0
Dead trees	156±0	703±110	468±110	156±110
Average height of black spruce (meters)	3.4	3.4	3.5	3.1
Average diameter of black spruce (centimeters; range 2.5-10)	4.82	4.80	4.97	4.34
Estimated biomass of live black spruce (kilograms per hectare):[4]				
Total tree	19 020	23 780	18 250	6 560
Needles	4 040	4 030	3 844	1 530
Bark	2 530	3 160	2 420	900
Cones	620	780	600	210
Live branches	2 350	2 940	2 250	850
Dead branches	850	1 060	810	310
Bole	6 650	8 310	7 980	2 740

[1] ± = standard error.

[2] Based on 2 transects, 4 meters wide and 32 meters long, in each unit.

[3] Under 2.5-centimeter d.b.h.

[4] Weights determined by regression equations developed by Van Cleve and Hunt (data on file at Department of Forest Soils, University of Alaska, Fairbanks; used with permission); where, log y = log a + b log x; y = weight; x = basal diameter; and a and b are constants determined for each component and for the total tree. Total tree weight does not equal the sum of the components.

Conditions for the experimental fire were met in early July of 1975, but a very intense wildfire that burned 2 000 hectares within the Washington Creek drainage caused the experimental fire to be cancelled. Rainy weather during the remainder of the summer prevented the burning conditions from being met again in 1975.

At Fairbanks, 30 km southeast of the site, the 1976 summer season was early and somewhat warmer than average. Figure 3 shows the 30-year average for degree days for Fairbanks, the 1976 curve for Fairbanks, and the degree day accumulation for a black spruce stand at Wickersham, less than 2 km away and in a similar topographic position. Table 4 lists the daily temperatures at the site and figure 4 shows them graphically.

At the site of the experimental fire, temperatures and precipitation were recorded continuously starting June 2, when a Forest Service rain gage, a tipping-bucket recording gage, and fuel moisture sticks were installed. Figure 4 also shows the precipitation record, relative humidity, and temperature for the Washington Creek site for June, July, and August.

As is normal for the general Fairbanks region, precipitation

Table 3--Estimates of biomass of black spruce added to units 1L and 4L, Washington Creek experimental fire site, June 1975

Component[1/]	Unit 1L	Unit 4L
	Kilograms per hectare[2/]	
Total tree	26 500	15 600
Needles	4 500	2 000
Bark	3 400	2 000
Cones	900	500
Live branches	3 100	1 800
Dead branches	1 100	700
Bole	12 000	7 200

[1/]Each component, including total, was calculated separately from regression equations developed by Van Cleve and Hunt (data on file at Department of Forest Soils, University of Alaska, Fairbanks; used with permission); where, $\log y = \log a + b \log x$; y = weight; x = basal diameter; and a and b are constants determined for each component and for the total tree. Total does not equal sum of components.

[2/]Based on total weight added to the unit, converted to kilograms per hectare, and rounded to closest 100 kg.

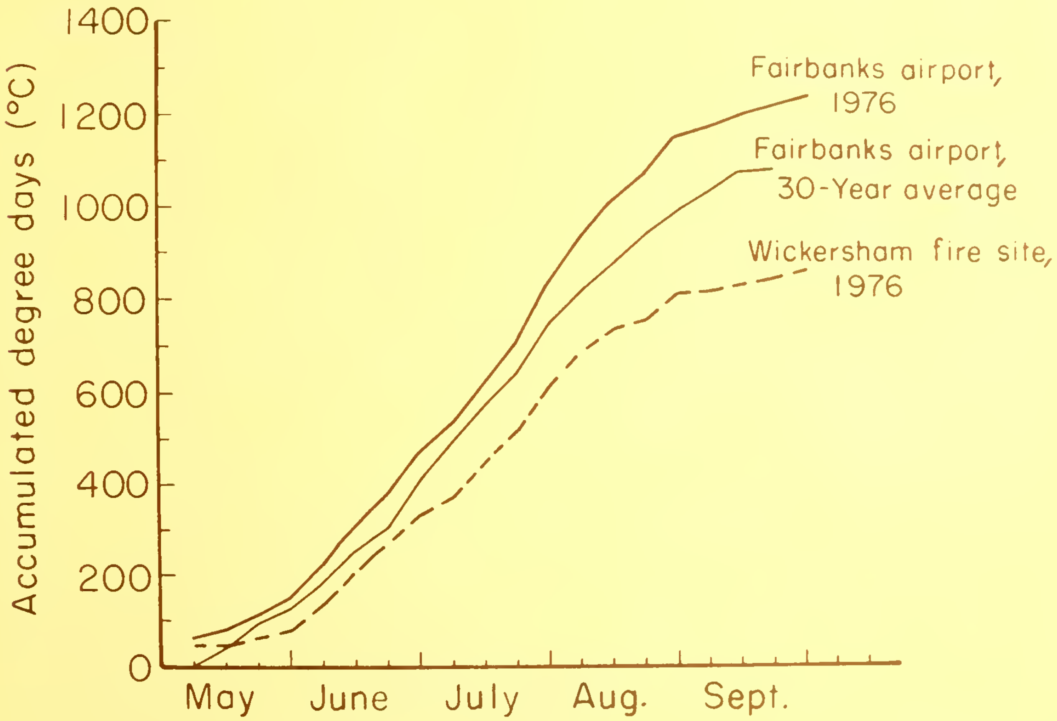

Figure 3.--Accumulated degree days (based on 5°C) for 30-year average and for 1976 at Fairbanks airport and for 1976 at the Wickersham site, 2 km from the Washington Creek experimental fire site.

Table 4--Average, maximum, and minimum air temperatures (°C), Washington Creek experimental fire site, 1976[1]

Day of month	June			July			August			September		
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum
1	[2]14	[3]	[3]	[2]12	15	10	21	28	14	9	16	7
2	[2]15	[3]	[3]	[2]13	[3]	[3]	20	26	16	10	17	6
3	14	19	10	[2]13	[3]	[3]	19	24	14	9	15	5
4	14	20	9	[2]13	[3]	[3]	19	24	15	2	6	-1
5	15	22	10	[2]11	[3]	[3]	20	25	14	4	10	-3
6	7	12	4	19	22	14	20	28	16	6	12	5
7	9	14	4	19	25	13	16	19	13	9	15	4
8	10	15	4	15	21	11	[2]15	[3]	[3]			
9	12	17	8	15	20	10	18	21	14			
10	15	20	8	17	22	10	18	24	13			
11	14	19	9	18	23	13	19	24	14			
12	15	21	9	17	22	12	17	22	13			
13	18	24	11	17	23	12	17	24	11			
14	20	26	13	16	21	10	19	25	13			
15	18	24	13	15	20	11	15	18	11			
16	17	24	10	16	22	12	13	18	9			
17	12	18	8	14	20	10	11	16	7			
18	9	14	7	15	21	11	12	18	10			
19	12	17	9	17	22	10	11	16	7			
20	14	20	7	20	26	14	11	17	5			
21	13	19	9	22	29	15	12	17	5			
22	12	16	6	20	29	14	13	19	8			
23	9	11	7	19	27	14	15	21	9			
24	10	14	8	17	21	12	17	24	12			
25	11	14	8	16	20	13	17	22	12			
26	15	22	8	14	17	12	16	23	11			
27	18	23	14	15	21	11	15	21	10			
28	14	17	9	17	21	12	13	18	10			
29	12	18	9	20	27	13	13	18	8			
30	13	17	9	13	17	10	12	17	7			
31				16	22	7	9	17	5			

[1] Average temperature is based on 12 readings at 2-hour intervals. A thermograph was installed June 2 and removed September 8.

[2] Data reconstructed from Wickersham site.

[3] Missing data.

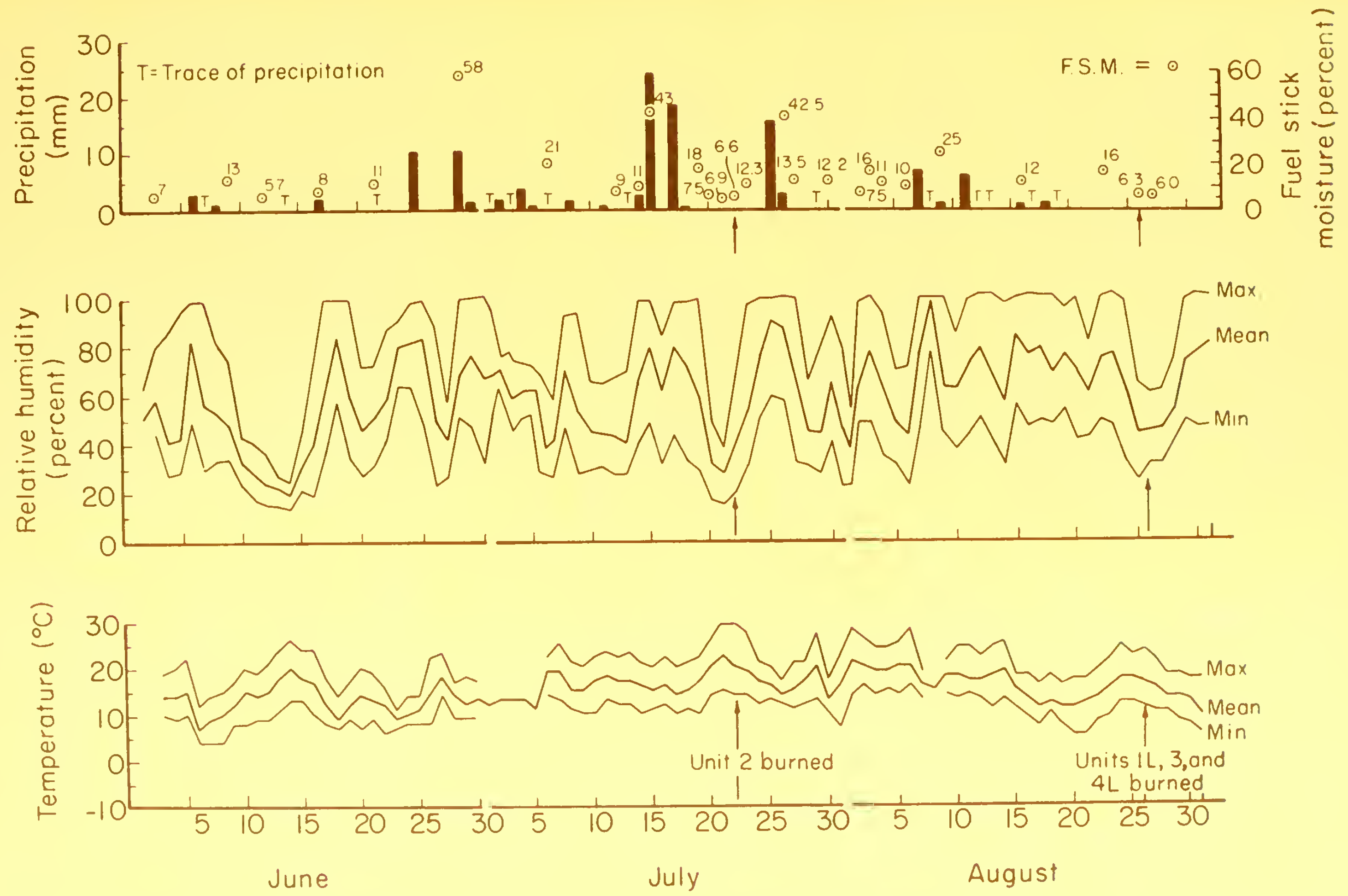

Figure 4.--Air temperature, precipitation, relative humidity, and moisture in fuel sticks (F.S.M.) for the Washington Creek experimental fire site, summer 1976.

during April was low. Usually at Fairbanks precipitation increases through the summer; monthly averages in millimeters are: April 6.4, May 18.6, June 35.3, July 46.7, and August 55.9. No long-term records are available for Washington Creek, but the pattern can be assumed to be much the same, with somewhat higher amounts because of the higher elevation.

At Washington Creek 36 mm of precipitation fell in May, but only 27 in June. The burning condition limits were first met between June 10 and 15, but at that time a large number of wildfires kept the BLM fire crews busy and prevented any burning attempt. Cooler weather with high relative humidity and some precipitation prevented the prescribed conditions from being met again in June.

The month of July had an interesting precipitation pattern. Until July 15, only 17 mm of rain fell. Then, on July 15, a cloudburst dropped 24 mm on the site in less than 1 hour and a thunderstorm on the 17th added another 19 mm. After this 43 mm of rain in 3 days, prospects for the experimental fire conditions being met in July did not appear likely; however, a hot rainless period from July 16 to July 22 lowered the relative humidity to 32 percent and the moisture in the fuel sticks to 6.6 percent so that one unit (2) could be burned on July 22 within the limits set.

When unit 2 was burned on July 22, the organic layer was high in water content from the previous heavy rains. Burning of the other units on July 22 was cancelled because of a rain and hail storm, accompanied by strong gusty winds.

During the 1st week in August, it appeared that burning conditions would again be met. In the afternoon of August 6, the relative humidity was 34 percent and the fuel stick moisture had dropped to 7.8 percent. The second series of fires was planned for August 7, but moist air moved into the area, and the burning was cancelled. On August 8, 10 mm of rain fell and it seemed unlikely that conditions would be met again in 1976. The remainder of August was exceptionally warm and dry; only 8 mm of precipitation fell between August 9 and 18. The conditions were again met on August 26, and the other three units were burned.

In the 1976 fire season, periods that met the fire conditions occurred several times during the summer; but the intervals when the conditions were met were extremely brief. This is especially illustrated by the graph of relative humidity (fig. 4) which shows the periods in June, July, and August when the average humidity fell below 50 percent.

Conditions at the Time of Burning and Ignition Procedures

The first unit to be burned (2) was ignited at 1152 on July 22, 1976. Conditions at the time of ignition were:

Fuel stick moisture content	6.6 percent
Relative humidity	32 percent
Speed and direction of wind	0-2.2 m/s (0 to 5 mi/h), from S.S.E.
Temperature	24°C (76°F)

Before ignition, two tanker trucks were positioned and hoses laid out along the firebreaks. All persons at the site were briefed on the sequence of ignition and predicted fire behavior. Safety was stressed, and escape routes were set and discussed. Figure 5 shows the organic layer moisture content by volume (obtained by multiplying the moisture content (expressed as weight) by the bulk density, which in the upper 10 cm varied from 0.02 to 0.08 g/cm^3) just before the fire. The moisture content in the top 10-cm layers was only slightly higher on July 22 than on August 26, but below the 10-cm level it was much higher on July 22.

The unit was ignited on the lower southeast corner; heat developed rapidly, and the fire soon started to crown. It moved across the unit in 7 minutes. The fire was especially intense near the center of the unit.

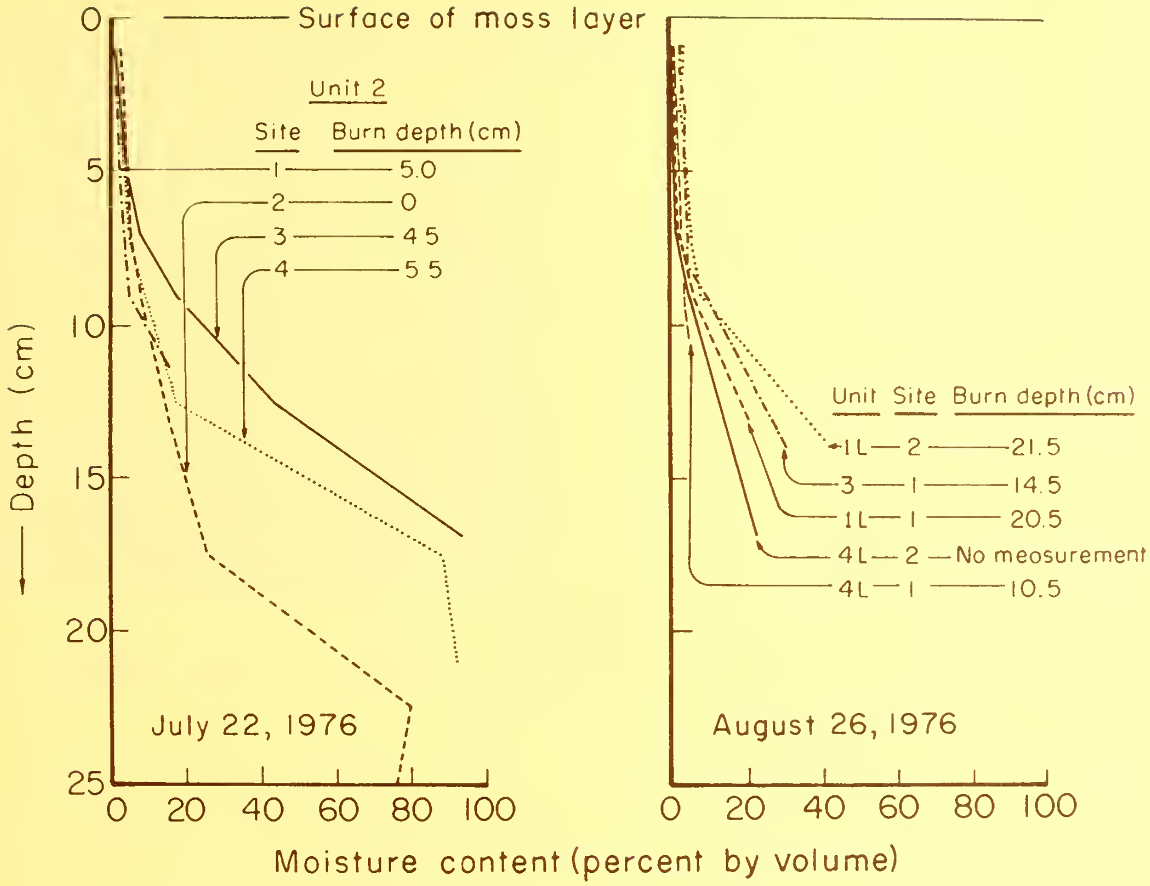

Figure 5.--Moisture content by volume as a function of depth for all units burned in the summer of 1976, Washington Creek experimental fire site.

This fire did not burn heavily in the organic layer, and it was possible to work in the plot within a few minutes of time of burning. As indicated by the vertical temperature profile (table 5) and the high percentage of tree needles consumed, the fire was hot at the 0- to 3-m level but not within the forest floor. At the 5-cm depth in the soil, the temperature sensitive pellet with the lowest melting point, 43°C, did not melt; at the 5-cm layer above the ground, the heat sensitive paint with the highest melting point melted at 121°C.

Soon after, preparations were started for burning unit 1L. But before these preparations were very far along, a thunderstorm, bringing heavy rains, moved into the area; this precluded any further fires at that time.

From August 1 to August 26, precipitation at the study site totaled only 16 mm. By August 26, burning conditions were again met; and the last three units were burned. Conditions at the time of ignition were:

Fuel stick moisture content	6.6 percent
Relative humidity	40 percent
Speed and direction of wind	2.7-3.6 m/s (6 to 8 mi/h), from S.S.E.
Temperature	19°C (66°F)

Table 5--Some measured indications of fire intensity in 4 units burned in 1976, Washington Creek experimental fire site

Indicator	Height, m	Unit 1L	Unit 2	Unit 3	Unit 4L
Time to cover entire unit (min)		9	7	29	6
Average H_2O evaporated (ml)		65	5	16	107
Range (ml)		[1]0-70	0-10	0-30	20-210
Highest temperatures (°C) recorded from heat sensitive paints at each height on center pyrometer	2.75	66	288	66	454
	2.25	66	288	66	454
	1.75	66	288	121	454
	1.25	121	288	121	[2]660
	.75	121	288	121	[2]660
	.25	288	288	288	[2]660
Highest temperature recorded from heat sensitive paints (°C):					
6 to 15 cm (above surface		288	288	288	454
Range		<43-288	121-288	<43-288	288-454
0 to 5 cm (above surface)		288	121	288	454
Range		<43-288	121-121	<43-288	121-454
2 to 3 cm in organic layer		No data	43	288	121
Highest temperature recorded by temperature sensitive pellets (°C):					
Surface		[3]>83	[3]>83	[3]>83	[3]>83
5-cm depth in organic layer		43	43	43	69
10-cm depth in organic layer		<43	<43	<43	<73

[1] 1 can tipped over--1 can in unburned area.

[2] Temperature sensitive paint with highest temperature tolerance (660°C) melted.

[3] Pellets with highest melting point (83°C) melted.

[4] Pellets with lowest melting point (43°C) did not melt.

Unit 1L was ignited at 1242 on August 26, 1976, beginning at the southeast corner (fig. 6). Within 1 minute, the fire moved into the tree crowns along the lower edge; however, the burning of crowns became spotty except near the center of the unit. At 1250, the crowns in one area burned with flames to 16 m. The entire area was covered by fire in about 9 minutes, and most of the active burning was over by 1256. Unlike the July 22 fire, the fire on all the units burned on August 26 continued to burn in the organic layer for several hours and in a few spots smoldered and periodically flamed for several days.

The 26 500 kg/ha of fuels that had been loaded on this unit did not seem to contribute significantly to the fire intensity but might have resulted in the large number of persisting ground fires. The limited data from the heat paints, temperature sensitive pellets, and water evaporation indicated that this was one of the least intense of the four fires.

Unit 4L was ignited at 1413. The pattern of ignition was

Figure 6.--Lighting the fire at unit 1L; photo shows rapidity with which tree crowns began to burn.

altered to reduce the fire spotting experienced during the fire on unit 1L. Ignition was started in the middle of the southeast boundary and continued to the southwest boundary to the corner of the unit (fig. 7). Because of light winds during burning, most of the spot fires occurred just uphill in previously burned unit 2. The fire completed its run across the unit in 6 minutes.

Figure 7.--Lighting the fire in unit 4L; photo shows rapid development of intense crown fire.

From all indications, the fire in unit 4L was the hottest. There were several areas where observers indicated a "very hot crown fire." The loaded fuel, 15 600 kg/ha, seemed to add to the spread and intensity of the fire and to the depth to which it burned into the organic layer.

Temperatures were hotter at all levels than in the other units. The aluminum backing for the heat paints burned at the three lower levels on the vertical pyrometer, and temperatures at 2.75 m were 454°C or greater. Temperatures at 10 cm in the soil reached 73°C (table 5). Nearly 90 percent of the trees had at least 50 percent of the needles consumed, and nearly 70 percent of the ground vegetation was heavily or moderately burned.

Unit 3 was ignited at 1501. It was touched off at the east corner, and from there the torchmen moved northeast and southeast along the perimeter (fig. 1).

There was some spotty torching; but the fire was primarily a slow-moving ground fire, very different from the fires in the other three units. The fire took 29 minutes to burn to the other end of the unit.

The temperature profile and the low percentage of needles consumed indicated that this fire was the least hot of the fires; however, the ground fire continued actively for several days and resulted in nearly 50 percent of the ground vegetation being heavily or moderately burned.

EFFECTS OF THE FIRES

Thickness of the Forest Floor

One of the most important parameters on which to measure effects of fire is forest floor thickness. In this region, where moss and lichen remains can quickly accumulate to depths of well over 50 cm, causing lower soil temperatures and immobilizing much of the nutrient capital, what fire does to this layer is of paramount importance.

Results of the forest floor measurements are summarized in table 6. From these results, one would infer that fires burned most intensely on units 3 and 4L and that burning was least severe on unit 2 and intermediate on 1L. Unit 2, with only 24-percent reduction in forest floor thickness, was burned a month earlier than the other three plots at a time when moisture content of the forest floor was considerably higher (fig. 5). Consequently, although the fire built up considerable heat and moved quickly through the crowns of the trees, it consumed only a few surface centimeters of the forest floor because of the high moisture content.

Because of low amounts of earlier rainfall, the moisture content of the forest floor was relatively low by late August, especially below 10 cm, when units 1L, 3, and 4L were burned (fig. 5). This set the stage for the effects measured on units 3 and 4L. Although these two units were almost identical in reduction of forest floor thickness (table 6), the characteristics of the fires were dissimilar. Unit 4L was subjected to an intense fire which entered the crowns soon after ignition and quickly moved across the unit. After the fire, the unit appeared heavily burned and almost 100 percent of the forest floor was deeply charred. In contrast, unit 3 experienced a slow, creeping ground fire which torched only in a few isolated trees and gave the appearance of a far less intense fire. Many green trees remained after the fire and an appreciable portion of the forest floor was unburned. The almost two-thirds reduction in forest floor thickness measured on unit 3 can be attributed to the fact that in areas covered by the ground fire virtually all the organic material was consumed down to mineral soil. Thus, measurements on unit 3 generally either showed little change (unburned or lightly charred) or virtually all organic material was consumed by a deeply burning ground fire. On the other hand, postfire measurements on unit 4L showed a more uniform decrease in forest floor thickness.

No significant effect of fuel loading could be detected on forest floor thickness after the fire (table 6). We can only speculate what the results would have been had the units been burned soon after fuel loading. But almost certainly fires on the loaded units would have been

Table 6--Mean forest floor thickness before and after experimental fire in 4 units at the Washington Creek experimental fire site[1/]

Item	Unit			
	1L	2	3	4L
	Centimeters			
Thickness before burning	21.6±.67	19.8±.57	23.2±.66	22.4±.67
Thickness after burning	11.6±.68	14.9±.72	7.8±.55	7.2±.49
Preburn-postburn difference	10.1	4.9	15.4	15.2
	Percent			
Reduction in thickness	43	24	61	62

[1/] Each value is based on 126 observations; ± = standard error.

considerably hotter had cured needles still been on the loaded slash.

These results indicate that controlled burning can effectively reduce forest floor thickness in black spruce. This burning causes nutrient mineralization, soil warming, and stepped up rates of organic matter decomposition. It also creates a favorable environment for regeneration of shrubs and trees by stimulating sprouting and exposing bare mineral seed bed. These results also show the importance of the moisture status of the forest floor in controlling some effects of fire. If the burning prescription is aimed at reducing forest floor thickness, its moisture content, as well as the moisture content of above-ground fuels, should be monitored.

It is well to keep in mind that considering only the average reduction in forest floor thickness can be somewhat misleading, for this viewpoint can give the impression that forest floor materials were burned uniformly over an entire area. Actually this is seldom the case. Most often, after a fire the forest floor constitutes a mosaic of widely different conditions--from completely unburned to severely burned. For this reason, the proportion of the area within burning condition classes was measured, as well as forest floor thickness (table 7).

The high degree of variability in the data indicates to some degree the variability with which the fire consumed the ground vegetation. Especially in the three units burned in August, there were many examples of total consumption of the organic layer; and yet only a few decimeters away the vegetation was scorched or unburned.

Some differences in the degree of burning of the ground vegetation are apparent. In unit 2, for example, which had a hot crown fire but was burned when the underlying organic layers were moist, 97 percent of the ground vegetation was in the lightly burned class. Only occasional spots, mostly at the base of trees, burned to mineral soil. Because of the heat from the crown fire, however, none of the plots or transects escaped scorching of the moss layer.

The greatest amount of destruction of the ground vegetation occurred in loaded unit 4L. In that unit,

Table 7--Area in 5 forest floor fire severity classes after fire in black spruce, Washington Creek experimental fire site[1]

Fire severity classes	Unit 1L	Unit 2	Unit 3	Unit 4L
	Percent, based on ten 1-m^2 plots			
1. Heavily burned	24.0±11.1	2.0±1.5	37.0±10.2	49.4±13.5
2. Moderately burned	25.0±11.2	.2± .2	11.9± 4.1	6.1± 6.4
3. Lightly burned	37.5±13.2	97.1±1.5	49.3± 9.3	34.5±12.4
4. Scorched	7.5± 5.1	.7± .5	1.8± 1.0	0
5. Unburned	6.0± 5.4	0	0	0
	Percent, based on ten 10-m-long transects			
1. Heavily burned	34.2± 5.9	2.1± 1.0	36.8± 5.1	58.0± 4.9
2. Moderately burned	21.0± 6.2	16.0± 9.6	16.0± 3.9	17.0± 2.9
3. Lightly burned	36.1± 8.4	75.0±10.2	42.0± 4.6	24.9± 5.7
4. Scorched	1.0± .6	6.9±2.1	4.5± 1.1	.1± .03
5. Unburned	7.7± 5.8	0	1.7± .5	0

[1] ± = standard error.

nearly 50 percent of the area was heavily burned and in most cases the fire burned to mineral soil. No scorched or unburned area was found, which showed that the whole unit was lightly to heavily burned.

The data for unit 3 show that the fire did not burn as a hot crown fire but was primarily a slow-burning ground fire, which consumed much of the ground vegetation and organic layer. Much of the area was within the lightly burned class, but approximately 40 percent of the unit was burned nearly to mineral soil.

Unit 1L showed the largest percentage of unburned area in spite of the fact that the fire burned rapidly through the stand. The high percentage of unburned area resulted primarily from one upper corner not burning.

In summary, the two burning dates with different forest floor moisture conditions, the loading of two of the units, and the difference in the intensity of the crown fires in the units resulted in a wide variation in the degree of burning of the ground vegetation both within each unit and between units. This variation will provide a good opportunity to follow the revegetation under these varying conditions of fire intensity.

Soil Temperatures

Temperatures were taken with a 90-cm metal temperature probe in unit 2 and control unit 5. Because of the shallow stony soils, it was usually impossible to insert the probe deeper than 20 cm.

The few soil temperature readings from the summer of 1976 are shown in table 8. On July 22, soil temperatures were taken at unit 2 at 1100, less than an hour before ignition. They were taken again at 1218, less than 20 minutes after the fire. There was an increase of 7°C at the 5-cm level, 6°C at 10 cm, 3°C at 15 cm, but no increase below that level. After 24 hours the temperatures in the burned unit were nearly the same as those in control unit 5.

Table 8--Soil temperature (°C) for units 2 and 5, Washington Creek experimental fire site[1/]

Unit and depth in soil	Before burning		After burning		
	June 15	July 22	July 22	July 23	July 27
Unit 2 (burned July 22):					
-5 cm	5.3±0.7	14.3±2.2	21.3±1.3	17.3±1.4	12.7± .6
-10 cm	4.0± .6	10.7±1.9	16.7±2.4	12.0±1.2	10.3± .9
-15 cm	2.0±0	10.2± .3	13.3±3.3	7.7± .3	9.0± .6
-20 cm	1.5±0	5.3± .3	5.7± .3	6.0± .6	6.7± .7
Unit 5 (unburned control):					
-5 cm	8.7± .9			17.3± .7	13.3± .3
-10 cm	7.0± .6			10.7±1.2	10.0±1.2
-15 cm	5.3± .7			6.7± .3	8.3± .9
-20 cm	2.0±0			4.0± .6	6.3± .7
-50 cm	0				

[1/] ± = standard error.

Phosphorus Content of the Forest Floor

Depending on horizon, the mass of available phosphorus (P) was increased up to 50 times that in the unburned control and the concentration of available P to approximately 40 times that in the control (table 9). Maximum increases in P availability were found in the ashed green moss layer, 01, in the burned units; smaller increases in P concentration appeared in the partially charred 021 horizon (tenfold over the control) and 022 horizon (twofold over the control). Although charring was not readily evident in the 022 horizon, increases in P concentration, especially for the fuel loaded units, indicated that fine ash may have penetrated this layer either during the fire or through physical disturbance at the time of sample collection.

For the total forest floor a maximum increase in available P of approximately sevenfold occurred for the fuel loaded units and a fourfold increase for the nonloaded units.

The importance of increased available P to plant growth and soil microbial activity has yet to be established. General observation at sites of previous fires indicated rapid sprouting and growth of willow and aspen and marked improvement in productivity of blueberry (*Vaccinium uliginosum*). Reduced competition from other plants for moisture, light, and nutrients may be important. Elevated soil temperature resulting from darkened surfaces, as well as increased nutrient availability, may also stimulate growth of plant species after fire.

Postburn Vegetation

The 1-m^2 vegetation quadrats were inventoried immediately after the fire and at the end of the growing season, and the presence or absence of green needles and the percent of needles consumed by the fire were recorded for trees along the transects.

Table 9--Available phosphorus in forest floor of burned units and unburned control, Washington Creek experimental fire site[1/]

Available phosphorus and unit	Horizon of forest floor: 01	021	022	Total
	Milligrams per square meter			
Mass of phosphorus:				
Control	5.1± 1.3	19.1± 4.9	52.2±19.9	76.3
1L	205.1±39.0	101.9± 9.5	203.3±53.9	510.3
2	201.8±58.0	46.4	77.7±31.3	325.9
3	180.1±31.9	91.1±13.8	66.7±23.6	337.9
4L	257.1±31.9	83.5±10.0	175.4±51.5	516.0
	Parts per million			
Concentration of phosphorus:				
Control	7.7± .4	11.3± 2.2	25.2±12.4	
1L	279.5±59.2	109.6± 7.1	59.0±14.0	
2	115.2±39.1	37.6	20.8	
3	227.1±41.8	70.5±12.7	16.6± 4.4	
4L	308.8±33.7	71.2±10.9	53.4±12.0	

1/ ± = standard error.

Trees

Determining the percentage of trees immediately killed by the fire was impossible because some trees that appeared alive after the fire may not survive. To obtain some idea of the relative damage to the trees and saplings, we recorded the percentage of needles consumed by the fire soon after the fire and before the needles started to fall:

1. 76 to 100 percent
2. 51 to 75 percent
3. 26 to 50 percent
4. 0 to 25 percent; many needles green.

Table 10 shows a general relationship between the intensity of fire evaluated by other means and the percentage of needles consumed. Thus, units 2 and 4L, which had the hottest observed crown fires, had the highest percentage of needles consumed. All trees and saplings on unit 4L had 25 percent or more of the needles consumed. Only 9 percent of the trees in unit 3, which was subjected to a slow-moving fire that seldom crowned, had 75 to 100 percent of the needles consumed.

In general, more needles were consumed on the saplings than on the taller trees, which indicated that the hottest part of the fire was below the higher levels of the tree crowns.

The few birch trees within the stands appeared to be killed by the fire. Also, all alder and willow shrubs within the vegetation plots appeared to have been killed back to the soil surface.

Figures 8 through 15 are pairs of photographs of the same transects and vegetation plots before and after the fires. Figures 8 and 9, transect 1 in unit 2, show the large amount of material consumed by the fire. Figures 10 and 11 are of vegetation plot 31 within unit 2, burned on July 22. The post-fire photograph shows that the moss layer was killed by the fire, but little of the underlying organic layer was consumed.

Figures 12 and 13 are of transect 2 in unit 4L. This unit had the most intense fire. Figure 13 shows that most of the needles have been burned. Figures 14 and 15, of vegetation plot 63 from within the same unit, 4L, show that much of the organic material has been consumed by the fire.

Table 10--Consumption of needles of black spruce trees and saplings by fire, Washington Creek experimental fire site

Needles consumed	Unit 1L	Unit 2	Unit 3	Unit 4L
Percent		Percentage of trees[1]		
76-100	33	47	9	39
51-75	32	16	38	55
26-50	28	22	44	6
0-25	7	14	9	0
		Percentage of saplings[1]		
76-100	76	62	43	78
51-75	16	15	38	20
26-50	8	8	17	2
0-25	0	14	2	0

[1] Based on total number of trees and saplings in two 4-m by 32-m transects in each unit.

Figure 8.--Unit 2, transect 1, 1 year before the fire. Note the alder in left foreground, the dense branches of the spruce that reach nearly to the ground, and the ground cover of mosses and low shrubs.

Figure 9.--Unit 2, transect 1, on July 23, 1 day after the fire. Note that a large amount of needles and low shrubs have been consumed by the fire. Smoke from one small smoldering fire can be seen.

Figure 10.--Unit 2, vegetation plot 31, 1 year before the fire.

Figure 11.--Unit 2, vegetation plot 31 taken from the side opposite that shown in figure 10). Ground vegetation and low branches on the spruce have been almost totally consumed by the fire.

Revegetation

All the vegetation plots were inventoried immediately after the fire and in September, at the end of the growing season. In the units burned in late August, no vegetation had developed. All units indicated 100-percent destruction of above-ground vegetation except unit 1L, where one plot showed some unburned moss.

In unit 2, burned on July 22, there was some regrowth by the end of the summer. Shoots of both *Calamagrostis canadensis* and *Salix scouleriana*, having developed from underground parts not killed by the fire, were scattered throughout the stand. The shoots of *S. scouleriana* had reached a height of 30 cm. Approximately 70 percent of these shoots had been browsed by hares (*Lepus americanus*) by the end of September.

Figure 12.--Unit 4L, transect 2. Note abundance of branches and other fuels 0-2 m above the ground. The photograph was taken in June 1975, before additional black spruce were placed on the unit.

Figure 13.--Unit 4L, transect 2, 1 day after the fire. Most of the needles have been consumed by the fire. The boles of the spruce added to the unit can be seen on the ground.

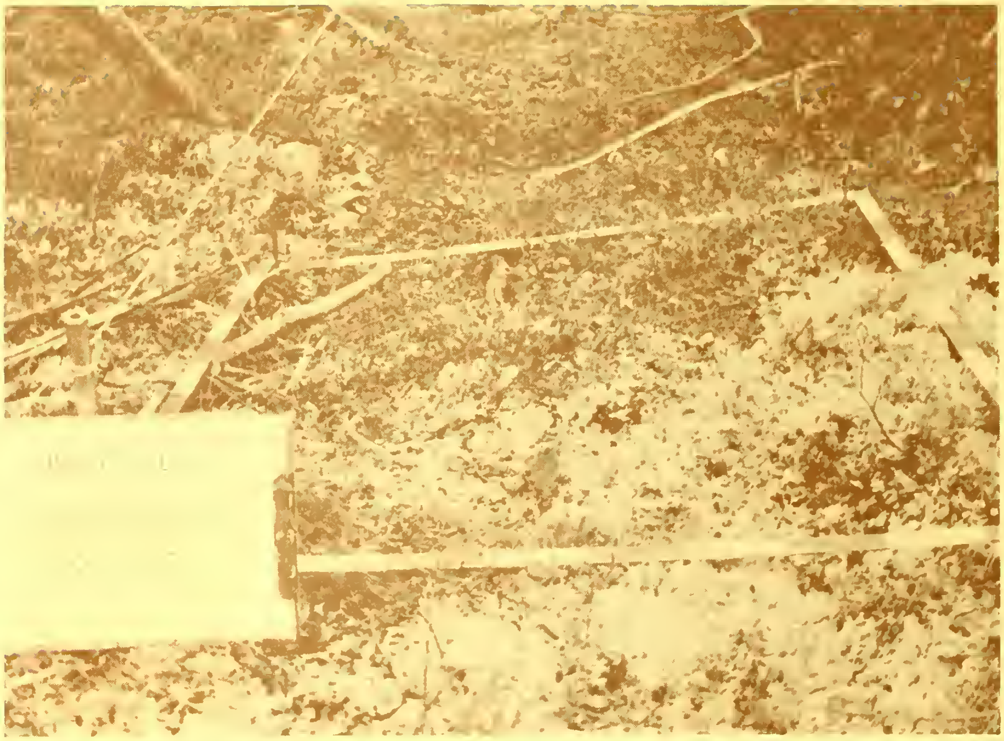

Figure 14.--Unit 4L, vegetation plot 63, 1 year before the fire. Note the abundance of fruticose lichens. The photograph was taken before additional black spruce were placed on the unit.

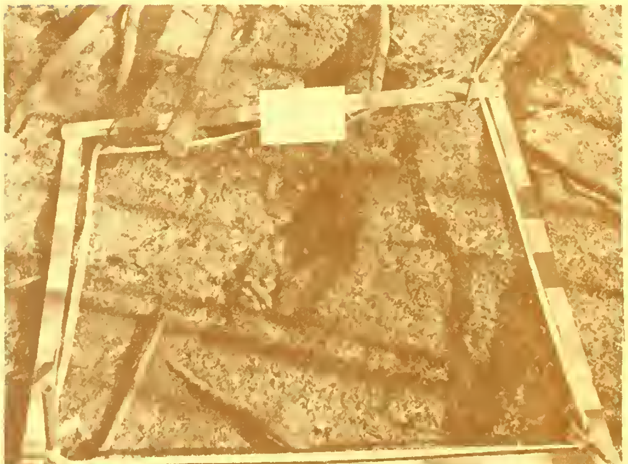

Figure 15.--Unit 4L, vegetation plot 63, 1 day after the fire. Note the heavy charring of the moss and lichen layer. Remains of the added black spruce can be seen in and around the unit.

Seed Fall

Black spruce has semiserotinous cones that open to release seed after fire. Seed traps were placed in each stand immediately after the fire, and the seed were collected weekly until the first snow. The results are shown in table 11. For the control area for the seed fall, we have used data from a nearby unburned study site in Washington Creek.

Seed fall began immediately after the August 26 fire, but not in quantities greatly exceeding the quantity from the control. During September, about twice as many seeds fell in units 2 and 3 as in the control. In unit 4L, where temperatures exceeded 454°C at 2.75 m, seed fall was much less. The fire may have been hot enough to actually consume many of the cones.

Fuel

The information obtained from the fuel measurements is shown in table 12. Before units 1L and 4L were loaded, quantities of downed fuels varied from 7.5 to 12.7 metric tons per hectare. Afterward the loaded units had 16.6 and 24.1 tons per hectare of downed fuels.

After the fires, three units showed no significant lowering of total fuel amounts. In fact, unit 3 showed an increase because of downed trees as result of the fire. Unit 4L, the most heavily burned, did show a reduction of more than half the downed dead fuels. All the units showed a decrease in the amount of the finest fuels--twigs below 0.64-cm diameter. Quantities of material considered to be rotted before the fire were recorded as zero in all the units.

Table 11--Black spruce seed dispersal at the Washington Creek experimental fire site compared with dispersal of seed in a nearby unburned stand[1]

Date	Unburned control	Unit 1L	Unit 2[3]	Unit 3[2]	Unit 4L[2]
			Seeds per square meter		
July:					
28	12.2±1.94		1.2±0.80		
August:					
4	14.2±4.62		20.0±4.42		
11	5.2± .96		14.8±4.48		
18	13.8±1.46		11.6±2.48		
24	4.8±1.40		6.0±1.26		
September:					
1	4.6±1.44	[4]	14.0±3.50	[5]	[5]
7	5.4±1.14	[4]	12.0±2.74	12.4±6.14	0.8±0.80
15	5.4±1.10	[5]	16.4±2.30	14.8±8.42	1.6± .74
22	5.0±1.70	8.8± 3.24	8.7±4.14	11.6±6.30	.8± .48
October:					
6	4.6± .94	15.2±8.27	6.0±3.07	2.4±1.46	2.0±1.08

[1] ± = standard error.

[2] Burned August 26.

[3] Burned July 22.

[4] No seed trap.

[5] Trap installed.

Table 12--Downed fuels before and after 1976 experimental fires, Washington Creek experimental fire site

Fuel size class	Unit 1L		Unit 2		Unit 3		Unit 4L		Unburned control
	Before	After	Before	After	Before	After	Before	After	
Centimeters	Metric tons per hectare								
0-0.64	1.40	0.91	0.58	0.34	0.81	0.15	2.45	0.16	0.70
0.64-2.5	3.23	3.82	1.10	2.16	3.46	4.87	4.86	2.28	3.36
2.5-7.6	9.52	7.83	2.37	2.03	7.15	6.82	9.21	7.85	5.42
7.6+	1.90	3.45	1.25	1.63	.60	1.19	5.01	4.62	--
Rotted 7.6+	.54	--	2.21	--	.68	--	2.57	--	.75
Total	1/ 16.6	16.0	7.51	6.2	12.7	14.7	1/ 24.1	14.9	10.2
Total before loading	8.6						9.9		

1/ Total fuel after loading.

SUMMARY AND CONCLUSIONS

The conditions set up for these experimental fires were:

Fuel stick, moisture content	5 to 20 percent
Relative humidity	20 to 45 percent
Speed and direction of wind	0-4.5 m/s (0-10 mi/h), from S.W. to S.E.
Air temperature	10°- 27°C (50°-80°F)

Despite these rather generalized conditions, there were surprisingly few periods during the summer of 1976 when these conditions were met. Throughout most of the summer, fuels were too moist for a successful fire. Two dates on which burning limits were met were July 22 and August 26. One small experimental unit was burned in July, and three units were burned in August.

Although aboveground conditions were almost identical on the 2 burning days, depth of burning differed appreciably. This difference may mostly be attributed to moisture conditions of the forest floor at the time of burning. Because of periods of rainfall just before burning, forest floor moisture content was rather high on July 22--about 60 percent by volume at the 15-cm depth. In contrast, it was only about 30 percent at 15 cm on August 26.

With one exception, the fires moved quickly across the units and completely covered the approximately 0.1-ha units in 6 to 9 minutes. On three out of four units, the fire quickly entered the crowns, although on only one (4L) did it crown in virtually all the trees on the unit. The exceptional unit was the last to be ignited on August 26. The fire on this unit was a slow-moving ground fire that took 30 minutes to traverse the unit.

After the fires, the burned units presented an appearance similar to that encountered in a wildfire area. Aboveground vegetation was almost completely killed, and the forest floor reflected a mosaic of different fire intensities. The average reduction in thickness of the forest floor ranged from 24 percent on unit 2 (burned July 22) to 62 percent on 4L. This striking difference was attributed to the higher content of water in forest floor materials on the July burning date. Likewise, proportions of areas within forest floor fire severity classes also reflected this difference in forest floor moisture content. For example, although the unit burned in July had only 2 percent of its area classed as heavily burned, the three units burned in August had about 34 to 58 percent of their total area in the heavily burned class.

Soil temperatures measured soon after the fires indicated that the heat generated by the fires had little long-lasting effect on soil temperatures. On the other hand, fire had a dramatic effect on the chemistry of the forest floor. Analysis of samples taken soon after the fires disclosed an increase of up to 50 times the amounts of available phosphorus in the burned area as in the unburned control. Maximum increases in P availability were in the upper portion of the forest floor--in the ashed green moss layer and the two units loaded with fuel.

Since these fires were only the first of a projected series of experimental fires, the main conclusions that will be helpful in designing future work are:

1. With the right fuel and climatic conditions, fire on small units in spruce can be made to simulate at least moderately severe wildfire conditions. When this study was initiated, we were uncertain whether fires would be sufficiently intense on such small units (only about 0.1 ha). For this reason two of the four units were loaded with fuel. It is now apparent that such loading was unnecessary, for the unloaded units burned with about the same intensity as the loaded units.

2. Future work with experimental fires in black spruce should, at the very least, include monitoring of forest floor moisture, as forest floor materials are an extremely important fuel in controlling fire effects in this type. Conditions other than forest floor moisture were almost identical at the time of the two periods of burning (July and August 1976); yet postfire characteristics on the unit burned in July were far different from those on units burned in August. Most of the differences could be explained by the high forest floor moisture content in July.

3. More efficient and accurate means of measuring fire intensity when the fire is underway are needed. In this study, we used temperature sensitive pellets and heat paints with indifferent success. More information is needed on such parameters as rate of spread, flame length, and weather variables to calculate fireline intensity.

4. A five-class forest floor fire severity class system works well for categorizing forest floor conditions after fire in black spruce--unburned, scorched, lightly burned, moderately burned, and heavily burned. We suggest that future soil sampling after fire be stratified on this basis. We have a long way to go to fully understand the considerable effects of fire on soil properties in the taiga.

Acknowledgments

These experimental fires involved the efforts of many people--from the Bureau of Land Management and University of Alaska, as well as U.S. Forest Service. Bureau of Land Management personnel, under the leadership of Bill Hill, were responsible for igniting and controlling the fires. Austin Helmers, formerly at the Institute of Northern Forestry, played a crucial role in designing the units and setting up the meteorological station. Many individuals participated in data collection, both during the fires and afterwards. They included John Zasada, Terry Moore, Jerry Wolff, and Larry Hunt. To everyone who assisted, we extend our gratitude. Portions of the work were financed by National Science Foundation grant BMS 75-13998.

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English Equivalents

$(9/5^{\circ}C) + 32 = {}^{\circ}F$
1 centimeter = 0.39 inch
1 meter = 3.28 feet
1 hectare = 2.47 acres
1 kilometer = 0.62 mile
1 square meter = 10.76 square feet
1 kilogram = 2.20 pounds
1 gram = 0.035 ounce

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

PNW-333 April 1979

METHOD OF ESTIMATING GROUND FUELS UNDER TWO INCHES IN DIAMETER IN SOUTHWESTERN PONDEROSA PINE STANDS

by

T. W. Eakle[1] and R. F. Wagle[2]

Abstract

Depth and loading of two soil horizons were measured on three areas from the Fort Apache Indian Reservation in Arizona. Regression equations were developed to estimate soil horizon loading (per centimeter squared) from depths (centimeters), (model: ln y = 1 + b ln X, where y = loading and X = depth). Coefficients of determinations were 0.58 and 0.65 for the 01 and 02 soil horizons, respectively.

KEYWORDS: Fuels (forest fire), residue measurements, soil horizons, litter, ponderosa pine, *Pinus ponderosa*.

Acknowledgments

We wish to thank Ms. Marion Swartz, University of Arizona Computer Center, the White Mountain Apache Tribe, and the Bureau of Indian Affairs staff of the Fort Apache Indian Reservation for their cooperation and the use of their facilities.

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INTRODUCTION

Due to the immense interest in forest fire control the capability to predict fuel loadings (weight per unit area) has become of utmost importance. Fuel loading is an entity that can be correlated readily with fire behavior and can possibly point the way to predicting fire damage in both prescribed burns and wildfire situations. Probably the best approach for estimating fuel loadings in western forests is that compiled by Brown (1974). We feel that our results can and should be used in conjunction with Brown's inventory method which deals more specifically with down and dead trees and slash. As Brown writes (p. 2), his method "...avoids the time-consuming, costly, and often impractical task of collecting and weighing large quantities of forest debris." It must be mentioned, though, that estimating fuel weight via specific gravity (the basis of Brown's method) is less accurate than actually weighing the fuel.

Our research in prescribed burning necessitated the collection and weighing of moderate sized samples of 01[3] and 02[4] soil horizons. Since these data were costly to collect and regression equations based on them have been useful to us, we have tabulated our results so that others working in ponderosa pine forests can utilize our regression results. These data can be used as an aid for deciding when, where, and how to prescribe burn in ponderosa pine stands.

These data, contained in this report, are directly applicable to southwestern ponderosa pine forests. They deal specifically with stands (populations) located on the Fort Apache Indian Reservation in Arizona. With some additional testing to determine local variation, however, they may be useful over much of the range of the species.

METHODS

Data were collected at three different sites: One in a xeric area and two in relatively mesic areas (as indicated by the understory vegetation). Approximately one-half of the samples came from xeric areas and one-half from the mesic areas.

The 01 and 02 layers in subplots located in the vicinity of permanent plots used for other research purposes were measured for depth, collected, and weighed. The data were collected as follows:

(1) Two or three 1- x 1-ft subplots[5] were located via over-the-shoulder tosses.

(2) Three depths were measured for each subplot of the 01 and 02 layers, and a mean was determined. (See table 1) A sharp, thin spatula was driven by hand into the mineral soil and bent back toward the observer who

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[3] 01 - Organic horizons in which the original form of most vegetative matter is visible to the naked eye. Corresponds to the H layer described in the literature on forest soils (Wilde 1958, Soil Survey Staff 1951 and 1962, Buol et al. 1973).

[4] 02 - Organic horizons in which the original form of most plant or animal matter cannot be recognized by the naked eye. Corresponds to the H layer described in the literature on forest soils (Wilde 1958, Soil Survey Staff 1951 and 1962, Buol et al. 1973).

[5] Two subplots were sampled for each plot in the xeric area where the most permanent plots were located, and three were sampled for each plot in the mesic areas where fewer permanent plots were located. Thus, subplot numbers collected from each area were approximately equal.

Table 1--Descriptive statistics for the 01 and 02 litter layers

	Litter weight			Litter depth		
Litter layer	Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
	gm/cm^2		Percent	cm		Percent
01	0.129	0.067	51.94	1.459	0.800	54.83
02	.259	.234	90.35	.979	1.031	105.31

then measured the vertically exposed 01 and 02 layers. No apparent compaction occurred between layers with this technique.

(3) The 01 and 02 layers were collected from each subplot and placed in separate paper bags and air dried for 2 to 3 weeks. The 02 layer's lower boundary ended where the mineral soil began.

(4) The bags of 01 and 02 layers were then oven dried for 24 hours at 120°C and weighed. The first series of bags were dried for longer periods of time, but no weight changes were noted after 15 additional hours of drying.

A data base consisting of mean depths (in centimeters) and weights (in grams) for 1-ft^2 areas was thus obtained for the 01 and 02 layers (see appendix A). Simple linear regression was used to derive prediction equations for weight per unit areas as a function of depth. The predicted equations are plotted on figure 1 and corresponding values are shown in appendices B and C, without correction for inherent $\log_e$ bias (Baskerville 1972).

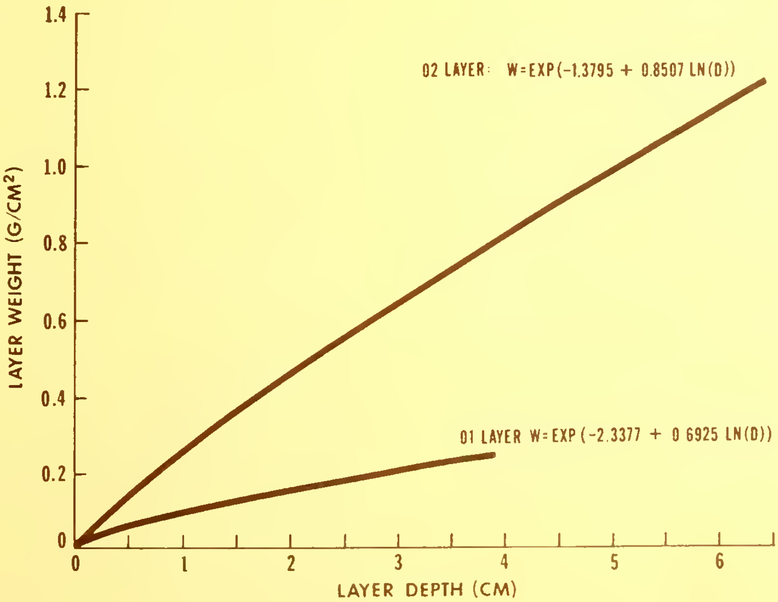

Figure 1.--Weight prediction of the 01 and 02 litter layers, where W=weight and D=depth.

RESULTS AND DISCUSSION

Davis et al. (1968), in a study of ponderosa pine duff on two small 1/4-acre plots, measured duff tonnages per acre of 10.2 tons/acre in one area and 17.6 tons/acre in the second area. Ffolliott et al. (1976) gave an average of 7 tons per acre for the entire forest floor for four small watersheds located on alluvial and sandstone soils (total of 140 acres). This compared to an average of 9.3 tons per acre of ponderosa pine duff in a study made on soils developed from basalt and volcanic cinders (Ffolliott et al. 1968). Ffolliott et al. (1976) stated that "no consistent differences were found in the forest floor characteristics between sandstone and alluvium soils," and that "the means (with 0.95 confidence limits) for depth and weight are comparable with those for forest floors developed on volcanic soils."

Similar relationships for organic material depth and weights occurred between soil types in this study. More material per acre, however, for any given 01 or 02 depth generally occurred in this study. This was to be expected because Ffolliott was measuring only needle fall and duff originating from needles, insofar as possible, in his studies. All duff recognizable as woody or herbaceous in origin was removed from his samples before weighing.[6] In the present study, all dead organic materials up to 2 inches in diameter were included in the samples weighed--although only a few had twigs over 1/4 inch in diameter.

Mean bulk densities (weight per unit volume) were calculated for each soil horizon: 0.129 gm/cc for the 01 layer and .259 gm/cc for the 02 layer. There were no significant differences within and between the sampling areas for the mean bulk densities of the soil surface organic layers. It should be pointed out, however, that bulk densities varied by a factor of 4 at the 1-cm depth in the 01 layer and a factor of 5 at the 1-cm depth in the 02 layer. The same degree of variability occurred in the data shown in Ffolliott et al. (1968, 1976).

As table 2 shows, the regression equations obtained for the 01 and 02 layers are capable of providing modest estimates of their respective loadings (r^2 = .58 for 01, and r^2 = .65 for 02). Both regression slopes were found to be highly significant. The equations are of the form:

$$\ln \hat{y} = \ln a + b \ln x$$

where:
- $\hat{y}$ = weight of litter (gms/cm^2)
- b = regression coefficient
- a = regression coefficient
- x = depth of litter layer (cm)

This form has the property of passing through the origin, and the curve has a variable slope, cbx^{b-1}. The slope decreases as depth increases. This mathematical form appears to better fit the field observations than the straight line model. The weight of the 01 layer did not decrease linearly as it decomposed and entered the 02 layer, nor did the weight of the 02 layer decrease linearly as it decomposed to soil.

The coefficients of variability demonstrated how variable the 02 layer is compared to the 01 layer. This observation is not surprising since the 02 layer was more difficult to measure and collect than the 01 layer.

The discrepancy in sample sizes, 219 for the 02 layer versus 240 for the 01 layer (table 2), is

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[6] Personal communication with P. F. Ffolliott.

Table 2--Linear regression results for predicting fuel weights for the 01 and 02 litter layers

Litter layer	Number of observations	Regression coefficients		Standard error	r^2
		ln a	b		
01	240	-2.3377	.6925	.3917	.58
02	219	-1.3795	.8507	.5277	.65

caused by the occasional absence of the 02 layer beneath the 01 layer.

As an aid to the forest manager or fire control officer, extensive tables explicating horizon weights are shown in grams per square centimeters and tons/acre in appendices B and C.

In conclusion, this information should provide a more accurate means of predicting fine fuel loading in the ponderosa pine type than any method previously available. It should particularly be of use in conjunction with Brown's method when estimates of total fuel loading are desired. When used in this way, however, Brown's method should be modified to omit measuring materials 2 inches in diameter and smaller.

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APPENDIX A

Explication of data

Layer depths (cm)	Number of observations 01	Number of observations 02	Layer depths (cm)	Number of observations 01	Number of observations 02
0.1	1	8	2.1	2	0
.2	5	19	2.2	9	1
.3	9	21	2.3	3	0
.4	9	19	2.4	5	1
.5	11	17	2.5	9	4
.6	3	9	2.6	1	0
.7	7	21	2.7	4	0
.8	13	14	2.8	2	3
.9	6	9	2.9	0	0
1.0	24	17	3.0	6	0
1.1	4	5	3.1	0	0
1.2	19	13	3.2	1	0
1.3	8	6	3.3	0	0
1.4	3	6	3.4	2	0
1.5	21	7	3.5	4	1
1.6	6	2	3.6	0	0
1.7	8	2	3.7	0	0
1.8	16	1	3.8	0	0
1.9	9	2	3.9	0	1
2.0	9	4	4.0	1	0
			4.5	0	2
			5.5	0	2
			6.0	0	1
			6.5	0	1
			Total	240	219

APPENDIX B

Predicted 01 litter weights[1] in both
grams per square centimeter and short tons/acre

Depth (cm)	gm/cm^2	Tons/acre	Depth (cm)	gm/cm^2	Tons/acre
0.1	0.020	0.9	2.1	0.161	7.2
.2	.032	1.4	2.2	.167	7.4
.3	.042	1.9	2.3	.172	7.7
.4	.051	2.3	2.4	.177	7.9
.5	.060	2.7	2.5	.182	8.1
.6	.068	3.0	2.6	.187	8.3
.7	.075	3.4	2.7	.192	8.6
.8	.083	3.7	2.8	.197	8.8
.9	.090	4.0	2.9	.202	9.0
1.0	.097	4.3	3.0	.207	9.2
1.1	.103	4.6	3.1	.211	9.4
1.2	.110	4.9	3.2	.216	9.6
1.3	.116	5.2	3.2	.221	9.8
1.4	.122	5.4	3.4	.225	10.1
1.5	.128	5.7	3.5	.230	10.3
1.6	.134	6.0	3.6	.234	10.5
1.7	.139	6.2	3.7	.239	10.7
1.8	.145	6.5	3.8	.243	10.9
1.9	.151	6.7	3.9	.248	11.1
2.0	.156	7.0	4.0	.252	11.2

[1] Weights are oven dry.

APPENDIX C

Predicted 02 litter weights[1/] in both grams per square centimeter and short tons/acre

Depth (cm)	gm/cm^2	Tons/acre	Depth (cm)	gm/cm^2	Ton/acre
0.1	0.035	1.6	3.1	0.659	29.4
.2	.064	2.9	3.2	.677	30.2
.3	.090	4.0	3.3	.695	31.0
.4	.115	5.1	3.4	.713	31.8
.5	.140	6.2	3.5	.731	32.6
.6	.163	7.3	3.6	.748	33.4
.7	.186	8.3	3.7	.766	34.2
.8	.208	9.3	3.8	.784	35.0
.9	.230	10.3	3.9	.801	35.7
1.0	.252	11.2	4.0	.819	36.5
1.1	.273	12.2	4.1	.836	37.3
1.2	.294	13.1	4.2	.853	38.1
1.3	.315	14.0	4.3	.871	38.8
1.4	.335	15.0	4.4	.888	39.6
1.5	.355	15.9	4.5	.905	40.4
1.6	.375	16.7	4.6	.922	41.1
1.7	.395	17.6	4.7	.939	41.9
1.8	.415	18.5	4.8	.956	42.6
1.9	.435	19.4	4.9	.973	43.4
2.0	.454	20.2	5.0	.990	44.2
2.1	.473	21.1	5.1	1.007	44.9
2.2	.492	22.0	5.2	1.023	45.7
2.3	.511	22.8	5.3	1.040	46.4
2.4	.530	23.6	5.4	1.057	47.1
2.5	.549	24.5	5.5	1.073	47.9
2.6	.567	25.3	5.6	1.090	48.6
2.7	.586	26.1	5.7	1.106	49.4
2.8	.604	27.0	5.8	1.123	50.1
2.9	.623	27.8	5.9	1.139	50.8
3.0	.641	28.6	6.0	1.156	51.6
			6.1	1.172	52.3
			6.2	1.189	53.0
			6.3	1.205	53.7
			6.4	1.221	54.5
			6.5	1.237	55.2

[1] Weights are oven dry.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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VEGETATIVE PROPAGATION OF 11 COMMON ALASKA WOODY PLANTS

by

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ABSTRACT

Vegetative propagation trials were conducted with stem, root, and rhizome cuttings of *Alnus*, *Arctostaphylos*, *Ledum*, *Populus*, *Salix*, *Shepherdia*, *Vaccinium*, and *Viburnum*. With the exception of *Alnus incana* and *Shepherdia canadensis*, stem cuttings of all species produced some roots. Softwood stem cuttings of *Salix bebbiana* and *Viburnum edule* rooted much better than hardwood cuttings of the same species; hardwood and softwood stem cuttings of other species were about equal in performance. Rooting media, wounding, and hormone treatments did not affect rooting of stem cuttings in the majority of cases. Root or rhizome cuttings of *Vaccinium uliginosum* and *Shepherdia canadensis* appeared more promising for vegetative propagation of these species than stem cuttings.

KEYWORDS: Vegetative propagation, stem cuttings, root cuttings, rhizome cuttings, woody plants, Alaska .

[1] At the time of this study, Patricia Holloway was Research Assistant, Agricultural Experiment Station, University of Alaska, Fairbanks.

INTRODUCTION

Restoration and/or rehabilitation of sites severely disturbed by pipeline, highway or similar construction, and mining is often mandated by law. Although the most common practices used to replace vegetation are best described as agronomic (grass seeding and fertilization), there is increasing interest in the use of native plants (Johnson and Van Cleve 1976, Freeman et al. 1977). Since woody plants are a major component of forested and nonforested Alaska ecosystems, there is a need to determine methods for obtaining adequate quantities of suitable plant materials for revegetation purposes.

Woody plant materials can be propagated by seed or by various vegetative methods. There is a great deal of information available on ways to propagate woody plants (Hartmann and Kester 1975, U.S. Department of Agriculture, Forest Service, 1974); however, its general applicability to Alaska species is not known. For example, it was generally believed that North America willow seed was nondormant and could not be stored. Research with Alaska willows identified species with dormant seed and revealed that seed of at least five species (dormant and nondormant seeded species) could be stored for up to 3 yrs without a significant reduction in viability[2/] (Brinkman 1974, Zasada and Viereck 1975, Zasada and Densmore 1977). Results of this type suggest that surveys of reproductive characteristics may be necessary to determine the full potential of each species for revegetation programs.

This report summarizes the results of a study designed to examine the rooting response of stem cuttings of 11 native Alaska shrub and tree species in a controlled environment:

Scientific name[3/]	Common name
Alnus crispa (Ait.) Pursh ssp. *crispa*	American green alder
Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung	Thinleaf alder
Arctostaphylos uva-ursi (L.) Spreng. var. *uva-ursi*	Bearberry
Ledum palustre L. subsp. *groenlandicum* (Oeder) Hult.	Labrador tea
Populus balsamifera L.	Balsam poplar
Salix alaxensis var. *longistylis* (Rydb.) Schneid.	Feltleaf willow
Salix bebbiana Sarg.	Bebb willow
Salix scouleriana Barratt.	Scouler willow
Shepherdia canadensis (L.) Nutt.	Buffaloberry
Vaccinium uliginosum L. ssp. *alpinum* (Bigel.) Hult.	Bog blueberry
Viburnum edule (Michx.) Raf.	Highbush cranberry

2/ Unpublished data on file at Institute of Northern Forestry, USDA Forest Service, Fairbanks, Alaska.

3/ Nomenclature follows Hultén (1968).

Smaller studies were also undertaken to test these species in the field and to examine shoot production potential of underground parts of these species.

METHODS

Hardwood and Softwood Stem Cuttings

Hardwood stem cuttings were collected between September 17 and October 15, 1976, from sites near Fairbanks, Alaska. All material was moistened, wrapped in polyethylene bags, and placed in cold storage at 4.5°C for approximately 2 wk after which it was trimmed for further treatment.

Cuttings of *Salix* spp., *Alnus* spp., and *Populus balsamifera* consisted entirely of new growth with the proximal cut not greater than 1 cm below a node, and with a minimum of three viable buds. The cuttings of the remaining shrub species consisted of all available new growth plus a heel of 1-yr-old tissue.

The stems of each *Salix* species were further separated into base and tip cuttings. The base cutting contained the oldest of the newly hardened tissue immediately above the 1-yr-old stem tissue. The tip cuttings contained stem tissue from the apex of the newest growth.

The cuttings were divided into two groups. One group was buried in flats of sterilized native peat which were wrapped in opaque polyethylene bags and placed in cold storage for later planting in the field. The remaining group of cuttings was planted immediately and placed on an intermittent mist propagation bench in the greenhouse (22°C average air temperature, 26.7°C bottom heat). The mist cycle was approximately 5 sec of mist every 15 min.

The propagation bench was divided into 5 randomized blocks with 20 treatments per block and 82 cuttings per treatment. Supplemental lighting was provided by two 40-watt cool-white fluorescent bulbs suspended 1 m above the bench.

Cuttings of each species were divided between two propagation media, horticultural grade perlite and sand. Further treatments within these media included:

1. Control.
2. Powdered auxin treatment. The proximal portion of each stem cutting was dipped into a powdered formulation of Indole-3-butyric acid (IBA), Hormodin #3.
3. Wounding treatment. The bark of the proximal end of each cutting was severed with the pointed tip of a knife for approximately 2-3 cm upward from the base.
4. Powdered auxin-wounding treatment. A combination of treatments 2 and 3 above.
5. Liquid auxin-wounding treatment. Following wounding as in treatment 3 above, cuttings were soaked for 5 min in a concentrated, 2,000 ppm liquid formulation of IBA.

Cuttings of all treatments were checked three times weekly for successful rooting, which was defined as the first indication of root emergence from the cutting surfaces. The data recorded for each treatment included the percentage of successfully rooted cuttings for each species and the average time it took for roots to emerge. The rooted cuttings were planted in flats of moist peat for possible transplanting into the field sites.

Rooting percentages were treated statistically with the analysis of variance for randomized complete block design and, where applicable, with Duncan's New Multiple Range Test at the 5-percent level (Steel and Torrie 1960).

With slight variations, this experimental design was repeated for the study of softwood cuttings. Cuttings were collected from sites near Fairbanks, Alaska, between July 5 and July 19, 1977, and immediately trimmed to cutting length for further treatment:

Species	Average length (cm)
Alnus crispa	17
Alnus incana	20
Arctostaphylos uva-ursi	10
Ledum palustre	15
Populus balsamifera	20
Salix alaxensis	20
Salix bebbiana	20
Salix scouleriana	20
Shepherdia canadensis	16
Vaccinium uliginosum	10
Viburnum edule	6

Leaves were removed from the lower 2-4 cm of each cutting. All other leaves were trimmed to approximately three-quarters of their original size to reduce water loss. The softwood cuttings were planted in the greenhouse in sand or perlite media after undergoing identical treatments as the hardwood cuttings. The propagation bench design was identical except for the elimination of supplemental lighting and a slightly shorter mist cycle averaging 5 sec every 12 min.

Root and Rhizome Cuttings

Root and rhizome cuttings were collected from *Salix* spp., *Alnus* spp., *Shepherdia canadensis*, *Arctostaphylos uva-ursi*, *Viburnum edule*, *Vaccinium uliginosum*, *Ledum palustre*, and *Populus balsamifera* from sites near Fairbanks, Alaska, between September 17 and October 15, 1976. Sections 5 to 10 cm long were buried horizontally in wooden flats containing sterilized native peat: 25 cuttings per flat and 2 flats per species. One flat of each species was moistened and placed immediately in the greenhouse. The flats were enclosed in individual, clear polyethylene bags to increase moisture retention. Data recorded included the percentage of cuttings producing shoots, the number of days to maximum shoot emergence, percent survival, and new root production following a 2-mo growing period.

The remaining group of flats was enclosed in individual, opaque polyethylene bags and placed in cold storage for 6 mo. Following this period, 15 of the 25 cuttings of each species were planted in flats of peat in the greenhouse and handled identically to the first group of flats. The remaining 10 cuttings of each species were returned to cold storage for the duration of winter, after which they were planted in the field.

Data were recorded for three groups of cuttings: cuttings of each species planted directly in the greenhouse after collection, cuttings planted in the greenhouse after a 6-mo cold storage period, and cuttings planted in the field site after an approximate 9-mo cold storage period.

Field Study

One of the two field sites was located at the Agricultural Experiment Station farm at the University of Alaska, Fairbanks. The soil at this site is classified as Tanana silt loam (Rieger et al. 1963). The land had been cleared more than 10 yr ago. Cultivation in the study area during the past 5 yr was limited to mechanical weed control. The field site was nearly level, and soil moisture content at the time of planting was 19 percent.

Cuttings planted at this site included half of the hardwood stem cuttings which had been maintained in flats of peat in cold storage during the winter and the rooted cutting transplants from the greenhouse hardwood cutting study.

The unrooted hardwood stem cuttings were planted on June 6, 1977, and subsequent care of experimental plots consisted of hand weeding. Cuttings were directly inserted into the soil to three-quarters their length after being treated as follows:

1. Control.
2. Liquid auxin treatment. The proximal end of the cuttings was soaked for 5 min in a 2,000 ppm liquid formulation of IBA.
3. Powdered auxin treatment. The proximal portion of each cutting was dipped into a powdered formulation (Hormodin #3) of IBA.
4. Repetition of treatments 1, 2, and 3 with the addition of soaking the distal portion of the stem cuttings in a commercially prepared antitranspirant.

A randomized complete block design was used with four blocks of 6 treatments and 65 cuttings per treatment. Successful rooting and establishment within each treatment were recorded as the percentage of cuttings that survived after 3 mo. Cuttings which survived produced leaves and new buds. Results were treated statistically with an analysis of variance for randomized complete block design and where applicable, with Duncan's New Multiple Range Test at the 5-percent level of significance (Steel and Torrie 1960).

The rooted cutting transplants were removed from the greenhouse on June 10, 1977, and hardened in a coldframe for 2 wk prior to planting. Cuttings were planted with a ball of saturated peat surrounding the roots. No treatments were administered after planting. Results were recorded as the percent survival following a 3-mo growing season.

The second field site was located in the Bonanza Creek Experimental Forest approximately 21 miles south of Fairbanks, Alaska. The soil at this site is classified as Steese silt loam (Furbush and Schoephorster

1977). The experimental site was located on an east-facing, 49-percent roadside slope with soil moisture content of 12 percent at the time of planting. Limited natural regeneration of white spruce, birch, and willow was evident, but cover from these plants was minimal. The site was not prepared prior to planting nor were any treatments administered during the growing season.

Cuttings planted at Bonanza Creek included the remaining unrooted hardwood stem cuttings and the cold storage treated root, rhizome, and sucker cuttings. Both were planted on June 13, 1977. Treatments, experimental design, data collection, and analysis for the unrooted hardwood cuttings were identical to those for Experiment Station farm site. The root cuttings were planted horizontally, approximately 2 cm below the soil surface, and the percent shoot production was recorded for each species.

RESULTS

Rooting in a Controlled Environment

Alnus spp. Only 3 of a total of 1,000 *A. crispa* hardwood cuttings formed roots. All softwood cuttings failed to produce roots. Neither hardwood nor softwood cuttings of *A. incana* produced roots.

Arctostaphylos uva-ursi. Both hardwood and softwood stem cuttings initiated roots (table 1). Treatment and media differences were not significant for either type of cutting. Thin, fibrous clusters of roots formed randomly along the buried portion of the stems within approximately 6 wk of bench planting.

Ledum palustre. Few roots were initiated on either hardwood or softwood stem cuttings (table 1). The number of cuttings rooting successfully was not sufficient to show any real differences between treatments. Diffuse clusters of very thin, branching roots formed along the buried stems, mostly within the heel or 1-yr-old tissue. Rooting generally occurred within 3 mo of planting.

Populus balsamifera. Both hardwood and softwood stem cuttings had relatively high rooting percentages (table 1). Root initiation generally occurred within 3 wk after planting in the greenhouse. Initial root formation occurred near a viable bud; however, further rooting occurred randomly along the buried stem. Some callus tissue was formed on the base of the cuttings which were treated with the powdered formulation of IBA.

Roots were preceded by the formation of protrusions of cells which subsequently split the bark and through which the roots emerged. The formation of these protrusions occurred very quickly after bench planting, even on the cuttings which eventually failed to produce roots.

Treatment differences were significant for both softwood and hardwood stem cuttings. Wounding seemed to enhance root production in hardwood cuttings, but roots did not emerge solely from the severed region. Wounds which were subsequently treated with powdered IBA tended to form callus tissue in the severed region rather than roots.

Table 1--Rooting percentages of hardwood and softwood stem cuttings of selected Alaska woody plants

Species	Type of cutting[1/]	Treatment: Sand: Control	Sand: Wound-liquid IBA[2/]	Sand: Wound-pow-dered IBA	Sand: Wound only	Sand: Pow-dered IBA only	Perlite: Control	Perlite: Wound liquid IBA	Perlite: Wound-pow-dered IBA	Perlite: Wound only	Perlite: Pow-dered IBA only	Average performance: Sand	Average performance: Perlite	Average performance: Hard-wood cutting	Average performance: Soft-wood cutting
Arctostaphylos uva-ursi	H	40	56	65	48	60	44	32	48	52	36	54	42	48	--
	S	36	36	40	32	40	32	24	44	32	36	37	34	--	36
Ledum palustre	H	8	0	0	0	8	16	12	12	12	8	3	12	8	--
	S	16	8	12	16	16	12	12	8	8	8	14	10	--	12
Populus balsamifera	H	[3/]60abc	46a	50ab	69bc	56ab	63abc	53ab	60abc	76c	79c	56	66	61	--
	S	53b	53b	63b	49b	61b	23a	50b	40ab	23a	47ab	56	37	--	47
Salix alaxensis	Hb	60	56	62	64	64	54	68	74	64	70	61	66	64	--
	Ht	54	48	42	56	50	50	50	40	58	54	50	50	50	--
	Sb	62	54	62	50	54	54	68	62	62	54	56	60	--	58
	St	44	40	44	32	28	36	40	36	48	44	38	41	--	40
Salix scouleriana	Hb	62	50	58	56	56	64	60	64	64	66	56	64	60	--
	Ht	60	56	78	66	68	66	58	72	50	68	66	63	65	--
	Sb	60	58	64	60	64	48	50	60	54	64	61	55	--	58
	St	55	45	58	50	48	50	55	58	56	58	51	55	--	53
Salix bebbiana	Hb	Less than 1 percent rooted													
	Ht	Less than 1 percent rooted													
	Sb	54	62	46	46	54	50	54	30	42	72	52	50	--	51
	St	44	46	40	30	66	50	38	34	34	42	45	40	--	42
Vaccinium uliginosum	H	7	13	13	13	7	10	7	17	17	13	11	13	12	--
	S	3	17	0	3	3	0	17	3	0	17	5	7	--	6
Viburnum edule	H	1 of 250 cutting produced roots													
	S	48ab	32a	92c	32a	80c	44b	28b	84c	24b	92c	57	54	--	56
Alnus crispa	H	3 of 1,000 cuttings produced roots													
	S	3 of 1,000 cuttings produced roots													
Alnus incana	H	No cuttings produced roots													
	S	No cuttings produced roots													
Shepherdia canadensis	H	No cuttings produced roots													
	S	No cuttings produced roots													

1/ H = hardwood cutting
S = softwood cutting
Hb = hardwood cutting from base of annual growth
Ht = hardwood cutting from tip (apical section) of annual growth
Sb = softwood cutting from base of annual growth
St = softwood cutting from tip (apical section) of annual growth.

2/ IBA = Indole-3-butyric acid.

3/ Treatments with same letter in a row were not significantly different at $P \leq 0.05$. The absence of letters indicate no significant difference.

Salix spp. *S. alaxensis* stem cuttings produced numerous roots from both hardwood and softwood cuttings with most root formation occurring within 2 wk of planting (table 1). Treatment differences were not statistically significant within either tip or base cuttings or between the sand and perlite media. *S. alaxensis* exhibited the diffuse pattern of rooting (Chmelar 1974), with roots arising near viable buds showing the best growth.

Results were similar for *S. scouleriana* cuttings which rooted within 4 wk of planting (table 1). Treatment differences were not statistically significant for either base or tip cuttings nor between propagation media. Unlike *S. alaxensis* cuttings, initial rooting occurred at the base (basal pattern (Chmelar 1974)) near the proximal cut of the stem. Rooting progressed sporadically upward from the base along the buried stem surfaces.

Few hardwood stem cuttings of *S. bebbiana* rooted; rooting percentages were significantly higher for the softwood cuttings (table 1). The great difference between hardwood and softwood cuttings may not be characteristic of the species but possibly a favorable response to heavy pruning. The stem cuttings collected in the fall were noticeably very thin and short. The fall pruning of growing tips appeared to stimulate prolific shoot growth which was both thicker and longer than on the hardwood cuttings. These provided the bulk of the softwood cuttings for the summer experiments. Treatment differences were negligible for *S. bebbiana* softwood stem cuttings of both tip and base types. Rooting was random (Chmelar 1974) and was most prolific on the part of the stem section located immediately below the surface of the propagation medium.

Shepherdia canadensis. This species failed to produce roots from stem cuttings under the prescribed experimental greenhouse conditions. Both hardwood and softwood stem cuttings became soft and black shortly after planting. No evidence of callus formation at the proximal cut or along wound surfaces was apparent.

Vaccinium uliginosum. Rooting percentages from both hardwood and softwood stem cuttings of blueberry were poor, and the number of rooted cuttings was not sufficient to reveal any significant differences between treatments (table 1). Rooting generally occurred within two mo after planting, with thin, fibrous roots forming indiscriminately along the buried portion of the stem.

Viburnum edule. From a total of 300 highbush cranberry hardwood cuttings, 1 produced roots. In contrast, softwood cuttings initiated numerous roots (table 1). Cuttings rooted equally well in the sand and perlite media, but rooting was more prolific and averaged 2 wk earlier in sand. Rooting was significantly increased by treating cuttings with powdered IBA.

Roots generally formed within 6 wk after planting. They were in large clusters near the base of each cutting, primarily in the heel (1-year-old tissue). Root emergence was preceded by the development of cell protrusions along the buried portion of the stem as much as 1 wk before root emergence. Callus formation was minimal at the base of these cuttings. Softwood cuttings whose leaves had fallen or had been removed did not produce roots.

Root and Rhizome Changes

Alnus crispa, Arctostaphylos uva-ursi, *Ledum palustre*, *Populus balsamifera, Shepherdia canadensis, Vaccinium uliginosum,* and *Viburnum edule* were successfully propagated from root or rhizome cuttings when planted in the greenhouse immediately after fall collection. Following cold treatment, only *L. palustre, Populus balsamifera, Vaccinium uliginosum,* and *Viburnum edule* survived to regenerate from this type of material (table 2).

Table 2--Results of propagation with root, rhizome, or sucker cuttings

Species	Type of cutting	Immediately planted: Percent success, shoot production	Immediately planted: Percent survival and root production	Cold treated: Percent success, shoot production	Cold treated: Percent survival and root production	Average no. days to maximum shoot emergence
Alnus crispa	root	4	100	0	0	7
Arctostaphylos uva-ursi	root	60	100	0	0	46
Ledum palustre	rhizome	64	31	100	53	49
Populus balsamifera	root	100	0	73	100	14
Shepherdia canadensis	root	24	100	0	0	46
Vaccinium uliginosum	rhizome	52	100	53	100	56
Viburnum edule	rhizome	100	28	100	100	28

Field Trials

Unrooted hardwood cuttings of *Populus balsamifera* exhibited varying degrees of rooting at the two field sites (table 3). At the Agricultural Experiment Station field site, rooting was observed for all treatments within each block, but treatment differences were not statistically significant. Shoot growth at the termination of the experimental growing

Table 3-- Average rooting and survival percentages of hardwood stem cuttings of *Populus balsamifera* L. ssp. *balsamifera* which were directly inserted into the ground at field sites

Treatment	Bonanza Creek Experimental Forest	Agricultural Experiment Station
Control	0	25
Powdered IBA[1/]	8	58
Liquid IBA	17	33
Antitranspirant (AT)	0	25
Powdered IBA-(AT)	0	41
Liquid IBA-(AT)	25	25
Average performance, all treatments	8	35

1/ IBA = Indole-3-butyric acid.

averaged 7 cm in length for all treatments. Rooting and survival of cuttings at the Bonanza Creek field site appeared to be confined to the treated cuttings and predominately to the liquid IBA treatment. The number of cuttings rooting successfully was not sufficient to show any differences between treatments. New shoot lengths averaged 5 cm, and considerable insect damage was noted on the new growth on several of the cuttings.

With the exception of *S. alaxensis*, none of the species survived one growing season in the field.

More than 50 percent of the rooted hardwood cuttings of *Salix alaxensis*, *S. scouleriana*, and *Populus balsamifera* survived transplanting into flats of peat from the greenhouse propagation bench. Subsequently fifty cuttings of each species were planted at the Agricultural Experiment Station field site. At the conclusion of the growing season 38 percent of the *S. scouleriana*, 44 percent of the *S. alaxensis*, and 82 percent of *Populus balsamifera* transplants remained alive. None of the root or rhizome cuttings planted at Bonanza Creek produced new shoots during the growing season.

DISCUSSION AND CONCLUSION

The results reported here for hardwood and softwood cuttings indicate a variety of responses for these species under controlled temperature and moisture conditions. With the exception of *Alnus incana* and *Shepherdia canadensis*, all species exhibited some root production. With few exceptions there was little difference between the two rooting media and the wounding and hormone treatments used. The rooting potential of the various species, excluding *Alnus* spp. and *S. canadensis*, are similar to those reported earlier for the same or similar species (Bailey and Bailey 1934, Bogdanov 1968, Hartmann and Kester 1975, Holden 1975). Lepisto (1970) reported rooting percentages of up to 74 percent with *Alnus incana* and 33 percent with *A. glutinosa*. Average success with *A. incana* was 43 percent and *A. glutinosa*, 16 percent.

Although limited in scope, propagation trials with roots and rhizomes indicated that this approach should be investigated in more detail. These plant parts are more difficult to collect; however, our results suggest that propagation of species such as *Vaccinium uliginosum* and *Shepherdia canadensis* could be more successful using these materials rather than stem cuttings.

With the exception of *Populus balsamifera*, direct planting of unrooted cuttings was not successful. Based on work with similar *Populus* species (e.g., McKnight 1970) and other Alaskan observations, the results with balsam poplar were expected. The almost total failure of *Salix alaxensis* to survive, however, was unexpected. Previous work with this species had resulted in 2-yr survival of 55-60 percent (Zasada et al. 1977). These previous trials were with material collected and planted in early May on a coarser textured soil. These differences in success with *Salix alaxensis* are an example of the range in success that may occur when unrooted cuttings are planted in the field. Factors such as soil water content, season of planting, and methods of collecting and handling cuttings are critical to success and must be considered for each planting site.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

PNW-335 July 1979

RESPONSE OF THINNED LODGEPOLE PINE AFTER FERTILIZATION

by

P. H. Cochran, Principal Research Soil Scientist

Abstract

Significant increases in volume, basal area, and bole area growth continued during the second 4-year period after application of N, P, and S. Height growth, which was not increased significantly during the first 4-year period after treatment, was increased by the initial fertilization during the second 4-year period. Grass production in the understory continues to be higher on the fertilized plots.

KEYWORDS: Fertilizer response (forest tree), increment (volume), increment (height), lodgepole pine, *Pinus contorta*.

Metric Equivalents

1 pound/acre = 1.121 kilograms/hectare
1 acre = 0.405 hectare
1 foot = 0.304 8 meter
1 inch = 2.54 centimeters
1 square foot/acre = 0.229 568 square meter/hectare
1 cubic foot/acre = 0.069 972 cubic meter/hectare

INTRODUCTION AND METHODS

Earlier, I reported[1] on a study to determine response of a pole-sized lodgepole pine stand to high application rates of fertilizer (600, 300, and 90 lb/acre[2] of N, P, and S respectively). The study, established in the fall of 1970 on the LaPine soil (a Typic Cryorthent), consisted of ten 1/10-acre plots in a 43-year-old stand thinned during 1966-1967. Five plots were randomly chosen for fertilization. Every tree on each plot was initially measured with an optical dendrometer and then remeasured at the ends of the fourth and eighth growing seasons (table 1).

Table 1--Some stand parameters for the study plots after eight growing seasons

Treatment and plot number	Basal area	Bole area[1]	Volume[1]	Average height	Average diameter[2]	Trees
	- - Sq ft/acre	- -	Ft^3/acre	Feet	Inches	No./acre
Fertilized:						
9	30.8	3,833	474	30.8	7.3	100
7	43.9	6,970	864	42.8	7.8	130
10	48.8	7,231	936	42.2	8.2	130
5	69.7	11,068	1,341	42.8	7.8	210
1	68.2	11,014	1,504	49.8	8.8	160
Control:						
6	28.5	4,712	429	30.9	5.5	170
8	44.1	7,261	812	39.4	6.2	160
4	52.1	7,866	928	40.4	7.7	160
3	54.4	9,107	1,093	44	7.6	170
2	66.5	11,976	1,414	45.2	7.4	220

[1] Values are above a 1-ft stump.

[2] Actual average diameter , not diameter equivalent to the average basal area.

[1] Cochran, P. H. 1975. Response of pole-sized lodgepole pine to fertilization. USDA For. Serv. Res. Note PNW-247, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

[2] Metric equivalents are on front cover.

During the first 4-year period, fertilization caused significant increases in annual volume, basal area and bole area growth, as well as grass production in the understory. Height growth did not respond to fertilization. This note reports response to the initial application of N, P, and S during the second 4-year period. Analysis of covariance (with basal area as the covariate) was used to determine if growth rates of volume, basal area, and bole area were increased by fertilization during the second 4-year period. Treatment effects on height growth and grass production were tested with t-tests.

RESULTS AND DISCUSSION

During the second 4-year period, growth of volume, basal area, bole area, and height were all significantly increased ($p \leq 0.05$) by the initial fertilization (table 2, figs. 1-3). Average annual height growth was 0.37 ft greater than for the non-fertilized trees (table 2) even though no significant difference in height growth occurred during the first 4-year period. Values for average annual growth of volume, basal area, and bole area equivalent to 40 sq ft/acre of basal area at the start of the growing

Table 2--Average annual growth for the second 4-year period after treatment

Treatment and plot number	Basal area	Bole area[1/]	Volume[1/]	Height
	--Sq ft/acre per year--		Ft^3/acre per year	Ft/tree per year
Fertilized:				
9	2.2	224.5	38.0	1.0
7	2.9	394	70.5	1.0
10	2.6	378.5	67.2	1.0
5	4.7	601.5	108.2	1.0
1	3.4	517.5	103.2	1.0
Average	3.2	423.2	77.4	1.0
Control:				
6	1.6	255.5	34.5	0.7
8	2.2	276.25	43.8	.6
4	2.0	268.5	41.5	.6
3	2.2	325.5	57.5	.6
2	2.0	386.0	69.5	.7
Average	2.0	302.4	49.4	.6

1/ Values are above a 1-ft stump.

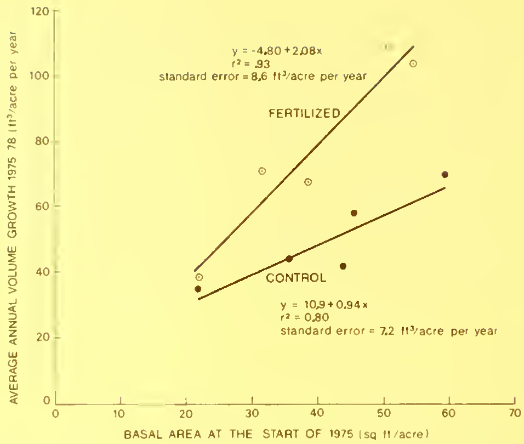

Figure 1.--Average annual volume growth during the 1975-78 growing seasons as a function of the basal area at the start of the 1975 growing season.

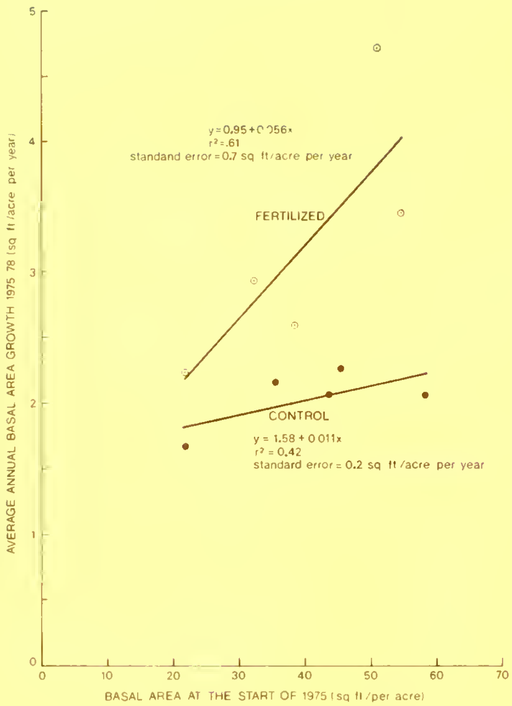

Figure 2.--Average annual basal area growth for the 1975-78 growing seasons as a function of basal area at the start of the 1975 growing season.

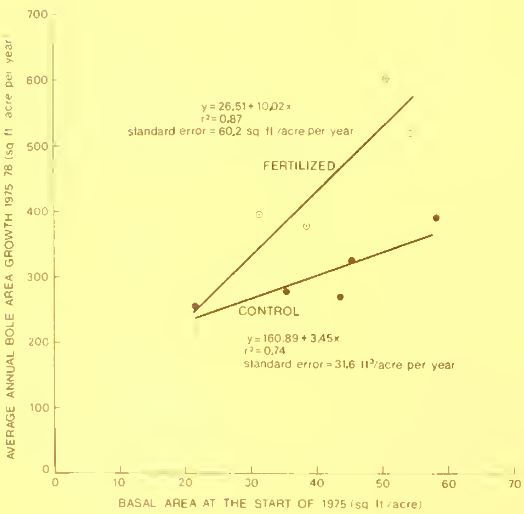

Figure 3.--Average annual bole area growth for the 1975-78 growing seasons as a function of basal area at the start of the 1975 growing season.

period were 62, 60, and 43 percent higher for the fertilized treatments than for controls (table 3). These percent increases due to fertilization are lower than the increases obtained during the first 4-year period (100, 100, and 77 percent) (see table 3).

Table 3--Comparison of average annual growth for each 4-year growing period[1/]

Growing period and type of growth	Average annual growth		Increase of fertilized treatments over controls
	Fertilized	Control	
			Percent
First growing period (1971-74):			
Volume[2/] (ft^3/acre per year)	73.8	36.8	100
Basal area (sq ft/acre per year)	3.2	1.6	100
Bole area[2/] (sq ft/acre per year)	432.5	244.7	77
Second growing period (1975-78):			
Volume[2/] (ft^3/acre per year)	78.4	48.5	62
Basal area (sq ft/acre per year)	3.2	2	60
Bole area[2/] (sq ft/acre per year)	427.3	298.9	43

1/ Values represent growth produced by 40 sq ft of basal area per acre at the start of the growing period. The 40-sq-ft unit was used because it was within the range of initial basal areas for both growing periods and was close to the mean basal area for the 10 study plots at the start of the second period. Any other basal area within the range of the data could have been used with the appropriate regressions to calculate growth rates.

2/ Values are above a 1-ft stump.

These reductions in percent increases of volume and bole area occurred during the second 4 years even though response of height growth to fertilization was delayed 4 years.

Production of grasses in the understory was monitored only for the 1978 growing season by clipping on four 2- by 12-ft transects randomly located on each plot. Grass production was increased ($p \leq 0.05$) by fertilization:

Treatment	Treatment averages dry weights (16 lb/acre)	Plot Ranges lb/acre
Fertilized	16.2	3.6-28.5
Control	4.2	0.7-6.6

Response of grass to fertilization also seems to be decreasing with time. In 1971 and 1974, treatment averages for fertilized plots were 37.8 and 68 lb/acre while treatment averages for non-fertilized plots were 7.4 and 3.7 lb/acre.

The application rates in this study are about three times as high as I would recommend for fertilization of thinned lodgepole or ponderosa pine stands on an operational basis. Further, the influence of S and particularly P seems minor in comparison to N for ponderosa pine on related soils.[3]

Although fertilization continues to produce very large increases in yields, a questionable future still exists for fertilization of low-producing stands of lodgepole pine. Inquiries about fertilization continue to arise from land managers, however, and studies like this will be valuable in assessing the role of fertilization in fiber production for the future.

* * * * *

[3] Cochran, P. H. 1979. Response of a pole-sized ponderosa pine stand to nitrogen, phosphorus and sulfur. USDA For. Serv. Res. Note PNW-319, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

GPO 988-896

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PNW RESEARCH NOTE

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

PNW-336 July 1979

RESPONSE OF A 110-YEAR-OLD DOUGLAS-FIR STAND TO UREA AND AMMONIUM NITRATE FERTILIZATION

by

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and

RICHARD E. MILLER, *Principal Soil Scientist*

ABSTRACT

Basal area response to 150 pounds of nitrogen per acre applied as urea or ammonium nitrate was monitored on 1/5-acre plots for 4 years in a recently thinned, 110-year-old, site II, Douglas-fir stand. Nitrogen fertilization significantly increased growth. Basal area increment was increased 59 percent over the controls by ammonium nitrate and 37 percent by urea. The difference in response between urea and ammonium nitrate was statistically significant. Crown class had a highly significant influence on basal area growth of individual trees; however, the increases in growth due to fertilization were not significantly different by crown class.

KEYWORDS: Nitrogen fertilizer response, increment (basal area), urea, ammonium nitrate, Douglas-fir, *Pseudotsuga menziesii*.

More than 1 million acres of coniferous forests in western Washington and Oregon have been fertilized with nitrogen (N) since 1966. Urea fertilizer (46-percent N) has been used almost exclusively. Ammonium nitrate (34-percent N) has also been used as a nitrogen source, but it is more costly because of its somewhat higher initial cost and the higher cost of application associated with its lower nitrogen content. The relative effectiveness of these two nitrogen sources for increasing tree growth may depend on specific site conditions because different forms of nitrogen are subject to different transformations and fates within forest ecosystems (Wollum and Davey 1975). For example, urea applied to the forest floor is more likely to volatilize or to become temporarily immobilized in living or dead organic matter than is ammonium nitrate (Knowles 1975). Ammonium nitrate, however, is more subject to losses by leaching.

We present the initial results of a fertilizer trial which compared the responses to urea and ammonium nitrate in a recently thinned, 110-year-old, site II, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stand. In this stand, 4-year basal area response to ammonium nitrate was significantly greater than response to urea.

THE STUDY AREA AND TREATMENT

The Fall Creek study area is in the western Cascade Range about 30 miles southeast of Eugene, Oregon, on the Willamette National Forest. The elevation is about 1,800 feet; the topography is gently sloping and the aspect generally northern. Soil texture ranges from silt loam to clay loam in the surface horizons and from clay loam through loam in the subsoils. Annual precipitation averages 70 inches.

Douglas-fir is the dominant species in the study area--93 percent of the basal area is in Douglas-fir. Western redcedar (*Thuja plicata* Donn) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) are common associates, especially in the lower crown classes. Prior to the 1974 growing season, the Douglas-fir averaged 111 years old with a site index (100-year base) of 168 or site II. The stand had been commercially thinned in the summer of 1973, the year before fertilization. About 70 square feet of basal area per acre were removed in a low thinning (fig. 1); the average diameter of the cut trees was less than the average diameter of the original stand. Average stand characteristics among treatments were similar before and after thinning (table 1).

We measured growth on 12 circular, 1/5-acre plots to compare three treatments: 150 pounds of nitrogen per acre as urea granules, 150 pounds of nitrogen per acre as ammonium

Figure 1.--About one-quarter of the basal area of this 110-year-old stand was subsequently removed in thinning prior to fertilization.

nitrate prill, and no nitrogen (control). The plots were selected for uniformity and lack of thinning damage from 22 plots that had been systematically located in the study area in the 1940's. We randomly assigned four plots to each treatment.

The fertilizers were applied by hand on March 27, 1974, to 1/2-acre plots centered on the 1/5-acre measurement plots. This provided a 30-foot-wide treated buffer for the fertilized plots. At the time of application, the soil was moist and the weather cool and drizzly; moreover, 5 inches of rain fell during the week after fertilization. Under these conditions, nitrogen losses by volatilization of urea were probably minimized; however, losses by leaching of ammonium nitrate were probably increased.

MEASUREMENTS AND ANALYSES

On the study plots, all trees 1.6 inches and larger in diameter were numbered and tagged. Diameter at breast height, crown class, and tree condition were recorded for each tree prior to fertilization and again 4 years after fertilization. In addition, 18 dominant trees, equally distributed among the treatments, were measured for height. The height and corresponding diameter measurements of the 18 trees were

Table 1--Stand characteristics in the Fall Creek study plots before fertilization

Characteristics	Treatment			
	Control	Ammonium nitrate	Urea	Average
Site index (100-year base)	169	172	162	168
Volume (cubic feet per acre to a 4-inch top)	11,600	12,400	12,000	12,000
d/D[1]	.85	.76	.77	.80
Basal area (square feet per acre)[2]	214/295	230/302	221/281	222/293
Number of stems per acre[2]	104/162	102/176	136/212	114/183
Average diameter[3] of Douglas-fir (inches)[2]	25.6/23.1	25.7/22.2	23.4/20.7	24.9/22.0

1/ The ratio, d/D, is the ratio of the quadratic mean diameter of cut trees to that of all trees before cutting.

2/ Figures above the slash describe the stand after thinning and before fertilization (spring, 1974); figures below the slash describe the stand before thinning (spring, 1973).

3/ Diameter of the tree of mean basal area (quadratic mean diameter).

used to determine a mean tarif[1] number for the stand at the start and end of the measurement period. We estimated plot volume (to a 4-inch top, d.i.b.) by multiplying basal area of the plot by the stand tarif number; we estimated gross volume growth by multiplying gross basal area growth by the tarif number corresponding to the midpoint of the treatment period.

We analyzed the effects of fertilization on 4-year gross basal area growth. Although forest managers are primarily interested in volume growth, we had too small a sample of heights to provide a sensitive measure of response in volume growth. We assumed, however, that in this mature stand differences in basal area growth reflect comparable differences in volume growth because the slow height growth indicated that basal area growth was the major component of volume growth. No statistical analyses were made of volume growth; the data on volume and volume growth have been included for the reader's information.

We examined effects of treatments on mean annual basal area growth using analysis of variance with the response data adjusted by covariance for differences in initial basal area (i.e., basal area after thinning). Orthogonal comparisons tested fertilization versus no fertilization and urea versus ammonium nitrate. In addition, we were interested in examining the effect of crown class on response to treatment. We investigated this by analyzing the experiment as a split plot design with fertilization as the main plot treatment and crown class the split plot treatment. Split plot analysis assumes that the split plot treatment, crown class in this case, are independent of each other. In general, crown classes are not independent and, in fact, are in direct competition for the site's resources. We assumed for this analysis, however, that 4-year growth by one crown class would not be a major factor influencing the 4-year growth of trees in another crown class. In our analyses, we used the 5- and 1-percent probability levels to judge results as significant or highly significant.

RESULTS AND DISCUSSION

There was a significant increase in gross basal area growth after fertilization; moreover, growth with ammonium nitrate was significantly greater than growth with urea. When treatment means were adjusted for differences in initial basal area, the annual basal area increment on ammonium nitrate plots averaged 59 percent higher than that on the control plots; annual basal area increment on the urea plots was 37 percent more than on the controls (table 2). During the 4-year period, gross basal area growth was 5.4 square feet per acre more on the ammonium nitrate plots than on the control plots; gross basal area growth on the urea plots was 3.4 square feet per acre more than on the control plots. The comparable 4-year increases in volume growth were 296 and 184 cubic feet per acre, respectively.

Gross growth was only slightly different from net growth. On all plots, two suppressed western hemlock trees died during the 4-year period, and two western hemlock trees were added as ingrowth.

[1] The tarif number is the number of cubic feet in a tree of basal area 1.0; it is derived from the relationship between diameter and height (Turnbull et al. 1970).

Table 2--Mean annual growth per acre at Fall Creek, based on 4-year data

Treatment	Basal area growth		Volume growth[1]
	Square feet[2]	Percent	Cubic feet
Control	2.30	100	125
Ammonium nitrate	3.65	159	199
Urea	3.15	137	171

[1] Volume growth = basal area growth x average tarif number.

[2] Means adjusted by covariance analysis for initial differences in basal area.

Crown class had a highly significant influence on basal area growth of individual trees (fig. 2). Over all treatments, the average dominant

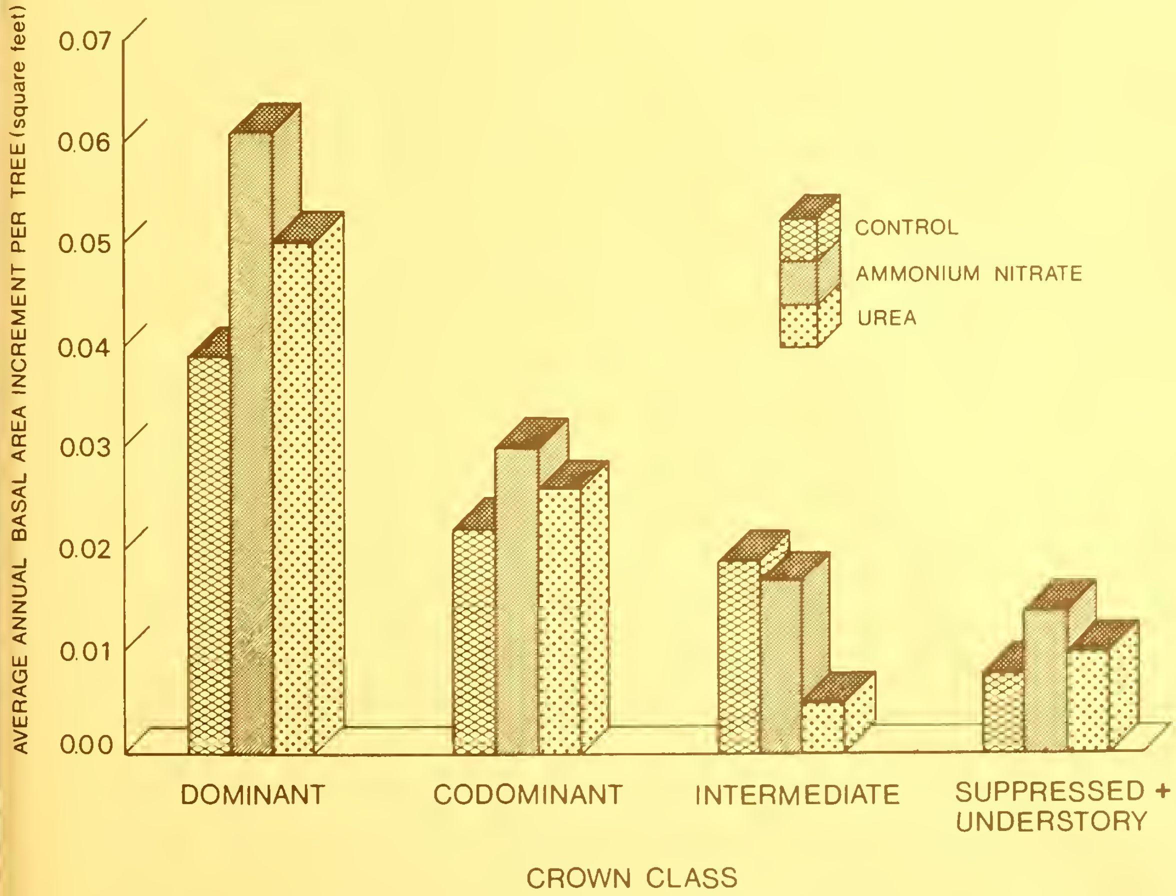

Figure 2.--Average annual basal area growth at Fall Creek by crown class and treatment, 4-year basis.

tree grew more than the average codominant tree; this relationship extended through the lower crown classes. The increases in growth due to fertilization, though, did not differ significantly by crown class. This experiment probably did not provide a sensitive test of crown class-fertilizer interactions, however, because: (1) there were very few trees in the intermediate crown class, (2) western hemlock and western redcedar trees were included in the analysis, and (3) the recent thinning probably released trees differentially.

The results from this study may be compared with the results of another urea and ammonium nitrate trial we reported previously (Miller and Harrington 1979). That trial was in an unthinned, 80-year-old, site I, Douglas-fir stand near McCleary, Washington. In the McCleary trial, we found that 200 pounds of nitrogen per acre increased volume growth 20 percent or about 280 cubic feet per acre during a 4-year period and that urea and ammonium nitrate did not differ significantly in their effect on volume growth.

We can only speculate why urea fertilization was less effective than ammonium nitrate in the Fall Creek trial. Immobilization of urea in the forest floor was probably a major factor. Although we have no direct measures of differences between the forest floor at the two locations, we observed a thicker forest floor in the older stand used in the Fall Creek study. Thus we can assume that the area had a greater potential for temporary immobilization of urea. Moreover, the lower dosage applied at Fall Creek (150 versus 200 pounds per acre) would have been less likely to compensate for this immobilization. Differences in volatilization of urea or leaching of ammonium nitrate were probably not major factors in determining the differential response. Both areas had moist, cool soil and wet, cool weather during and after application which probably minimized volatilization losses. In addition, we have no basis for suspecting that conditions at McCleary would have encouraged greater leaching of ammonium nitrate and thereby have reduced its effectiveness at that location.

The Fall Creek and McCleary studies have demonstrated that fertilization can increase growth in mature stands. Moreover, the 4-year results from the Fall Creek study indicate that the effectiveness of fertilization may depend on the nitrogen source used. We recommend consideration of nitrogen fertilization to increase growth in postrotation-age Douglas-fir; however, we prefer to await longer term growth data from this study and from other studies before recommending specific nitrogen sources.

CONCLUSIONS

In this recently thinned, 110-year-old, site II, Douglas-fir stand:

1. Four-year basal area growth was significantly increased by nitrogen fertilization; 150 pounds of N per acre as ammonium nitrate increased basal area increment 59 percent over the controls, and 150 pounds of N per acre as urea increased basal area increment 37 percent. This represented 4-year increases in gross basal area growth of 5.4 and 3.4 square feet per acre, respectively.

2. Response to ammonium nitrate was significantly greater than response to urea.

3. The influence of crown class on basal area growth of individual trees was highly significant. The

increases in growth due to fertilization, however, did not differ significantly by crown class.

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METRIC EQUIVALENTS

1 square foot/acre	= 0.229 6 square meter/hectare
1 cubic foot/acre	= 0.069 97 cubic meter/hectare
1 stem/acre	= 2.471 stems/hectare
1 inch	= 2.54 centimeters
1 pound/acre	= 1.120 4 kilogram/hectare
1 mile	= 1.613 kilometer
1 foot	= 0.304 8 meter
1 acre	= 0.404 8 hectare

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

PNW-337 August 1979

AN EVALUATION OF TWO MEASURES OF COMPETITION FOR NATIONAL FOREST TIMBER SALES

by

Richard W. Haynes, *Principal Economist*

Abstract

The National Forest Management Act requires adequate monitoring systems to screen timber sales for collusive activity. This paper evaluates two measures of competition--overbid and the bid-appraisal ratio--in terms of their ability to provide a consistent measure of competition over time. If the purpose of the monitoring is to detect collusion in an individual sale, either measure is adequate. If the purpose of the monitoring is to evaluate competition over time, overbid is preferred.

KEYWORDS: Stumpage sales arrangement, stumpage prices, price determination, National Forest administration.

BACKGROUND

The National Forest Management Act (U.S. Laws, Statutes, etc. 1976) has focused attention on measuring the extent of competition for USDA Forest Service timber sales. The Act requires "adequate monitoring systems" to screen timber sales for collusive activity. From a practical standpoint, sale monitoring can be interpreted two ways: (1) Can individual sales be screened to determine if a sale was sold competitively? (2) Can groups of sales be screened to determine if noncompetitive bidding patterns exist over time? Corrective action is to be implemented once collusion has been detected.

Implementing a monitoring system requires that each sale be evaluated (after being sold) as either competitive or noncompetitive. In competitive sales, a number of buyers interact to establish prices that reflect the underlying supply and demand forces. The problem in monitoring sales is deciding whether a sale is competitive. An obvious measure would be number of bidders. All sales with only one bidder could be classified as noncompetitive, but, as Stigler (1966) points out, just the existence of a number of bidders does not mean that they have not colluded. On the other hand, a lack of bidders or a low bid price does not necessarily imply collusion.

The alternatives to the measures which have been tried are the bid appraisal ratio and overbid. The bid appraisal ratio is the more widely used of the two and is a ratio of total bid (net of road costs) to the appraised price.[1/] Overbid is total bid minus road costs and the appraised price.[2/] Both prices and costs are expressed on a per-thousand-board-foot basis. The two measures describe the premium (the amount over the minimum bid) that bidders are willing to pay for the timber on a particular sale. Either of these measures can be used to classify sales as noncompetitive or competitive by selecting sales with only limited competition and consequently whose premium is less than some arbitrary amount. This amount is usually established at a level that will single out "token bid" sales as being noncompetitive. Sales of this type are typically seen as those in which a number of bidders might be involved but only one bidder makes a token bid of, say, 5 cents over the appraised price.

The Question

The existence of two measures of competition raises the question of whether the measures are equivalent or whether there are unique differences making one measure more appropriate. The objective of this note is to examine the measures to determine which is better in the sense of uniformly evaluating competition on USDA Forest Service timber sales.

The question of uniformity involves the nature of the rating each measure assigns to a sale. The issue is whether the assigned rating is unique to each sale or only relative. For example, do the measures result in ratings that are temporally consistent; that is, do the measures assign the same value to two sales which have identical physical characteristics and bidder response if they are observed at different points in time? The measure which provides the more consistent rating is assumed to provide the better measure of competition.

The Appraisal Process

The USDA Forest Service appraisal process assigns to stumpage the residual of the estimated value of the mix of products which could be manufactured from the timber on a given sale minus the logging, manufacturing, and road costs estimated for that sale. An additional adjustment is made for profit and risk. As an example, suppose that the product selling value of a particular sale is $159 per thousand board feet; that is, the products that could be manufactured, including byproducts (e.g., chips), are worth $159 per thousand. The logging costs for the particular sale and the manufacturing

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[1/] Mead (1966) and Mead and Hamilton (1968) did much to popularize the bid appraisal ratio as a measure of competition in the early 1960's.

[2/] Studies by Haynes (1979) and Wiener (1979) have used overbid as a measure of competition.

costs for the assumed mix of products are $42 and $57 per thousand, respectively, and road costs and the estimate for profit and risk are $5 and $16 per thousand. The appraised stumpage price (A) is then

$$A_j=S_j-(L_j+M_j+R_j+P_j); \qquad (1)$$

where

S_j is the selling price for the j^{th} sale,

L_j is the logging cost for the j^{th} sale,

M_j is the manufacturing cost for the j^{th} sale,

R_j is the specified road costs for the j^{th} sale, and

P_j is the profit and risk allowance for the j^{th} sale.

In the sample, the appraised stumpage price would be $39 per thousand board feet ($159 - (42 + 57 + 5 + 16)).

In this study, the bid price, various costs, and selling price for individual sales are volume-weighted averages. The total bid price has been adjusted for road costs and corresponds to what is known as the statistical high bid. The appraised price is the volume-weighted average net appraised stumpage price as determined by the USDA Forest Service appraisal system. All data were taken from the standard USDA Forest Service sales report and were deflated by the wholesale price index for all commodities (1967=100) to offset the different rates of inflation in each year of the period covered by the data.

After deflation, the values represented in the study should be interpreted as the value expressed in 1967 dollars (the base year of the index). Furthermore, changes between two points in time should be interpreted as a real change, since inflationary increases have been factored out. The values could be converted to the original form by multiplying the value by the appropriate monthly wholesale price index--all commodities.

THE EFFECTS OF TIME ON THE COMPONENTS OF THE APPRAISAL SYSTEM

A key to evaluating the effectiveness of the bid appraisal ratio and overbid as measures of competition over time is to determine how the components of the appraisal process change over time. As formulated, equation 1 ignores the effect of time, but this can be remedied by including a compound interest factor with each component. The revised equation would be:

$$A(1+i_a)^n=S(1+i_s)^n-[L(1+i_l)^n+M(1+i_m)^n+R(1+i_r)^n+P(1+i_p)^n]; \qquad (2)$$

where

n is the number of periods,

$i_a, i_s, i_l, i_m, i_r, i_p$ are rates of change, and

$(1+i)^n$ is the compound interest factor for the i rate of change measured over n periods.

As stated, this relationship allows for different rates of change for each component because individual components change through time at different rates. For example, factors influencing changes in selling price may not be the same as those influencing changes in logging costs.

The importance of considering the effects of time can be illustrated in the following example: Assume that one of four identical sales will be offered each year for 4 years. Assume further that the appraisal components have changed at various rates, leading to a 10-percent-per-year change in the appraised price while overbid has remained unchanged. The changes in major variables of interest are shown below:

Year	Appraised stumpage (A)	Overbid (Ø)	Total bid (B)	Bid appraisal ratio (B/A)
1	39.00	35.00	74.00	1.90
2	42.90	35.00	77.90	1.82
3	47.20	35.00	82.20	1.74
4	51.90	35.00	86.90	1.67

Total bid may be expressed as follows:

$$B\ (1 + i_b)^n = A\ (1 + i_a)^n + Ø\ (1 + i_o)^n. \qquad (3)$$

In the example, the rate of change i_b would have to be less than i_a since i_o is equal to zero.

The example is useful in illustrating the concerns about the uniqueness of the value assigned to a given sale. In the example, differential increases in real costs and prices as reflected in an increasing appraised price led to a declining bid appraisal ratio through time for identical sales. This implies that bid appraisal ratios provide only an ordinal measure in that the assigned value is only relative to other sales observed at the same time. Overbid, in the example, is treated as a cardinal measure; that is, it provides an absolute (or real) measure as well as a consistent measure of competition in each of the 4 years. Overbid is consistent because it measures competition unaffected by differential increases in cost and price elements used in deriving the appraised price.

The example indicates that overbid is a better measure of competition in the sense that it is unaffected by differential rates of real cost and price increases. How realistic is the example, however, and what has been the actual experience in differential rates of inflation in the appraisal elements? These questions can be answered by testing the following hypotheses:

1. There are no real increases in overbid.
2. The rate of real increases in total bid is less than those for appraised price.
3. The rate of real increases in appraised price bears a direct relationship to the rates of real increases in the major components used in computing the appraised price.
4. The bid appraisal ratio declines through time.

The last hypothesis is a direct test of the implications from the first hypothesis. If the first is correct, then the fourth should be correct.

TESTING THE HYPOTHESES

USDA Forest Service sales data from the west side of the Pacific Northwest Region (the Douglas-fir region) were used to test the hypotheses. The data were compiled monthly from the 1,317 sales which were sold between July 1974 and June 1976 and the 652 sales which took place during 1977. The data for appraised price, overbid, and total bid are shown in figure 1; the data for selling price, logging costs, road costs, and manufacturing costs, in figure 2. The bid appraisal ratios, computed as the ratio of total bid and appraised price for the period, are shown in figure 3. The data should be interpreted as simple averages of all sales taking place within each month.

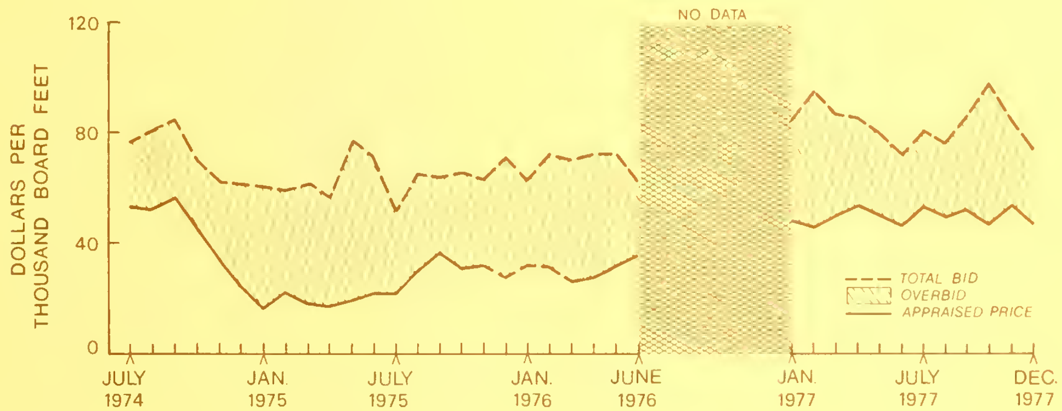

Figure 1.--Appraised price, overbid, and total bid.

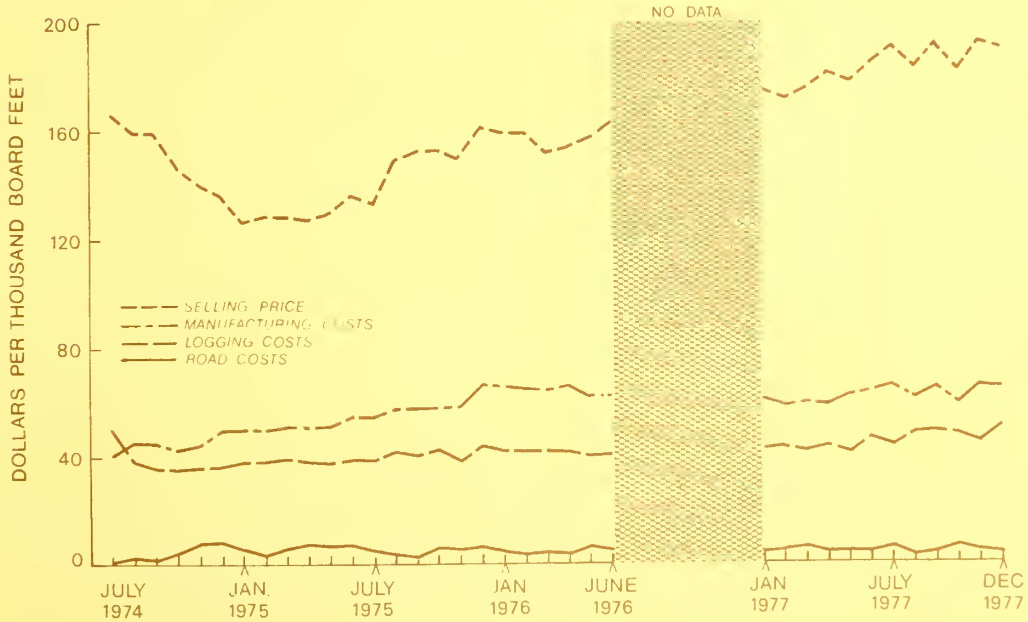

Figure 2.--Selling price, logging costs, manufacturing costs, and road costs.

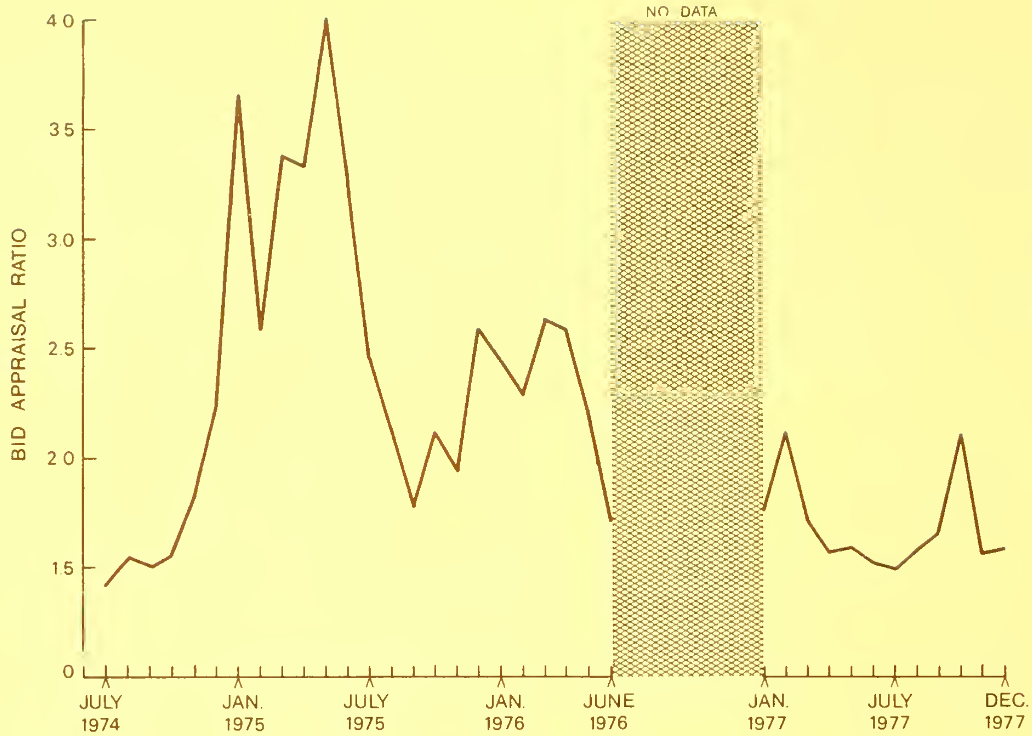

Figure 3.--The bid appraisal ratio.

Although perhaps not typical of the post-World War II period, the price swings in forest products markets, for the period July 1974 through December 1977 are typical of the experience during the last decade. These words of caution should not be interpreted to mean that the study will lead to atypical results. Rapid price movements should have little effect on the appraisal system, except to shift the appraised price up or down as shown in figure 1.

All hypotheses required estimates of the rates of real changes over time. These rates of change were estimated by fitting the variable in question as a function of time using a semilogarithmic functional form. The coefficient on time was then interpreted as the monthly rate of change.[3/] All estimated equations are shown in table 1.

[3/] The particular semilogarithmic form fitted was (for appraised price):

$$\text{Log } A = B_1 + B_2 \text{ time;}$$

where

Log is the natural logarithm,
time is an index of months with July 1974=1,
B_1 is the intercept coefficient, and
B_2 is interpreted as $e^{(1 + i)}$, where
i is the monthly rate of increase.

Taking the antilog of B_2 ($\hat{B}_2$) we can solve the relationship,

$$\hat{B}_2 = 1 + i, \text{ and}$$
$$i = \hat{B}_2 - 1;$$

where i is the monthly rate of change in appraised stumpage. This procedure is described in more detail in Johnston (1972).

Table 1--Estimated relationship between elements of appraisal and time

Element	Equation B_1	Equation B_2	R^2	Monthly rate of change
				Percent
Appraised price	[1] 3.2408 (31.33)	0.0155 (3.62)	0.28	1.562
Overbid	3.5517 (46.67)	-0.0005 (.168)	0	[2] 0
Total bid	4.1429 (105.21)	0.0067 (4.09)	.33	.668
Road costs	1.5516 (11.18)	0.0003 (.06)	0	[2] 0
Logging cost	3.6193 (162.67)	0.0051 (5.54)	.47	.511
Manufacturing cost	3.862 (141.03)	0.0086 (7.58)	.63	.863
Selling price	4.8938 (202.74)	0.0082 (8.23)	.67	.825
Bid appraisal ratio	0.9021 (10.63)	-0.0088 (2.52)	.16	-.888

[1] Student t values appear in parentheses.

[2] Rates of change were not computed as the B_2 coefficient was not significant.

In the first hypothesis, overbid experienced no statistically significant real changes through time; hence, the hypothesis was accepted. The test of the hypothesis was based on the t statistic which can be interpreted as the estimated coefficient B_2, which at the usual levels of confidence, is in all likelihood equal to zero. The second hypothesis was also accepted, as the rate of real changes in total bid was less than the rate for appraised price. The B_2 coefficients in each equation were significant, and the computed rates of growth (following the procedure outlined in footnote 3) were 0.668 and 1.562 percent for total bid and appraised price, respectively.

Testing the third hypothesis is not as exact a process as testing the first two hypotheses. The rates of change for selling value, logging, road costs, and manufacturing costs were computed by the procedure outlined in footnote 3. No rates of change were computed for the profit and risk component, since the estimate (expressed in percentage) changes mainly through administrative action. The estimated rates support the hypothesis that rates of change in the appraised price vary directly with rates of change in major components. That is not to say that the rate of change for the appraised price is a weighted average of the rates of change for the components. Absolute change in the appraised price, however, is a weighted sum of changes in the components. There is a need to remember that rates of change are relative measures and that appraised price starts at a lower base. For example, a compound rate of change of 1 percent for 4 years in selling value ($159.00 to $165.50) might translate into a 4-percent change in the appraised price ($39.00 to $45.50) for the same period.

The fourth hypothesis was also accepted. Although the explanatory power of the equation was quite poor, the coefficient on time was statistically significant and was negative.

DISCUSSION

Both bid appraisal ratio and overbid measure competition, but the evaluation of how well depends on individual preferences. Some may prefer the bid appraisal ratio because it explicitly links total bid to appraised price. For example, a bid appraisal ratio of 2.5 implies that the premium for timber on a sale was 2.5 times the appraised price though nothing is known about the magnitudes of the sums involved. On the other hand, overbid is an absolute measure, but to gain the same information one would have to know the appraised price.

The key issue is whether the assigned rating is unique to each sale. From an analytical standpoint, this is critical because analysis of competition invariably involves data collected at different times. The findings for the west side of the Pacific Northwest Region imply that the bid appraisal ratio declines through time as the various components of the ratio experience differential rates of real increases. At the extreme, sales classified as competitive in 1974 might be classified as noncompetitive if they took place in 1977. The extent of the decline can be computed in an average sense. First, the bid appraisal ratio can be computed as:

$$B/A = B\,(1 + i_b)^n / A\,(1 + i_a)^n = \left[A\,(1 + i_a)^n + \emptyset\,(1 + i_o)^n \right] / A\,(1 + i_a)^n$$

$$= 1.0 + \left[\emptyset\,(1 + i_o)^n / A\,(1 + i_a)^n \right].$$

If the rates of increase in table 1 for i_a and i_o and the average overbid and appraised price are used, the initial bid appraisal ratio is 1.95 and the ratio at the end of the data period 1.49.

It is true that the 1969 sales in the data period were not equal and that the decline might reflect a lowering of sale quality or other changes over time, but the point remains that bidders did not adjust their real perceptions of the relationship between sales characteristics and overbid. That is, the premium they are willing to pay has remained the same in real terms. Total bid, however, has increased as bidders have compensated for real increases in product prices and processing costs.

This analysis emphasizes the care needed in selecting a measure of competition for empirical analysis. If the analysis involves sales from different years, then overbid is a more reliable measure. The bid-appraisal ratio has declined over time, and use of this ratio to measure competition over time may give misleading results. If the analysis involves only timber sales from the same time, either measure will do an adequate job. The bid-appraisal ratio may be preferred in this case since it provides more information about the timber sale.

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A 3-YEAR PATTERN OF DISPERSED RECREATION AND FOREST FIRES IN PACIFIC NORTHWEST FORESTS[1]

by Mack L. Hogans, Research Social Scientist

Abstract

An exploratory study was conducted to determine the role recreationists played in the cause and prevention of wildfires in dispersed areas of selected Pacific Northwest Forests for a 3-year period, 1975-77. The study revealed that recreationists played both a desirable and an undesirable role. It suggests that the desirable role can be enhanced through prescribed management and research. The implications of the findings for management and future research are presented.

KEYWORDS: Recreation use (-forest damage, recreationists, fire prevention, fire causes (forest), dispersed recreation.

INTRODUCTION

An integral part of public natural resource management is to provide wild-land recreation opportunities while minimizing losses from wildfires (Folkman 1972). To accomplish this goal requires sound information about the fire hazards (accumulation of fuels and difficulty of access for fire suppression activity) and risk (the activities of recreationists). Historically, dispersed recreation in undeveloped wild-land areas was perceived to be a high wildfire risk that caused widespread destruction of forests. Developed campgrounds and picnic sites originally emerged in this country as an attempt to concentrate recreationists and minimize fire danger associated with use of dispersed areas (Ellison 1942). Today, dispersed recreation--defined as day activities and camping at informal undeveloped recreation sites along roads (Hendee et al. 1976b) and in roadless areas--is very important. It is one of the fastest growing forms of outdoor recreation, and public demand is steadily increasing.[2] Resource managers are charged with meeting this demand through resource management programs that enhances opportunities for recreation.

The degree to which resource managers might encourage or discourage dispersed recreation may be affected in part by their perception of its impact on natural resources and related values because of the danger of wildfire. In the Pacific Northwest the forest fire danger associated with increasing levels of dispersed recreation is of widespread concern to management. A recent survey found that 86 percent of the key land managers in Oregon and Washington generally perceive the wildfire risk as one of

[1] This study was conducted under a cooperative research agreement between the USDA Forest Service and the University of Washington's College of Forest Resources.

[2] USDA Forest Service. An assessment of the Nation's renewable resources 1980: A resources planning act report draft summary. Washington, D.C.

the major problems of dispersed recreation (Downing and Moutsinas 1978). They have attempted to reduce the fire danger through costly prevention, regulation, and enforcement programs. As an example, in 1979 the USDA Forest Service will spend over $2.6 million on prevention of wildfire in Washington and Oregon alone. Furthermore, recreationists in the Pacific Northwest are required to have a shovel, a bucket, and an axe if they camp outside the developed sites on USDA Forest Service lands. Fire patrols routinely travel forest roads and trails as a means of discovering and suppressing wildfires in dispersed areas. They also remind recreationists to be careful with fire and issue citations to those who violate agency fire policy. An important issue is whether or not these programs are effective and if managers' perception of the fire danger associated with recreation use in dispersed areas is real (Downing and Moutsinas 1978). At stake are valuable natural resources, large sums of public money, and benefits to recreationists.

Despite the concern about the potential for large and costly wildfire from dispersed recreation, the reality of the risk from this use is generally unknown. Although much is known about the fire hazards in dispersed areas, only recently has research provided data on dispersed recreationists which can help to establish risk[3] (Hendee et al. 1976b). This Research Note provides additional insight on the recreationists' role in causing wildfires so that fire management and prevention programs will more clearly reflect the reality of the problem in dispersed areas.

In this Note, I describe the relationship between wildfires and recreation use in dispersed areas on selected National Forests in Oregon and Washington.[4] I compared data from forest fire reports for a 3-year period (1975-77) with information on recreation use for the same time on three National Forests. The purpose of the study was to determine the role recreationists played in the cause, cost, prevention, control, and reporting of wildfires in dispersed areas. Specific objectives were to answer the following questions: How many wildfires resulted from recreation use in dispersed areas over a 3-year period? How large were they? When did they occur? How long did it take to control them? What was the range of costs for controlling the wildfires? Who reported and discovered the wildfires? What were users' perceptions of danger of fire in these settings? And finally, what were their preferences for prevention measures?

Results of this study can help managers strengthen their fire management and prevention programs in dispersed areas; in addition, they may determine if their concern about the wildfire risk from dispersed recreation is warranted.

METHODOLOGY

Individual fire reports from Forests on the study area were the principal source of data. These reports were completed by USDA Forest Service personnel each time a wildfire was discovered and suppressed in dispersed areas. We used six categories of information on a fire from the individual reports: (a) cause; (b) size; (c) time of discovery (hour, day, month); (d) amount of time required to control the fire; (e) cost for controlling; and (f) who discovered and reported the fire.

The fire reports were collected and aggregated from the Mount Baker-Snoqualmie, the Wenatchee, and the Mount Hood National Forests. The reports were then summarized. The cause of the fire was

[3] Clark, Roger N., Russell W. Koch, Mack L. Hogans, and Harriet H. Christensen. A profile of dispersed recreationists along forest roads in three forest areas of the Pacific Northwest: Their recreation patterns, opinions, and attitudes. Unpublished data on file at Wildland Recreation Research Project, Seattle, Wash.

[4] It is important to note that developed recreation sites on Forest Service lands have been fireproofed. Technically, no fire reports are made even if wildfires occur there. Because of this, it was impossible to compare the incidence of wildfires in developed areas with wildfires in dispersed areas.

The risk of large and costly wildfires from recreation use in dispersed areas is a major concern to resource managers.

compared with the other categories listed above. These data were supplemented with survey data on dispersed recreationists in selected drainages of the three Forests (see footnote 3).

Study Areas

The three Forests represented a cross-section of Forests in the Pacific Northwest where much dispersed recreation took place and the number of recorded wildfires was high.

Mount Baker-Snoqualmie National Forest:--The Mount Baker-Snoqualmie is located on the west side of the Cascade Range in western Washington. It is considered an urban Forest, drawing heavily on residents from the metropolitan Seattle area. It contains 1,128 miles of hiking, horseback riding, and motorized vehicle trails; and over 3,800 miles of forest roads where much dispersed recreation takes place. Dispersed recreation for the 3-year study period on the Mount Baker-Snoqualmie exceeded 5.2 million visitor-days.

Wenatchee National Forest:--The Wenatchee is located in the geographical center of Washington State. It contains 2,482 miles of trails for hiking, horseback riding, and motorized vehicle use. It has over 3,000 miles of forest roads and is just under a 2-hour drive from metropolitan Seattle. For the study period, dispersed recreation reached 9.9 million visitor-days.

Mount Hood National Forest:--Located in north-central Oregon, the Mount Hood is a little over a half-hour drive east from metropolitan Portland. The Forest lies on both sides of the Cascade Range; about 70 percent of its land area is on the west slope and the remainder on the east. It has 1,163 miles of hiking, horseback riding, and motorized trails, and just over 3,000 miles of forest roads. For the study period, 5.6 million visitor-days of dispersed recreation were recorded.

FINDINGS OF THE STUDY

The major findings are summarized and supported with tables. Then they are discussed, and implications for management and research are suggested. Finally, conclusions are drawn.

Wildfires caused by recreation were small.--Tables 1 and 2 show that recreation use was responsible for many small wildfires during the study period (1975-77). Of the 1,130 wildfires reported on the three Forests, 39 percent were the result of recreational activity in dispersed areas. Escaped, abandoned, or smoldering campfires were the leading cause, followed by smoking and miscellaneous activity (origin or cause generally unknown or undetermined). Recreation played only a minor role in wildfires resulting from use of equipment, burning debris, incendiary (deliberately set) fires, and children's activities. Fires by children in dispersed settings resulted from their playing with matches and fireworks.

Even though recreational activity in dispersed areas accounted for 39 percent of all reported wildfires, the overwhelming majority of these fires (93 percent) burned an area less than one-quarter acre (table 2). Many (number undetermined because of the inconsistency of reporting procedures) were "spot fires" that burned an area no larger than the size of the causative agent, such as a cigarette or a spark from a controlled campfire.

It is important to note some of the circumstances surrounding the reporting of fire statistics in the campfire categories (98 percent of total recreation-caused wildfires). If an unattended campfire is discovered by USDA Forest Service patrols in dispersed areas, they usually extinguish the fire and make a report even if the fire had not escaped. This may happen even if the recreationist has left the campsite for only a few minutes; e.g., to hike to a nearby stream within view of the campsite. Similarly, some recreation campsites in dispersed areas are located away from heavy fuels, such as gravel bars and deserted log landings, and pose little wildfire danger. Nevertheless, many times formal fire reports are made even for smoldering campfires which have little chance for escape. In some instances, formal fire reports are made of campfires in the presence of users who do not have a shovel, a bucket, and an axe in dispersed settings.

Table 1--Number and percent of wildfires, by cause and use, on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, 1975-77

Cause	Recreation use		Nonrecreation use		Total	
	Number	Percent	Number	Percent	Number	Percent
Campfires	287	98	5	2	292	26
Smoking	97	79	26	21	123	11
Miscellaneous	33	41	47	59	80	7
Children	10	50	10	50	20	2
Use of equipment	9	23	31	78	40	4
Incendiary	5	33	10	67	15	1
Burning of debris	2	2	80	98	82	7
Lightning	0	0	444	100	444	39
Railroad	0	0	34	100	34	3
Total and average	443	39	687	61	1,130	100

Table 2--Number and percent of recreation-caused wildfires on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, by size of fire, 1975-77

Cause	Size class (number of acres)										Total Total	
	A (0.25 or less)		B (0.26-9)		C (10-99)		D (100-299)		E (300-999)			
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfire	263	92	20	7	1	0	1	0	2	1	287	65
Smoking	95	98	2	2							97	22
Miscellaneous	29	88	4	12							33	7
Children	9	90	1	10							10	2
Use of equipment	9	100									9	2
Incendiary	5	100									5	1
Burning of debris	2	100									2	0
Total and average	412	93	27	6	1	0	1	0	2	1	443	100

Without this equipment on site, the campfire is determined "uncontrolled" even though recreationists are present. The full extent to which the above is happening is not fully known but it has important implications for management, especially about fire danger based on raw data.

Even though recreation-caused fires were generally small, there is the potential for large recreation-caused wildfires in dispersed areas. Seven percent of the recreation-caused wildfires ranged in size from class B to E (0.26 to 999 acres). Escaped campfires and miscellaneous recreational fires led in these size classes.

Some impromptu recreation sites in dispersed settings are located away from heavy fuels and pose little risk of wildfire.

Recreation-caused wildfires required relatively little time and cost to be brought under control.--Of the 443 reported recreation-caused wildfires, 71 percent were brought under control in less than 1 hour (table 3). Over one-third (35 percent) were controlled in less than 15 minutes. A large proportion (69 percent) cost less than $100 in personnel time and suppression equipment to be brought under control (table 4). Many of these were probably abandoned or unattended campfires.

Only a few recreation-caused wildfires in dispersed areas required considerable time and cost to be brought under control. The more costly fires were of class size B and larger, and most were on the Wenatchee National Forest which is considered a dry and hazardous fire area in the semiarid region of Washington State.

A comparison of recreation-caused with nonrecreation-caused wildfires shows that nonrecreation-caused wildfires tend to be larger and more costly (table 4); however, the relative differences are not great. The majority of recreation-caused wildfires cost less than $100 to be brought under control, whereas most of the nonrecreation-caused wildfires cost between $100 and $500. Because of USDA Forest Service fire reporting procedures and changes in the fire budgeting process during the study period, actual costs for the control of wildfires could not be determined. The figures presented here, however, represent an accurate range of costs for control efforts.

Recreation-caused wildfires were strongly related to times and locations of heavy use of areas of dispersed recreation.--Not surprisingly, the greatest incidence of recreation-caused wildfires (88 percent) on the three Forests occurred in the summer and fall months of June through October (table 5). These months have the most recreation use and are the most hazardous for fire in the Pacific Northwest. Typically, campfires and smoking associated with hunting, fishing, and firewood gathering in dispersed areas cause most of the wildfires related to recreation in the months of November and December.

Almost two-thirds (66 percent) of all recreation-caused wildfires were discovered either during or shortly after weekends (table 6). This finding is no surprise and is consistent with the observation that dispersed recreation use peaks on weekends (Hendee et al. 1976b). Many of the wildfires discovered during weekdays occurred in late summer and during the fall hunting season.

Generally, recreation-caused wildfires were found at low to middle elevation ranges (table 7); 61 percent were in the 1,500 to 3,500-foot range. The number of recreation-caused wildfires was dramatically lower at higher levels. This was not surprising because most dispersed recreation use takes place at lower levels (Hendee et al. 1976b), and less fuels and fewer roads are found at higher elevations.

Recreationists play a major role in discovering and reporting wildfires in dispersed areas.--Recreationists in dispersed settings actually discovered and reported a substantial number (26 percent) of wildfires during the 3-year period (table 8). They discovered and reported two-thirds as many wildfires (from all causes) as they reportedly caused. A striking observation is that they discovered and reported more wildfires than fire patrols did (10 percent more). Fire patrols surpassed recreationists in the discovery of wildfires for only one category (campfires). As a general rule, recreationists are more mobile and outnumber fire patrols in dispersed areas; therefore, they have more opportunities to discover wildfires. The discovery and reporting of wildfires in dispersed areas by recreationists suggest that they are concerned about fire danger.

The greatest number of recreation-caused wildfires were discovered between 1 and 4 p.m. and between 9 a.m. and noon. Discovery time in many of these instances was related to routine fire patrol schedules rather than the recreationist's use of fire. It should be noted, however, that 10 percent of the recreation-caused wildfires were discovered between the hours of 6 p.m. and 6 a.m. when fire patrols are usually off duty. This suggests that recreationists who are in dispersed settings also discover and report wildfires during times when it

Table 3--Number and percent of recreation-caused wildfires on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, by length of time to control the fires, 1975-77

Cause	Length of time required to control wildfires (minutes)									
	0-15		16-30		31-60		61-90		91-120	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	106	37	48	17	59	21	23	8	17	6
Smoking	33	34	16	16	22	23	15	15	4	4
Miscellaneous	11	33	4	12	6	18	6	18		
Children					1	10	5	50	3	30
Use of equipment	2	22	2	22	2	22			1	11
Incendiary	2	40	2	40					1	20
Burning of debris							1	50		
Total and average	154	35	72	16	90	20	50	11	26	6

Cause	121-150		151-180		Over 180		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	9	3	7	2	18	6	287	65
Smoking	2	2			5	5	97	22
Miscellaneous	1	3			5	15	33	7
Children			1	10			10	2
Use of equipment					2	22	9	2
Incendiary							5	1
Burning of debris			1	50			2	0
Total and average	12	3	9	2	30	7	443	100

Table 4--Number and percent of recreation- and nonrecreation-caused wildfires on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, by costs for control, 1975-77

Cause	Costs for controlling wildfires, in dollars												Total	
	0-100		101-500		501-1,500		1,501-5,000		5,001-25,000		over 25,000			
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	206	72	51	18	17	6	6	2	3	1	4	1	287	65
Smoking	63	65	21	22	9	9	4	4					97	22
Miscellaneous	20	61	7	21	5	15	1	3					33	7
Children	7	70	3	30									10	2
Use of equipment	4	44	4	44			1	11					9	2
Incendiary	4	80					1	20					5	1
Burning of debris	1	50	1	50									2	0
Total recreation-caused wildfires and average percent	305	69	87	20	31	7	13	3	3	1	4	1	443	100
Total nonrecreation-caused wildfires and average percent	171	25	317	46	112	16	59	9	15	2	13	2	687	100

Table 5--Number and percent of recreation-caused wildfires on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, by month, 1975-77

Cause	March		April		May		June		July		August	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	1	0	3	1	11	4	24	8	83	29	50	17
Smoking					3	3	8	8	28	29	22	23
Miscellaneous			1	3	1	3	6	18	14	42	3	9
Children							4	40	4	40	2	20
Use of equipment					1	11			4	44	1	11
Incendiary			1	20			1	20	1	20	1	20
Burning of debris											1	50
Total and average	1	0	5	1	16	4	43	10	134	30	80	18

Cause	September		October		November		December		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	56	20	38	13	19	7	2	1	287	65
Smoking	16	16	14	14	6	6			97	22
Miscellaneous	6	18	2	6					33	7
Children									10	2
Use of equipment	2	22	1	11					9	2
Incendiary	1	20							5	1
Burning of debris					1	50			2	0
Total and average	81	18	55	12	26	6	2	0	443	100

Table 6--Number and percent of recreation-caused wildfires on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, by day of week, 1975-77

Cause	Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday		Monday		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	27	9	23	8	21	7	29	10	45	16	90	31	52	18	287	65
Smoking	5	5	5	5	11	11	7	7	23	24	28	29	18	19	97	22
Miscellaneous	6	18	2	6	3	9			5	15	13	39	4	12	33	7
Children	1	10	2	20	1	10			2	20	3	30	1	10	10	2
Use of equipment	1	11	1	11	1	11			3	33	2	22	1	11	9	2
Incendiary					1	20	1	20			2	40	1	20	5	1
Burning of debris							1	100							2	0
Total and average	40	9	33	7	38	9	39	9	78	18	138	31	77	17	443	100

Table 7--Number and percent of recreation-caused wildfires on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, by elevation, 1975-77

Cause	Elevation (feet above sea level)									
	0-500		501-1,500		1,501-2,500		2,501-3,500		3,501-4,500	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	2	1	20	7	80	28	88	31	55	19
Smoking			4	4	34	35	32	33	16	17
Miscellaneous			6	18	12	36	9	27	6	18
Children			1	10	8	80			1	10
Use of equipment	1	11			3	33	1	11	3	33
Incendiary			1	20	1	20	2	40		
Burning of debris					1	50			1	50
Total and average	3	1	32	7	139	31	132	30	82	19

Cause	4,501-5,500		5,501-6,500		6,501-7,500		7,501-8,500		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	34	12	7	2			1	0	287	65
Smoking	8	8	3	3					97	22
Miscellaneous									33	7
Children									10	2
Use of equipment	1	11							9	2
Incendiary	1	20							5	1
Burning of debris									2	0
Total and average	44	10	10	2			1	0	443	100

Table 8--Number and percent of wildfires discovered and reported by recreationists, fire patrols, and others on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests, 1975-77

Cause	Recreationists		Fire patrols		Others		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Campfires	85	29	96	33	111	38	292	26
Smoking	46	37	25	20	52	42	123	11
Miscellaneous	40	50	10	13	30	38	80	7
Children	13	65			7	35	20	2
Use of equipment	19	48	1	3	20	50	40	4
Incendiary	9	60	1	7	5	33	15	1
Burning of debris	26	32	6	7	50	61	82	7
Lightning	47	11	37	8	360	81	444	39
Railroad	13	38	2	6	19	56	34	3
Total and average	298	26	178	16	654	58	1,130	100

is impractical for agency officials to be on duty. Recreationists may also extinguish wildfires caused by other recreationists or by natural causes, such as lightning, but not report this action to agency personnel. The Wildland Recreation Research Project witnessed this behavior on several occasions during the 1976 field season. The full extent to which this occurs is not known.

Users' perception of fire danger and fire prevention measures.--Table 9 and 10 show results of a recent survey conducted on selected drainages on the three Forests to determine recreationists' perception of fire danger in dispersed settings (see footnote 3, page 2).

Overnight users and day user had somewhat different perceptions of fire danger from dispersed recreation (table 9). Experience with fire and familiarity with dispersed recreation areas are important explanation variables for users' perception of fire danger. For example, impromptu campsites, where much overnight use occurs, are generally found near water (streams, lakes). And overnight users are required to have firefighting equipment on hand before they can camp. The security of easy access to water and firefighting equipment may shape the perception of overnight users about the lack of fire danger. Weather conditions and season of the year can also influence users' perception.

Table 10 shows that both day and overnight users had fairly close agreement on their views about appropriate fire prevention measures in dispersed settings. Agreement was strong among users that recreationists should carry a shovel, a bucket, and an axe in dispersed areas. Users also felt strongly that installing fire prevention signs, closing some roads, and even prohibiting fires when danger is high were acceptable prevention measures. There was moderate to strong opposition, however, to increasing fire patrols and closing entire areas. There may be several reasons for this opposition.

Closing an entire area may be viewed as a drastic measure--and unwarranted--based on the recreationists' experience with fire in dispersed settings. It is the only option among the six in table 10 that suggests permanency of closures and prohibition of fire use.

Increasing the frequency of fire patrols may be seen as a more direct attempt to regulate the use of fire and other desired activities of recreationists in dispersed areas; their voluntary options are displaced by this selection--a notion that may be unacceptable to users. This type of high visibility management is more characteristic of developed recreation areas.

DISCUSSION AND IMPLICATIONS FOR MANAGEMENT AND RESEARCH

Data from this study have important implications for management and research. They are discussed below.

Management's perception of fire danger from dispersed recreation.--The risk of wildfire from dispersed recreation is clearly established by data from this study; i.e., some wildfires occur as a result of this use. This would suggest that management's concern about this use is sometimes justified and restricting it under hazardous conditions is warranted. This suggestion, however, must be put in perspective.

Many recreation-caused wildfires were small spot fires. Only 7 of 100 went on to burn an area larger than one-quarter acre. Over half were controlled in less than 30 minutes. Even though a few fires were expensive to put out, more than two-thirds cost less than $100 to be brought under control. Furthermore, recreationists discovered and reported two-thirds as many wildfires (from all causes) as they reportedly caused. We also know--but not to what extent--that, during the same time, recreationists safely used, enjoyed, and suppressed a large number of campfires and cooking and warming fires. It appears that an irresponsible few are to blame for the fire problem in dispersed areas. In view of this, a reexamination of managers' perception of fire danger from recreation use in dispersed areas is warranted. This suggests the need for management strategies that consider the benefits dispersed recreationists provide to management in fire prevention.

From a management standpoint, any

Table 9--Percent of agreement that there is a great danger of recreationists accidentally starting a forest fire in dispersed recreation area drainages on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests

Type of user	Disagree	Neutral	Agree
Overnight users (N=884)	48	17	35
Day users (N=1224)	34	18	48

Source: Clark, Roger N., Russell W. Koch, Mack L. Hogans, and Harriet H. Christensen. A profile of dispersed recreationists along forest roads in three forest areas of the Pacific Northwest: Their recreation patterns, opinions, and attitudes. Unpublished data on file at Wildland Recreation Research Project, Seattle, Wash.

Table 10--Percent of agreement of recreationists' preferences of fire prevention measures in dispersed recreation area drainages on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests

Fire prevention measure	Overnight user (N=884)	Day user (N=1224)
Carry shovel, bucket, and axe	91	87
Prohibit fires when danger is high	81	86
Install prevention signs	88	86
Increase fire patrols	51	50
Close entire area	37	48
Close some roads if danger is high	80	85

Source: Clark, Roger N., Russell W. Koch, Mack L. Hogans, and Harriet H. Christensen. A profile of dispersed recreationists along forest roads in three forest areas of the Pacific Northwest: Their recreation patterns, opinions, and attitudes. Unpublished data on file at Wildland Recreation Research Project, Seattle, Wash.

recreation-caused wildfire in dispersed areas is undesirable because of its potential to spread. Data from this study suggest that a more reasonable fire management goal would be to reduce and eliminate the recreation-caused wildfires in dispersed areas that reach size class B and larger. A companion goal would be to reduce and eliminate all size class A wildfires burning beyond campfire rings that would rapidly spread and become size class B or larger fires. To make this distinction, however, would require collecting additional information for the formal fire reports.

Wildfire reporting procedures.--The current form and procedure for reporting wildfires is limited in producing data to help establish risk of wildfire from dispersed recreation; for example, precise measurements of the area burned from recreation-caused wildfires would be useful. It is also desirable to know if the fires were within fire rings, if they were left unattended, or if users were on the site but without the proper equipment, and so forth. The current reporting system excludes these data.

There is a need to integrate fire management functions with those of recreation planning and research. Research is learning more about users in dispersed areas, and supplemental data about the reported fires would be valuable in developing composite solutions to the wildfire problem. For example, the relationship between fire characteristics and established recreation site characteristics is an important link in understanding and controlling recreation-caused wildfires. A dispersed recreation management and research tool called Code-A-Site (Hendee et al. 1976a) can be used in conjunction with data from fire reports to fill this need. Code-A-Site provides an inventory of dispersed recreation sites and their characteristics and provides a trace measurement of recreational behavior on sites. Whenever possible, wildfire reports should be keyed to the closest informal recreation site identified in the Code-A-Site system.

Positive role of recreationists in fire prevention.--The supportive role that recreationists play in preventing wildfires provides an immediate opportunity for management to implement programs that make this role and behavior more effective. This study found that recreationists in dispersed areas reported a large number of wildfires from recreation and nonrecreation causes. It is conceivable that they also extinguished other wildfires that were never reported. This suggests that many recreationists are inclined to support putting out fires, including ones they did not start. The key is to cultivate and manage this support in a way that fire management goals can be met through intervention of recreation users.

Most USDA Forest Service fire prevention programs are aimed at making people aware of the safe use of fires during their visits to a Forest. This study suggests the need for programs that support and encourage recreationists to quickly report and possibly extinguish any wildfires they discover. Such programs may contribute to a reduction in the size and incidence of wildfires in dispersed areas, since many recreationists have demonstrated their desire and support for this activity. Management and research should develop programs that support the training of recreationists to accomplish this safely and effectively. Developed properly, such a program could save substantial fire prevention and suppression costs while enhancing users' benefits. Recreationists can become useful partners in fire management with the USDA Forest Service. As a general rule, dispersed recreationists are more mobile than USDA Forest Service patrols; if they are going to be traveling roads and exploring in dispersed areas, then management should capitalize on this behavior to strengthen the fire prevention program.

Management and research should also focus on shaping the perception of users in dispersed areas who feel there is only minimal danger of wildfires occurring in these settings. There is a need to stimulate greater vigilance in recreationists to be aware of the fire danger and react in an appropriate manner.

Research needs.--Additional research is needed on the role of dispersed recreationists in wildfire activity to support management programs and benefits

The use of fire appears to be an important part of the recreational experience for recreationists in dispersed areas.

to recreation users. This study raised some important questions that may be answered through additional research:

1. What is the relationship between recreation-caused wildfires and amount of recreation use? Is there an optimal level of recreation use to minimize wildfires? Data from this study suggest that size of wildfires in dispersed areas may actually decrease as levels of use increase since recreationists report (and possibly suppress) wildfires. Experimentation provides an opportunity to test this notion.

2. What potential impacts does restricting the use of fires in dispersed areas have on the experience of users? What are effective ways of reducing the incidence of fires while retaining the integrity of dispersed areas (different from developed "fireproofed" areas) for users' benefits? What uses, needs, and benefits do recreationists experience from fire in dispersed areas? When, why, and how do they use fire?

3. What is recreationists' knowledge of safe use of fire in dispersed areas? Do they know their role in reporting and extinguishing wildfires from other sources? What are effective programs to fill these gaps in information on this problem?

Results of this proposed research could strengthen management-oriented programs to reduce the incidence of recreation-caused wildfires in dispersed areas.

CONCLUSIONS

This study examined the relationship between wildfires and recreation use in dispersed areas on the Mount Baker-Snoqualmie, Wenatchee, and Mount Hood National Forests for a 3-year period, 1975-77. It revealed many of the roles recreationists played in the cause, cost, and prevention of wildfires in dispersed settings. The data showed that recreationists played both a desirable and an undesirable role in this activity. Although data for 3 years on three Forests cannot represent all possible situations, the patterns shown by these data are sufficiently clear to draw the following conclusions (caution should be used in generalizing beyond the study areas and time periods):

Recreation use in dispersed areas can lead to wildfires; but most of them will be small, and many will be discovered and reported by other recreationists. Furthermore, most of these fires will be controlled quickly with relatively little cost to the agency. Generally, recreationists perceive dispersed settings as having low to moderate fire danger and are supportive of most USDA Forest Service policies, except closing entire areas and increasing fire patrols. Additional management and research programs can lead to a reduction of the risk associated with recreation use in dispersed areas.

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Metric Equivalents

1 inch = 2.54 centimeters
1 mile = 1.609 kilometers
1 acre = 0.405 hectare
32°F = 0°C

GPO 989-030

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RESPONSE OF THINNED PONDEROSA PINE TO FERTILIZATION

by P. H. Cochran, *Principal Reasearch Soil Scientist*

ABSTRACT

Rates of height, basal area, volume, and bole area growth of thinned ponderosa pine were increased more than 50 percent by applications of nitrogren, phosphorus, and sulfur during the first 5-year period after application. Height growth was not related to stand density, but rates of volume and bole area growth were definitely correlated with basal area at the start of treatment.

KEYWORDS: Fertilizer response (forest tree), increment (volume), increment (height), ponderosa pine, *Pinus ponderosa*.

INTRODUCTION

How fast will thinned ponderosa pine (*Pinus ponderosa*) stands grow when fertilized repeatedly? This question becomes increasingly important as the land base available for intensive timber management continues to shrink while rising energy costs escalate prices of fertilization and other stand treatments. Both thinning and fertilization can substantially increase growth of remaining trees in the stand (Barrett 1973, Cochran 1978). Fertilization without thinning is not recommended since much of the increased growth may be by trees that will never reach marketable size. Response to fertilization lasts at least 4 years and possibly more than 8 years on some sites (Cochran 1977). To attempt to improve growth, I applied moderate amounts of fertilizer at 5-year intervals to plots in a ponderosa pine stand that had been precommercially thinned. The stand is representative of large areas on the Deschutes National Forest in central Oregon. This note compares growth rates of the fertilized and unfertilized treatments for the first 5-year period after initial application.

METHODS OF STUDY

Study Area

The study area is located approximately 20 miles south of Bend, Oregon.[1] Elevations range from 4,400 to 4,600 feet. Summers are very dry, and annual precipitation is approximately 24 inches. Topography of the area is gently sloping (2 to 7 percent), mostly to the west. The soil (Shanahan series) is a Typic Cryandept developing on Mazama pumice and ash.[2] The A1 horizon is 2 inches

[1]For metric equivalents, see page 8.

[2]For chemical and physical properties of some Shanahan soils, see Cochran (1973, 1977).

thick, and the AC horizon overlies an older, buried sandy loam at 26 to 32 inches. The predominant understory shrub is bitterbrush (*Purshia tridentata*), but some manzanita (*Arctostaphylos patula*) and snowbrush (*Ceanothus velutinus*) shrubs are present. Fescue (*Festuca idahoensis*) and needlegrass (*Stipa occidentalis*) are the predominant grasses.

The area was railroad logged in the 1920's, and the present stand had an average breast-high age of 34 years in 1974. Site index varies from 84 to 108 feet over the study site (Barrett 1978). The stand was thinned to an average spacing of about 17 feet (151 trees/acre) in 1972, and the slash was tomahawked in the late summer and fall of 1973.[3] The slash treatment reduced the understory vegetation to less than 5-percent cover.

Design and Installation

A completely randomized design with two treatments (control and fertilization) was installed. Twenty-four 0.2-acre plots with 33-foot buffer strips were established in the fall of 1973. Additional thinning was done on some of the plots and their buffer strips to provide a wider range in stand densities than normally found after precommercial thinning. Trees were tagged, d.b.h.'s were measured, and the basal areas were calculated for each plot. Twelve plots were randomly chosen for fertilization. Just before snowfall in 1973, nitrogen (N), phosphorus (P), and sulfur (S) at rates equivalent to 200 lb/acre N, 100 lb/acre P, and 33 lb/acre S were applied to each of these plots in the form of ammonium sulfate, urea, and triple super phosphate.[4]

[3]Tomahawking is a method for reducing fire hazard in slash by mechanical crushing with an implement called "Tomahawk" mounted on the front of a crawler tractor (Dell and Ward 1969).

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[4]Triple super phosphate also contains 12 percent calcium and 1 percent sulfur. Calcium is not a limiting element in this soil.

Measurements

At least 15 trees in each 0.2-acre plot were measured in the fall of 1973 and again in the fall of 1978 with optical dendrometers. Trees selected for measurement with a dendrometer encompassed the range of diameter classes. All forked trees were also measured with a dendrometer. Heights (h) of all trees not measured with dendrometers were measured with height poles. Diameter tapes were used for all d.b.h.'s (d). Volumes and bole areas above a 1-foot stump for the trees measured with a dendrometer were determined by Grosenbaugh's (1967) STX program with a modification of one of Brickell's (1970) equations to convert diameters outside bark to diameters inside bark (Cochran 1976). Equations relating volume (V) and bole area were developed from the nonforked trees measured with a dendrometer on each plot at the start and also at the end of the first 5-year period:

$$V = a + b\,(d^2h);$$

$$\text{Bole area} = a_1 + b_1\,(dh);$$

where

a, b, and a_1 and b_1 are regression coefficients.

These equations were then used to determine volumes and bole areas for trees on corresponding plots not measured with optical dendrometers. Basal areas, bole areas, volumes, heights, and diameters were computed for each plot at the end of the growing seasons in 1973 and 1978 (tables 1 and 2), and differences divided by 5 were used for average annual growth rates.

Statistical Analysis

Analysis of covariance was used to test the hypothesis that fertilization did not increase growth. The covariate was basal area at the start of the 5-year growing period. At 5-percent level of probability was chosen for determining significant differences in slopes or adjusted means.

Table 1--Some estimates for the fertilized and control plots at the start of the study

Plot number	Basal area	Bole area[1]	Volume[1]	Average height	Average diameter[2]	Trees per acre
	Square feet per acre		Cubic feet per acre	Feet	Inches	Number
Fertilized:						
11	80.5	10,094.5	1,184.0	39.5	7.9	225
1	78.0	8,744.0	1,151.5	39.4	8.7	180
18	67.0	7,801.5	958.5	39.0	8.4	170
10	64.5	7,951.0	1,020.0	41.3	8.6	155
2	55.5	6,002.0	721.5	34.4	8.0	150
13	51.0	6,737.5	719.5	38.5	7.5	165
22	45.8	5,319.0	585.0	33.6	7.3	150
24	45.5	5,201.5	584.5	33.1	7.3	150
17	41.0	4,492.0	492.5	31.3	7.2	140
9	39.5	4,832.0	511.5	34.2	7.0	140
20	29.8	3,323.5	345.0	32.9	7.3	100
15	28.1	3,071.5	320.5	30.5	7.1	100
Control:						
21	79.5	9,177.0	1,061.5	36.4	7.9	225
19	79.0	8,792.0	1,126.5	37.0	8.2	200
12	63.0	8,166.0	943.5	42.1	8.2	170
3	62.5	6,793.3	859.5	34.8	7.9	170
5	60.5	6,148.5	740.0	33.4	8.0	165
4	54.5	5,979.0	756.0	34.9	8.2	140
23	54.5	5,847.0	633.0	32.3	7.2	180
7	48.5	6,084.0	678.0	37.0	7.5	150
16	41.5	4,647.0	509.0	32.2	7.2	140
8	35.0	4,404.5	449.0	33.8	6.7	135
14	27.0	3,115.5	338.5	30.9	6.8	100
6	23.5	2,811.0	269.5	30.4	6.5	100

1/ Values do not include bole areas and volumes of 1-foot stumps.

2/ This diameter is the actual mean diameter and is not the diameter derived from the average basal area.

Table 2--Some estimates for the fertilized and control plots 5-growing seasons after the start of the study

Plot number	Basal area	Bole area[1]	Volume[1]	Average height	Average diameter[2]	Trees per acre
	Square feet per acre		Cubic feet per acre	Feet	Inches	Number
Fertilized:						
11	106.0	13,125.5	1,744.0	45.1	9.1	225
1	95.0	11,125.0	1,610.0	44.9	9.6	180
18	90.0	10,151.0	1,400.5	44.8	9.7	170
10	85.0	10,367.5	1,510.5	47.1	9.9	155
2	80.5	8,475.0	1,222.5	41.0	9.7	150
13	70.0	9,094.0	1,141.0	43.4	8.8	165
22	65.0	7,264.5	922.0	39.3	8.8	150
24	63.0	7,201.5	944.0	38.5	8.6	150
17	59.0	6,132.0	771.0	36.7	8.7	140
9	58.5	6,833.5	880.5	40.0	8.5	140
20	47.5	5,041.0	663.0	39.4	9.3	100
15	46.5	4,540.5	615.5	36.9	9.2	100
Control:						
21	95.5	11,041.0	1,385.0	40.9	8.7	225
19	93.0	10,331.0	1,403.0	40.9	8.9	200
12	74.5	9,625.0	1,199.0	46.1	9.1	170
3	77.0	8,240.0	1,107.5	38.3	8.8	170
5	75.5	7,703.0	1,008.0	37.6	8.9	165
4	67.5	7,059.0	948.0	39.5	9.2	140
23	69.0	7,358.0	884.5	35.9	8.2	180
7	61.0	7,488.0	934.0	40.8	8.5	150
16	57.0	6,107.0	777.5	36.4	8.5	140
8	44.0	5,390.0	618.5	33.6	7.5	135
14	36.0	3,764.0	477.0	34.4	7.3	100
6	34.0	3,657.5	411.0	32.3	7.8	100

1/ Values do not include bole areas and volumes of 1-foot stumps.

2/ This diameter is the actual mean diameter and is not the diameter derived from the average basal area.

RESULTS AND DISCUSSION

The average and range of correlation coefficients (r^2) and standard errors for the volume and bole area equations determined for 20 of the 24 plots were:[5]

	1974	
	r^2	Standard error ft^3/acre per year
Volume:		
Average	0.9671	0.46
Range	0.8885-.9975	0.22-.70
		ft^2/acre per year
Bole area:		
Average	.9723	2.3
Range	.9288-.9952	1.1-3.3

	1978	
	r^2	Standard error ft^3/acre per year
Volume:		
Average	0.9693	0.63
Range	0.8925-.9936	0.26-1.37
		ft^2/acre per year
Bole area:		
Average	.9795	2.6
Range	.9411-.9941	1.3-4.7

These high r^2 values and low standard errors indicate that the predictive equations for volume and bole area, developed from a subsample of 15 trees on each plot, were adequate for determining volumes and bole areas of the remaining plot trees.

As expected, no mortality occurred during the 5-year period after initial treatment. Fertilization significantly increased all determined growth rates, including height (figs. 1-4). Adjusted means of average annual growth rates for the control and fertilization treatments were:

	Control	Fertilized	Increase (Percent)
Volume growth (ft^3/acre per year)	46.4	80.6	74
Basal area growth (ft^2/acre per year)	2.6	4.0	54
Bole area growth (ft^2/acre per year)	262.9	429.8	63
Height (ft/year)	.74	1.15	55

[5]/ Four plots had just 20 trees (100 trees/acre, tables 1 and 2). All the trees in these plots were measured with dendrometers, and no equations were necessary for total volumes and bole areas.

Average annual height growth ranged from 0.4 to 0.9 foot/year for the control plots and 1 to 1.3 feet/year for the fertilized plots.

The relationship of height growth to stand density during this initial 5-year period is not clear (fig. 4). Above initial densities of 40 square feet of basal area per acre, height growth on control plots appears unaffected by initial density. At lower densities, height growth may have been reduced on the control plots. Oliver (1979) observed height growth of pole-size ponderosa pine in California over a 15-year period. He found that for the first 5-year period after thinning, there was no correlation between height growth and stand density. During the second 5-year period, there was a tendency for height growth to be reduced by stand density; but the correlation was not statistically significant. For the third 5-year period after thinning, height growth significantly decreased with stand basal area.

The significant increases in growth obtained in this study resulted from a combination of N, P, and S. Results from another study (Cochran 1978) show that most of the response is due to nitrogen. In that study, S and P in combination with N tended to increase volume production; but increases in volume were not significant at the 5-percent level of probability. Further evidence from the earlier study suggests but does not conclusively prove that S is more important than P (in combination with N) for increasing volume production. For land managers wishing to fertilize thinned ponderosa pine stands on soils developing from Mazama pumice or ash, I tentatively recommend a single application of 200 pounds of elemental N and 30 pounds of elemental S per acre. This recommendation may change as results from continued studies become available. Foresters can expect definite responses to N and S, noticeable on increment cores, which will last at least 5 years and possibly more than 8.

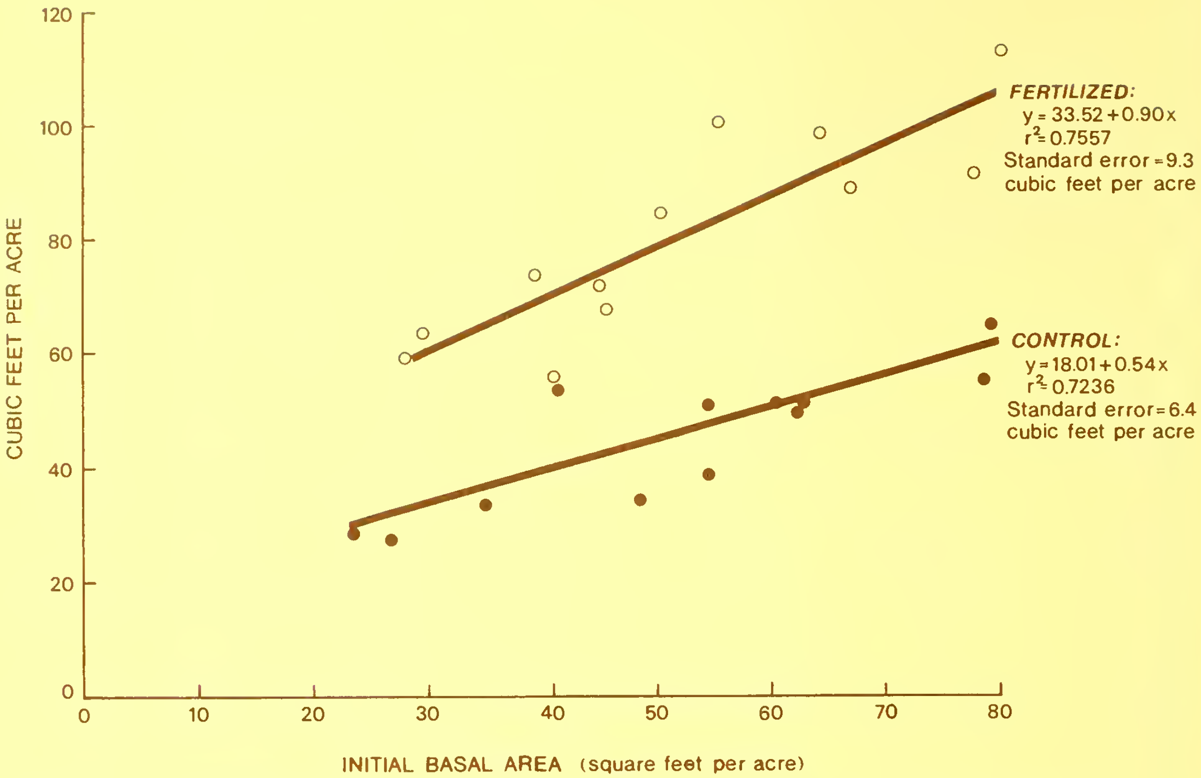

Figure 1.--Average annual volume growth during the 1974-78 growing seasons as a function of basal area at the start of 1974. Differences in slopes of the regression lines are not significant, but the adjusted mean for the fertilizer treatment is significantly greater.

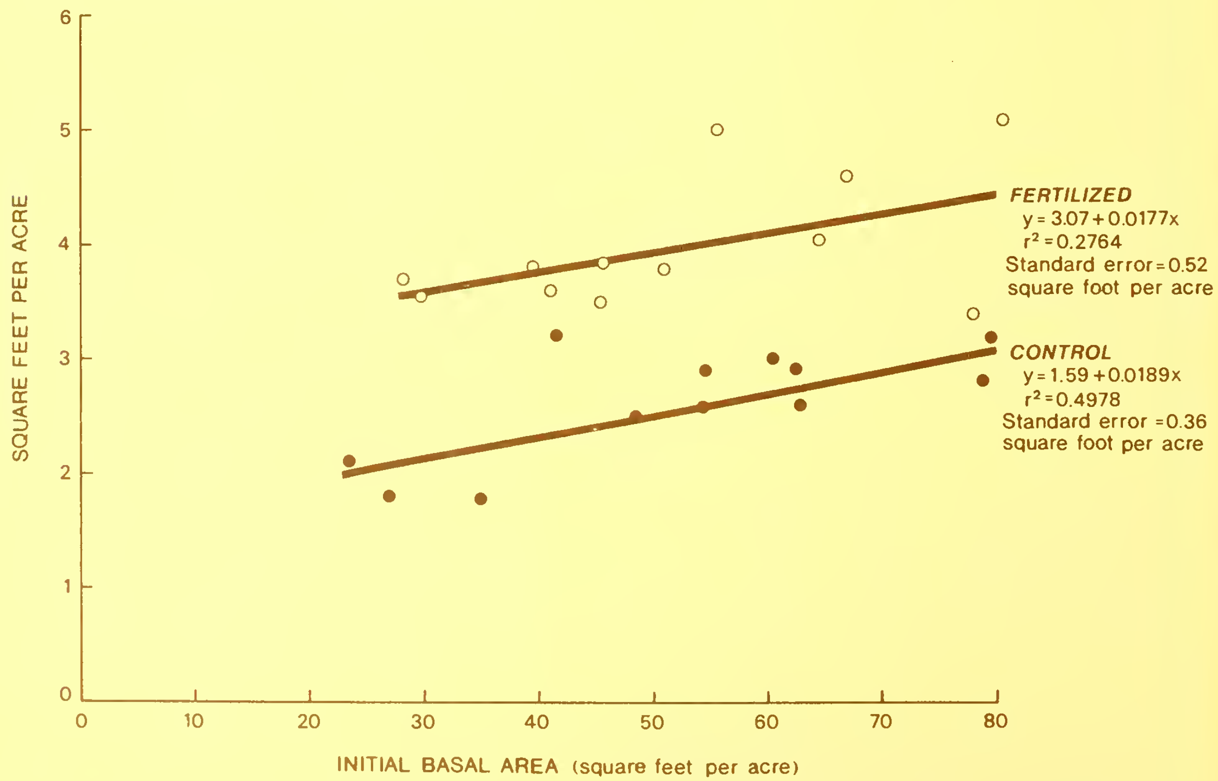

Figure 2.--Average annual basal area growth during the 1974-78 growing seasons as a function of basal area at the start of 1974. Slopes of the regression lines are not significantly different, but the adjusted means are significantly different.

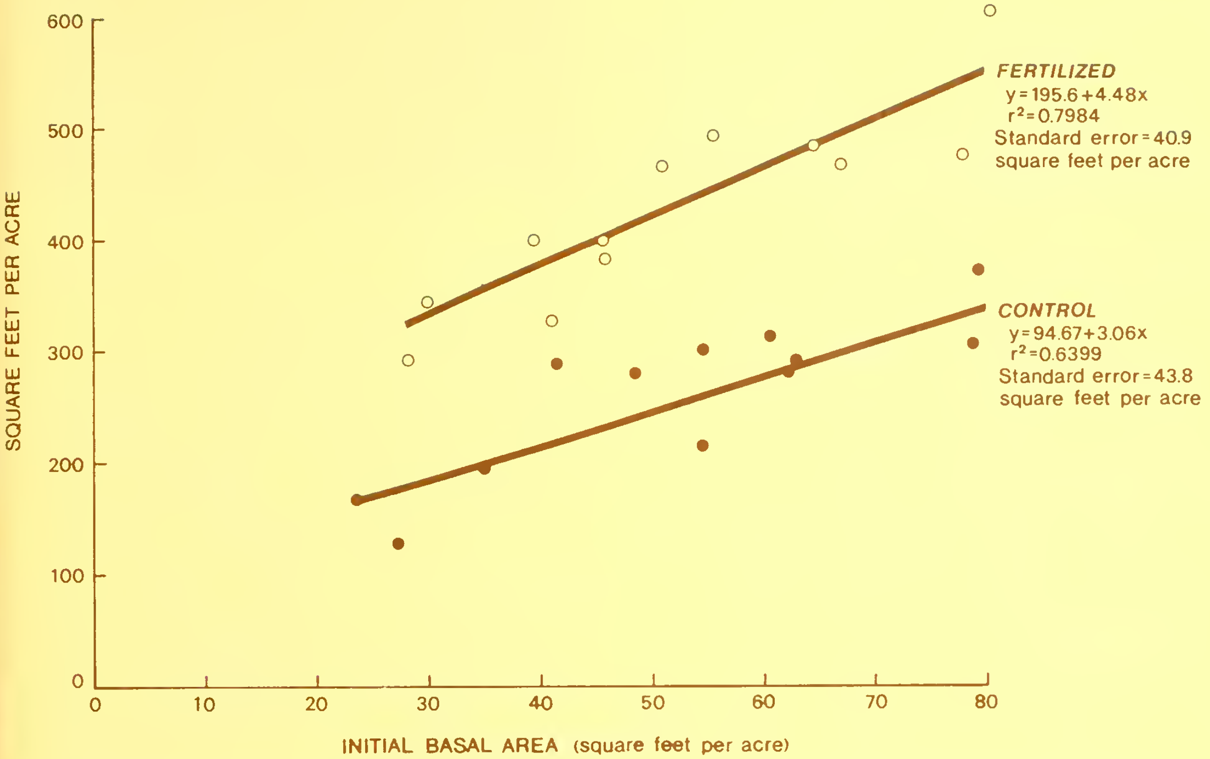

Figure 3.--Average annual bole area growth during the 1974-78 growing seasons as a function of basal area at the start of 1974. Slopes of the regression lines are not significantly different, but the adjusted means are significantly different.

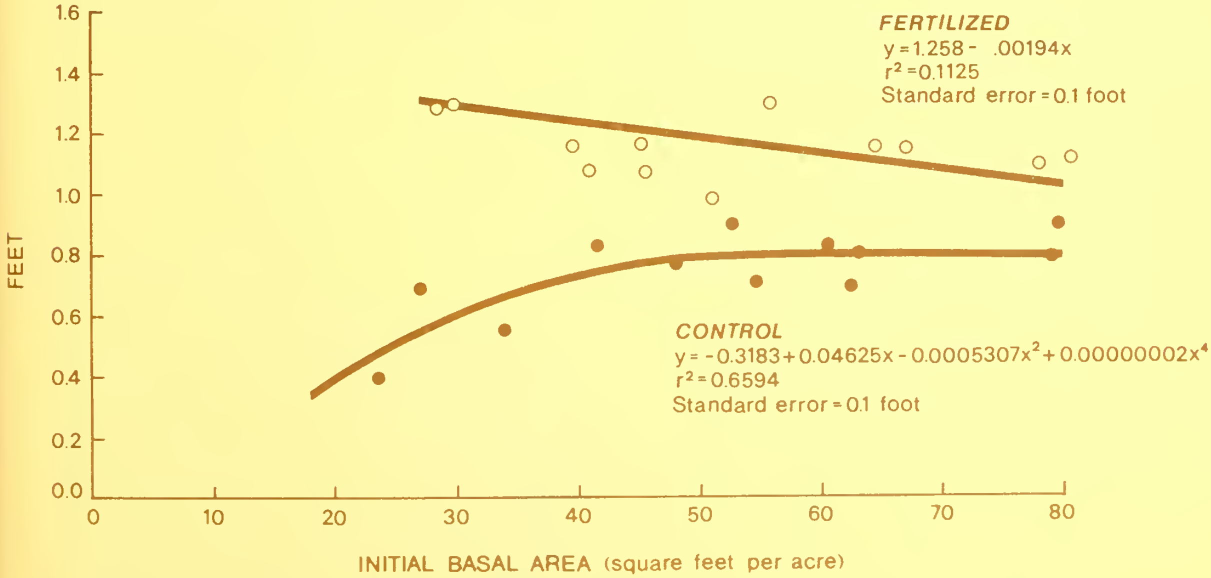

Figure 4.--Average annual height growth during the 1974-78 growing seasons as a function of initial basal area at the start of 1974. Adjusted means for the fertilized plots are significantly higher. The regression for the fertilized plots is not significant.

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METRIC EQUIVALENTS

1 square foot/acre = 0.229 568 square meter/hectare
1 cubic foot/acre = 0.069 972 cubic meter/hectare
1 pound/acre = 1.121 kilograms/hectare
1 tree/acre = 2.47 trees/hectare
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 acre = 0.405 hectare
1 foot = 0.304 8 meter

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PNW-340 September 1979

PRELIMINARY CROWN WEIGHT ESTIMATES FOR TANOAK, BLACK OAK, AND PACIFIC MADRONE

by J. A. Kendall Snell, *Forester*

Abstract

Preliminary tables for estimating dry weights of whole trees and of crown components are presented for California black oak and tanoak; total tree weight only for Pacific madrone. Crown component weights were generated from data of two earlier studies, one from the Appalachians and one from the Pacific Northwest.

KEYWORDS: Biomass, weight tables, crown weights, hardwoods, tanoak, *Lithocarpus densiflorus*, California black oak, *Quercus kelloggii*, Pacific madrone, *Arbutus menziesii*.

INTRODUCTION

To help land managers assess hardwood biomass, for either fire hazard appraisal or fiber utilization potential, this Research Note presents preliminary whole tree weights for three species--tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.), California black oak (*Quercus kelloggii* Newb.), and Pacific madrone (*Arbutus menziesii* Pursh.). For tanoak and California black oak, preliminary weights for tree components are also given.

DISCUSSION AND RESULTS

To construct the weight tables, I used two studies--one from the Pacific Northwest (Sundahl 1966) and an unpublished one from the Appalachians by Loomis.[1] Sundahl collected total tree weight data for three hardwood species in Yuba County, California.[2] The species

[1] R. M. Loomis. Unpublished data, on file at North Central Forest Experiment Station, East Lansing, Mich.

[2] Total tree weight includes bole (bark and wood), branches, and foliage.

sampled and their associated sample sizes were: 8 tanoak (0.8- to 19.8-inch d.b.h.), 7 California black oak (0.6- to 22.0-inch d.b.h.), and 10 Pacific madrone (0.4- to 22.1-inch d.b.h.).[3]

Regression equations for total tree weight were made for each species. The regression model used is:

$$\ln W = \ln a + b (\ln d);$$

where:

W = total tree weight (lb) by species.[4] Total weight includes foliage, all branchwood, unmerchantable tip, and bole.

d = diameter at breast height (inches),

a and b = regression coefficients,

ln = natural (Naperian) logarithm.

Regressions for each species showed high correlations, with coefficients of determination of 0.99. The regression line fit the data points so closely that any logarithmic bias would have been negligible. Therefore, the mean square error divided by 2 was not added to the "a" coefficient to correct for bias caused by logarithmic transformations (Baskerville 1972).

Sundahl (1966) collected total tree weight, separated out crown weight, but did not separate the crown into component size classes,[5] nor has any other west coast hardwood study examined crown component size classes with their respective weights. Therefore, a study on hardwoods from the Appalachians was used. Loomis (see footnote 1) had collected data on red oak (*Quercus rubra* L.) from the Appalachians and had separated the crown components. His data are unpublished but supply preliminary equations for weight of foliage and branchwood, as well as proportion functions to separate branchwood weight into component size classes.

Before I put together the results of the Pacific Northwest and Appalachian studies for preliminary weight estimates of west coast hardwood components, I made two assumptions:

1. Tanoak and California black oak (two Pacific Northwest species) have the same crown component size-class weights as red oak (an Appalachian species). Since there has been no study on Pacific Northwest hardwoods that examined crown weight by size-class components, this assumption was necessary to construct the weight tables.

2. Tanoak and California black oak total tree weights for a given d.b.h. are approximately the same. A graph of their respective functions indicated this was true.

With the above assumptions, I estimated weights for crown components of tanoak and California black oak combined (table 1). I used equations developed for the foliage and branchwood weight of the Appalachian species, red oak. I further separated the estimated branchwood weight into component size classes by using proportion functions also developed from red oak. The proportion functions could not be used with Sundahl's (1966) crown weights because of differences in crown definitions. Sundahl (1966) measured branchwood to 4-inch diameter, and the study on red oak measured branchwood up to where the branches joined the bole. The total crown weight, once calculated, was subtracted from Sundahl's (1966) total tree weight for an estimate of bolewood weight. The weight shown under "Bole" (table 1) includes weight for unmerchantable tip, dead branchwood, and bolewood.

The net effect of the above functional manipulation would possibly bias the crown component size-class weights. The total tree weight, however, is an unbiased estimate made from a limited source of data collected in Yuba County, California. Any bias in the crown component weights should be consistent, and the user should be able to recognize this by making periodic postactivity down-woody inventories (Brown 1974).

Assumptions similar to those outlined earlier for California black oak, tanoak, and red oak could not be made for Pacific madrone. Therefore, only the total weights of trees were estimated and

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[3] To change inches to centimeters, multiply by 2.54.

[4] After solving the equation, to change pounds to kilograms, multiply by 0.454.

[5] Component size classes: Foliage, 0- to 0.24- 0.25- to 0.99-, 1.0- to 2.99-, and 3.0+-inch diameter (outside bark) branchwood.

Table 1--Preliminary component weights of tanoak and California black oak[1/]

D.b.h.	Foliage	Branchwood diameter[2/] 0-0.24 inch	0.25-0.99 inch	1-2.99 inches	3+ inches	Crown	Bole[3/]	Total tree
Inches	Pounds[4/]							
1	0.5	0.2	0.1	0	0	0.8	2.2	3.0
2	1.3	.6	1.5	0	0	3.4	10.5	13.9
3	2.4	1.2	4.4	.4	0	8.4	25.7	34.1
4	3.7	1.8	6.9	4.2	0	16.5	48.1	64.6
5	5.1	2.6	9.7	10.9	0	28.3	77.7	106.0
6	6.8	3.4	12.8	21.3	0	44.2	114.7	158.9
7	8.5	4.3	16.2	35.7	0	64.7	159.0	223.8
8	10.4	5.3	19.8	54.8	0	90.4	210.6	301
9	12.4	6.4	23.7	73.2	5.8	121.5	269.5	391
10	15	8	28	87	21	159	335	494
11	17	9	32	102	42	202	409	610
12	19	10	37	118	68	252	489	741
13	22	11	42	135	100	309	576	885
14	24	13	47	152	138	374	669	1,043
15	27	14	52	171	182	446	770	1,216
16	30	16	57	190	234	526	876	1,403
17	32	17	63	210	293	615	990	1,605
18	35	19	69	231	359	713	1,109	1,822
19	38	20	74	253	434	820	1,235	2,055
20	41	22	80	275	517	936	1,367	2,303
21	44	24	87	299	608	1,062	1,504	2,566
22	48	26	93	322	709	1,198	1,648	2,846
23	51	27	100	347	819	1,344	1,797	3,141
24	54	29	106	372	939	1,501	1,951	3,452
25	58	31	113	399	1,068	1,669	2,111	3,780

[1/] To change pounds to kilograms, multiply by 0.454. To change inches to centimeters, multiply by 2.54.

[2/] The branchwood was measured to the main bole.

[3/] The bole weight includes the unmerchantable tip, dead branchwood, and bolewood.

[4/] Ovendry weight.

summarized in table 2. For an indication of Pacific madrone's total crown weight, Sundahl's (1966) tanoak and California black oak crown weights were averaged for large trees (12- to 22-inch d.b.h.) and subjectively compared with weights for Pacific madrone. The comparison indicated that Pacific madrone's crown weight was approximately 30 to 50 percent lighter than the average of tanoak and California black oak; however, a comparison of total tree weights from tables 1 and 2 indicated madrone's total weight is noticeably heavier.

Statistical analyses were not possible because of lack of compatible data and sampling designs between researchers. It was my intent to give practitioners who work in areas with substantial amounts of west coast hardwoods the capability of making reasonable biomass weight estimates. Because the values given in tables 1 and 2 are based on a limited number of trees, they should be used with caution.

To use the tables, estimate the number of trees per acre by species and d.b.h. and multiply by the corresponding coordinate value in the table. The product of the weight per tree from the table and trees per acre will give an estimate of weight per acre for any given d.b.h. class. Estimates should be made only on a per-acre basis, not for individual trees. This should help prevent gross bias in weight estimates.

Table 2--Preliminary total tree weights for Pacific madrone[1/]

D.b.h.	Total tree weight	D.b.h.	Total tree weight
Inches	Pounds[2/]	Inches	Pounds[2/]
1	2.6	13	1,031
2	13.2	14	1,225
3	34	15	1,438
4	66	16	1,672
5	112	17	1,925
6	171	18	2,199
7	244	19	2,494
8	333	20	2,810
9	438	21	3,148
10	560	22	3,508
11	699	23	3,890
12	856	24	4,295

[1/]Total tree weight includes: bole (wood and bark), foliage, unmerchantable tip, and all branchwood. To change pounds to kilograms, multiply by 0.454; to change inches to centimeters, multiply by 2.54.

[2/]Ovendry weight.

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A CHECKLIST OF THE VASCULAR PLANTS IN ABBOTT CREEK RESEARCH NATURAL AREA, OREGON[1]

by

Rod Mitchell, *Colorado Women's College, Denver, Colorado*

ABSTRACT

This paper is a checklist of 277 vascular plant taxa that have been collected or encountered in Abbott Creek Research Natural Area, Oregon; a brief description of five forested and two nonforested vegetation types is included.

KEYWORDS: Vascular plants, checklists (vascular plants), Oregon (Abbott Creek Research Natural Area)

INTRODUCTION

Abbott Creek Research Natural Area is located 19 km (12 miles) west of Crater Lake National Park in the Rogue River National Forest of southern Oregon (fig. 1). This Research Natural Area was established on November 18, 1946, as representative of the southwestern Oregon, Sierra-type mixed conifer forests and specifically because it contained excellent stands of sugar pine (*Pinus lambertiana*) (Franklin et al. 1972). The purpose of this note is to document the vascular flora of this Research Natural Area (RNA) to aid future scientific research (Franklin 1970, Moir 1972) and to complement a previous study of forest community composition in the Research Natural Area (Mitchell and Moir 1976).

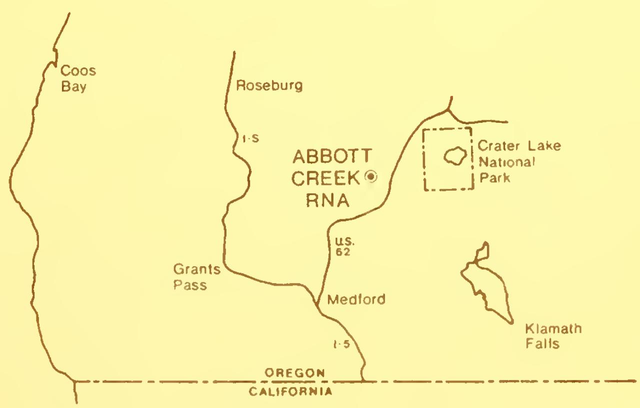

Figure 1.--Location of Abbott Creek Research Natural Area.

[1] This work was supported by a contract from the Pacific Northwest Forest and Range Experiment Station and the Pacific Northwest Natural Area Committee.

STUDY AREA

Abbott Creek Research Natural Area is located in Douglas and Jackson Counties and has a total area of 1 076 ha (2,660 acres). Its western border, defined by the main branch of Abbott Creek, provides the easiest access to major portions of the area. An unmaintained logging road parallels the southwestern boundary. This road is reached from U.S. Highway 26 via Forest Road 3047 (fig. 2). The northern border is defined by a ridge between the Rogue and Umpqua River drainages. The main access to this ridge is via trail remnants from Abbott Butte fire lookout, served by Forest Road 2923. The eastern edge of the area generally follows the Golden Stairs Trail, accessible at its southern end by Forest Road 3017 and by Forest Road 3016 at a more northern point. There are no maintained trails or roads within the RNA.

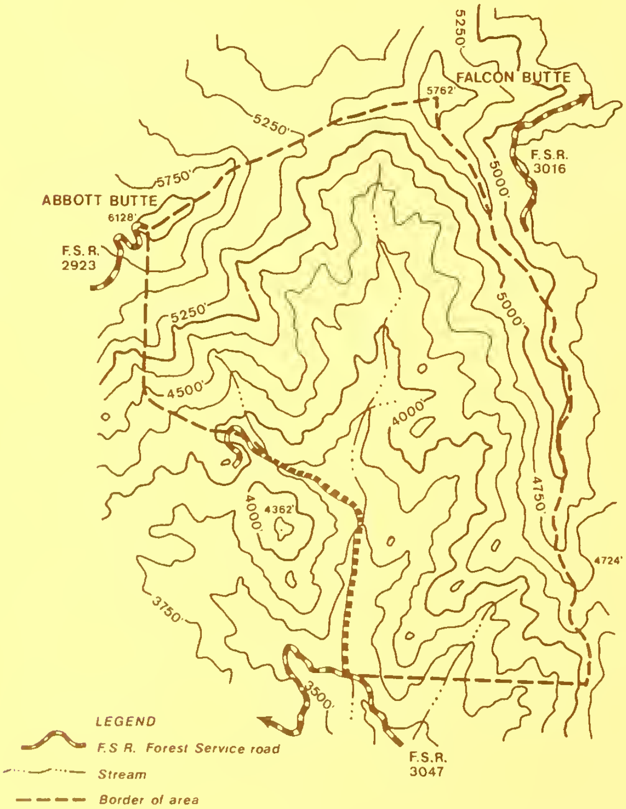

Figure 2.--Features of the Abbott Creek Research Natural Area and vicinity.

Physiography and Geology

The topography is quite steep; much of the area consists of slopes of 25 percent or more. Gentler terrain is found near Abbott Creek and on some high elevation benches south of Abbott Butte and between Abbott and Falcon Buttes. Abbott Butte is the highest point (1 869 m; 6,128 ft) in the Research Natural Area; the lowest point (1 006 m; 3,300 ft) is located in the southwest of the RNA.

The entire area is volcanic in origin. Soils belong to the Freezener-Coyata soil series (Power and Simonson 1969). Typically the soils are acid in reaction and well drained with dark reddish-brown, friable, loam surface layers Rock fragments range from abundant to less than 30 percent by volume.

Climate

A modified maritime climate characterizes the Research Natural Area. Most of the precipitation results from low pressure systems that move eastward across western Oregon from the Pacific Ocean. During the summers, this dominant climatic feature is modified by high pressure systems that shift fronts northward, resulting in clear, dry weather. This phenomenon results in cool, wet winters and warm, dry summers.

Grazing

The Research Natural Area lies within the Woodrull Cattle and Horse Allotment and presently experiences light grazing on its eastern border.[2] The USDA Forest Service has issued permits in the area since 1923. As early as the 1860's settlers used the area for grazing. It can be speculated that this grazing has affected the present flora, both through the introduction of species not originally found in the area and through a disproportionate amount of foraging on some of the original species.

VEGETATION TYPES

In the forested locations, 119 reconnaissance plots (Franklin et al. 1970) were used to sample vegetation (Mitchell 1972) and develop a classification. These included transects to determine the percentage of ground cover and frequency of understory species (Daubenmire 1968). Five major forest and two nonforested vegetation types have been recognized (Mitchell and Moir 1976). About 80 percent of the Research Natural Area is forested.

1. The *Abies magnifica* vegetation type located at higher elevations in the northwest corner of the RNA is floristically distinct and belongs to the *Abies magnifica* var. *shastensis* Zone (Dennis 1959, Whittaker 1960, Franklin and Dyrness 1973). The overstory consists of *Abies magnifica, Libocedrus decurrens, Abies concolor,* and *Tsuga mertensiana.* The understory averages over 80-percent cover and is dominated by *Adenocaulon bicolor, Bromus vulgaris, Circaea alpina, Erigeron aliceae, Montia sibirica, Osmorhiza chilensis, Trientalis latifolia, Ribes viscosissimum, Rubus parviflorus, Smilacina sessilifolia, Vancouveria hexandra* and *Vicia americana* which occur in over 67 percent of the locations sampled. The ecoclass is CR F9 (Hall 1978).

2. The *Abies concolor-Tsuga heterophylla/Acer circinatum-Taxus brevifolia* vegetation type is on the moist end of the gradient that includes the three other forested vegetation types that are part of the Mixed-Conifer Zone as it occurs in the RNA (Mitchell and Moir 1976). This vegetation type is found at the bottom of the major drainages, usually where there is a permanent streamflow. *Pseudotsuga menziesii, Abies concolor, Tsuga heterophylla, Pinus lambertiana,* and *Pinus monticola* comprise the overstory. The shrub layer is very well developed; *Acer circinatum, Taxus brevifolia, Castanopsis chrysophylla, Corylus cornuta,* and *Cornus nuttallii* are the most important representatives. The understory is quite dense and is dominated by *Achlys triphylla, Berberis nervosa, Chimaphila umbellata, Linnaea borealis, Pachystima myrsinites, Trientalis latifolia, Vaccinium membranaceum,* and *Whipplea modesta,* all of which occurred in over 78 percent of the locations sampled. The ecoclass is CH 32 (Hall 1978).

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[2]Walker, Gorden J., Range Technician, Prospect Ranger Station, Prospect, Oregon; personal communication, 1979.

3. The *Abies concolor/Linnaea borealis* vegetation type occurs on mesic slopes at lower elevations in the RNA. The overstory consists of *Pseudotsuga menziesii, Abies concolor,* and *Libocedrus decurrens.* The understory of this vegetation type is very well developed and is dominated by evergreen species. The major understory species are *Achlys triphylla, Berberis nervosa, Chimaphila umbellata, Corylus cornuta, Hieracium albiflorum, Linnaea borealis, Trientalis latifolia,* and *Whipplea modesta* which occur in over 71 percent of the locations sampled. The ecoclass is CW F3 (Hall 1978).

4. The *Abies concolor-Pseudotsuga menziesii/Whipplea modesta* vegetation type is located on dry midslopes to upper slopes that face south or west. The tree component is dominated by *Pseudotsuga menziesii* and *Libocedrus decurrens.* The understory is poorly developed, often with less than 10-percent total cover. *Castanopsis chrysophylla, Amelanchier alnifolia,* and *Garrya fremontii* occasionally provide a shrub layer. *Whipplea modesta* is about the only understory plant with significant cover values in most locations. *Berberis nervosa, Chimaphila umbellata, Hieracium albiflorum, Iris chrysophylla,* and *Trientalis latifolia* are found in 75 percent of the locations sampled. The ecoclass is CW S6 (Hall 1978).

5. The *Pseudotsuga menziesii-Libocedrus decurrens/Arctostaphylos nevadensis* vegetation type is found mainly on south- and west-facing slopes near ridgetops where there are poorly developed slabby lithosols. The overstory is open and dominated by *Pseudotsuga menziesii* and *Libocedrus decurrens; Pinus lambertiana* is also present. The shrub layer is quite well developed and dominated by *Arctostaphylos nevadensis, Castanopsis chrysophylla, Ceanothus prostratus,* and *Garrya fremontii,* all of which occur in 63 percent or more of the sample locations. The nonshrub component of the understory is quite sparse and is represented by *Arenaria macrophylla, Chimaphila umbellata, Hieracium albiflorum, Trientalis latifolia,* and *Whipplea modesta* which are present in 81 percent or more of the locations sampled. The ecoclass is CD C3 (Hall 1978).

6. A nonforested community occupies dry, rocky sites at midelevations on the western edge of the RNA. This is a very drought resistant and heterogeneous vegetation type. Most of the species are not found on other sites in the RNA. *Brodiaea pulchella, Madia minima, Perideridia bolanderi,* and *Stipa occidentalis* are the only species that occur in over 30 percent of the locations sampled; the total cover never reaches 50 percent. The ecoclass is GB 29 (Hall 1978).

7. There are several meadows on the northern edge of the Research Natural Area between Abbott and Falcon Buttes. These meadows continue north of the RNA at higher elevations. Snowpack remains as late as June and is followed by rapid growth of dense herbaceous vegetation. *Bromus vulgaris, Erigeron aliceae, Heracleum sphondylium, Hydrophyllum fendleri, Lonicera conjugialis, Melica spectabilis, Osmorhiza occidentalis, Pteridium aquilinum, Salix scouleriana,* and *Veratrum viride* are dominant members of this vegetation type. There is evidence that these meadows are being invaded by trees, especially *Libocedrus decurrens.* The ecoclass is FW 19 (Hall 1978).

CHECKLIST

Methodology

Specimens were collected of all vascular plants found within the Research Natural Area during the summers of 1971, 1972, and 1973. All specimens were verified by F. J. Hermann, Curator of the USDA Forest Service Herbarium, Fort Collins, Colorado, or by K. L. Chambers, Curator, Oregon State University Herbarium, Corvallis, Oregon. Voucher specimens were deposited in both herbaria.

The checklist of plants is arranged in alphabetical order by family. The nomenclature follows Peck (1961) but in several instances is updated by Hitchcock and Cronquist (1973). The common names follow various authorities, primarily Franklin and Dyrness (1973) and Garrison et al. (1976). Voucher specimens of most species are on file in the USDA Forest Service Herbarium, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, or the Oregon State University Herbarium, Corvallis, Oregon.

Most species are given abundance ratings by vegetation type. Some species, however, occupy highly specialized habitats and cannot be related to the seven types.

The checklist of the vascular plants indicate vegetation types where taxa are found, voucher specimen numbers, and the herbaria where deposited. The abbreviations for vegetation types are:

S -- *Abies magnifica* (Shasta red fir)
H -- *Abies concolor-Tsuga heterophylla/Acer circinatum* (western hemlock)
W -- *Abies concolor/Linnaea borealis* (white fir)
D -- *Abies concolor-Pseudotsuga menziesii/Whipplea modesta* (Douglas-fir)
I -- *Pseudotsuga menziesii-Libocedrus decurrens/Arctostaphylos nevadensis* (incense-cedar)
R -- Drought-resistant, heterogeneous species
M -- Herbaceous meadow

The abbreviations for abundance scale are:

A -- Abundant
C -- Common
R -- Rare

Abbreviations for the herbaria where voucher specimens are located are:

O -- Oregon State University Herbarium, Corvallis, Oregon
F -- USDA Forest Service Herbarium, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Species	Vegetation types S	H	W	D	I	R	M	Voucher number	Herbaria
ACERACEAE									
Acer circinatum Pursh (vine maple)		A						116	O/F
Acer glabrum Torr. (Rocky Mountain maple)		R						248	O/F
Acer macrophyllum Pursh (bigleaf maple)		C						340	O/F
APOCYNACEAE									
Apocynum androsaemifolium L. (spreading dogbane)						R		267	O
ARISTOLOCHIACEAE									
Asarum caudatum Lindl. (wild ginger)	C	C	C	R	R			57	O/F
BERBERIDACEAE									
Achlys triphylla (Sm.) DC. (deerfoot vanillaleaf)	R	A	A	C	R			164	O/F
Berberis nervosa Pursh (Oregongrape)	R	A	A	A	C			120	O
Vancouveria hexandra (Hook.) Moor. & Dec. (white inside-out-flower)	C	A	A		R			145	O/F
BETULACEAE									
Alnus sinuata (Regel) Rydb. (Sitka alder)							R	187	O/F
Corylus cornuta var. *Californica* (DC.) Sharp (California hazel)	C	A	A	C				143	O/F
BORAGINACEAE									
Cryptantha affinis (Gray) Greene (slender cryptantha)						C		128	O/F
Cynoglossum grande Dougl. ex Lehm. (great hound's tongue)				R				28	O/F
Hackelia jessicae (McGregor) Brand. (Jessica stickweed)							C	182	O/F
Mertensia ciliata (Torr.) G. Don (broadleaved lungwort)		C						16	O/F
CAMPANULACEAE									
Campanula prenanthoides Dur. (California harebell)	R			R				255	O/F
Campanula scouleri Hook. ex A. DC. (Scouler bellflower)	R							271	O
CAPRIFOLIACEAE									
Linnaea borealis var. *longiflora* Torr. (twinflower)		A	A					161	O/F

Species	Vegetation types							Voucher number	Herbaria
	S	H	W	D	I	R	M		
Lonicera conjugialis Kell. (purpleflower honeysuckle)							R	193	O/F
Sambucus racemosa L. (black elderberry)				R				379	O
Symphoricarpos mollis Nutt. (creeping snowberry)		C	C	R				361	O
CARYOPHYLLACEAE									
Arenaria aculeata Wats. (needle-leaved sandwort)						R		200	O/F
Arenaria macrophylla Hook. (bigleaf sandwort)	A		A	C	A			27	O/F
Silene campanulata Wats. (slender campion)						R		102	O/F
CELASTRACEAE									
Pachystima myrsinites (Pursh) Raf. (Oregon boxwood)	C	A	A			R		168	O/F
COMPOSITAE									
Achillea millefolium ssp. *lanulosa* Piper (western yarrow)	C						C	140	O/F
Adenocaulon bicolor Hook. (trail plant)	A	C	C	R	R			284	O/F
Agoseris aurantiaca (Hook.) Greene (orange agoseris)							R	328	O/F
Agoseris glauca (Pursh) Raf. (pale agoseris)							R	112, 202	O/F
Agoseris grandiflora (Nutt.) Greene (large-flowered agoseris)							R	265	O
Anaphalis margaritacea (L.) B. & H. (pearly everlasting)							C	259, 306	O/F
Antennaria racemosa Hook. (slender everlasting)		C						24	O/F
Arnica latifolia Bong. (broadleaf arnica)		C						144	O/F
Arnica spathulata Greene (spatulate arnica)				R				291	O
Aster ledophyllus Gray (Cascades aster)							R	319, 383	O/F
Balsamorhiza deltoidea Nutt. (Puget balsamroot)							R	199	O/F
Cirsium centaurea (Rydb.) K. Schum. (slender mountain thistle)					R			382	O/F
Cirsium vulgare (Savi) Airy-Shaw (common thistle)					R			363	O/F
Crepis occidentalis Nutt. (western hawksbeard)						R		196	O
Erigeron aliceae Howell (Alice fleabane)	C						A	260, 211	O/F
Erigeron foliosus var. *confinis* (Howell) Jeps. (leafy fleabane)						R		71	O/F
Erigeron inornatus Gray (rayless fleabane)						C		77	O/F
Eriophyllum lanatum var. *achillaeoides* (DC.) Jeps. (common woolly sunflower)						C		89	O/F

Species	Vegetation types S	H	W	D	I	R	M	Voucher number	Herbaria
Eupatorium occidentale Hook. (western eupatorium)						R		380	O/F
Hieracium albiflorum Hook. (white hawkweed)	C	C	A	A	A			163	O/F
Hieracium cynoglossoides Arv.-Touv. (houndstongue hawkweed)						R		324	O/F
Luina nardosmia (Gray) Cronq.							R	154	O/F
Madia bolanderi Gray (Bolander's tarweed)							A	334	O/F
Madia gracilis (Smith) Keck (common tarweed)						C		37	O/F
Madia minima (Gray) Keck (least tarweed)						C		68	O/F
Petasites frigidus (L.) Fries (alpine coltsfoot)							C	165	O/F
Rudbeckia occidentalis Nutt. (western coneflower)	C						C	301	O/F
Senecio integerrimus Nutt. (western groundsel)						R		35, 197	O/F
Senecio triangularis Hook. (arrowleaf senecio)							C	283, 311	O/F
Solidago canadensis L. (Canada goldenrod)							R	338	O/F
Taraxacum laevigatum (Willd.) DC. (smooth dandelion)						R		149	O
Taraxacum officinale Weber (common dandelion)						R		141	O
CORNACEAE									
Cornus nuttallii T. & G. (Pacific dogwood)	C	C	R	R				113	O/F
CRASSULACEAE									
Sedum oregonense (Wats.) Peck (creamy stonecrop)						C		67	O/F
CRUCIFERAE									
Arabis holboellii var. *retrofracta* (Grah.) Rydb. (Holboell rockcress)						C		79	O/F
Arabis microphylla Nutt. (littleleaf rockcress)						R		381	O/F
Athysanus pusillus (Hook.) Greene (sandweed)						C		126	O/F
Descurainia richardsonii (Sweet) Schulz (western tansy mustard)						C		315	O/F
CUCURBITACEAE									
Marah oregonus (T. & G.) Howell (Oregon wild cucumber)						R		38	O/F
CUPRESSACEAE									
Libocedrus decurrens Torr. (incense-cedar)	C	C	C	C	C				
CYPERACEAE									
Carex bolanderi Olney (Bolander sedge)		C						2, 368	O/F

Species	S	H	W	D	I	R	M	Voucher number	Herbaria
	Vegetation types								
Carex concinnoides Mack. (northwestern sedge)						R		159	F
Carex fracta Mack. (fragile-sheathed sedge)		R		R		R		14, 151, 167, 374	F
Carex hoodii Boott (Hood sedge)				R		R		61, 194, 320	O/F
Carex multicaulis Bailey (thick-fruited sedge)							R	244	F
Carex paucicostata Mack. (few-ribbed sedge)							R	337	F
Carex rossii Boott (Ross sedge)						R		26, 279, 289, 375	O/F
Carex subfusca W. Boott (rusty sedge)		R					R	10, 138, 335	F
EQUISETACEAE									
Equisetum arvense L. (common horsetail)		C						341	O/F
ERICACEAE									
Arctostaphylos nevadensis Gray (pine-mat manzanita)			R		A	R		376	O/F
Arctostaphylos patula Greene (green manzanita)					C			377	O/F
Chimaphila menziesii (R. Br.) Spreng. (little prince's pine)					R			277	O
Chimaphila umbellata (L.) Bart. (western prince's pine)	A	C	A	A	A			230	O/F
Gaultheria ovatifolia Gray (slender gautheria)		R	C					285	O/F
Pterospora andromedea Nutt. (pine drops)			R						
Pyrola aphylla Smith (leafless pyrola)						R		254, 276, 231	O/F
Pyrola asarifolia Michx. (large pyrola)								342	O/F
Pyrola dentata Smith			R	R	R			153, 290	O/F
Pyrola picta Smith (whitevein pyrola)			R	R	R			224, 270	O
Pyrola secunda L. (one-sided wintergreen)			R					177, 262	O
Rhododendron macrophyllum G. Don (Pacific rhododendron)		R	R					359	O/F
Sarcodes sanguinea Torr. (snow plant)		R	R					119	O/F
Vaccinium membranaceum Hook. (big huckleberry)		A	A					162	O/F
FAGACEAE									
Castanopsis chrysophylla (Dougl.) A. DC. (golden chinkapin)		A	A	A	C			252	O/F

Species	S	H	W	D	I	R	M	Voucher number	Herbaria
Quercus garryana Hook. (Oregon white oak)				R				110, 248	O/F
FUMARIACEAE									
Dicentra formosa (Andr.) Walp. (Pacific bleeding-heart)							R	46	O/F
GARRYACEAE									
Garrya fremontii Torr. (bear bush)					C			239	O/F
GENTIANACEAE									
Swertia umpquaensis (Peck & Appleg.) St. John (Umpqua swertia)	R						C	215, 299	O/F
GRAMINEAE									
Agropyron caninum (L.) Beauv. (bearded wheatgrass)						C		332	O
Agrostis exarata Trin. (spike bentgrass)						C		367	O
Agrostis scabra Willd. (winter bentgrass)							C	323	O/F
Bromus carinatus H. & A. (California brome)						C		210, 238, 295	O/F
Bromus orcuttianus Vas. (Orcutt's brome)						R		241	O/F
Bromus tectorum L. (cheatgrass brome)						C		237	O
Bromus vulgaris (Hook.) Shear (Columbia brome)	C	R					C	233, 286, 317, 388, 393, 268, 278, 282	O/F
Bromus vulgaris var. *eximius* Shear	R							178	O/F
Cinna latifolia (Trev.) Griseb. (drooping wood-reed)							R	353	O
Danthonia unispicata (Thurb.) Macoun (one-spike danthonia)						C		40	O
Elymus glaucus Buckl. (blue wildrye)	C						C	131, 218, 246, 281, 296, 322, 369, 385, 390	O/F
Festuca californica Vas. (California fescue)				R		R		109	O/F
Festuca microstachys Nutt. (Nuttall's fescue)					R			236	O
Festuca occidentalis Hook. (western fescue)				R	R	R		123, 235, 269	O/F

Species	Vegetation types S	H	W	D	I	R	M	Voucher number	Herbaria
Festuca reflexa Buckl. (twoflower fescue)						R		41	O/F
Festuca subulata Trin. (bearded fescue)	R							371	O
Festuca subuliflora Scribn. (crinkleawn fescue)								232, 287	O
Glyceria elata (Nash) Hitchc. (tall manna-grass)		R						372	O
Glyceria striata (Lam.) Hitchc. (fowl manna-grass)		R						347	O
Hierochloe occidentalis Buckl. (California sweetgrass)								153	O/F
Melica aristata Boland. (bearded melic)								263, 389	O/F
Melica californica Scribn. (western melic)						R		394	O/F
Melica harfordii Boland. (Harford's melic)								156	O/F
Melica spectabilis Scribn. (showy onion-grass)						R		198	O/F
Melica subulata (Griseb.) Scribn. (Alaska onion-grass)						R		30, 179, 219, 223, 356, 391	O/F
Phleum alpinum L. (alpine timothy)						R		220	O
Poa pratensis L. (Kentucky bluegrass)						R		330	O
Poa sandbergii Vas. (Sandberg's bluegrass)								245	O/F
Poa scabrella (Thurb.) Vasey (pine bluegrass)					R			33	O/F
Sitanion hystrix (Nutt.) J. G. Sm. (bottlebrush squirreltail)					C			87, 297, 325, 326, 327	O/F
Stipa lemmonii (Vas.) Scribn. (Lemmon needlegrass)						R		34, 354, 355	O/F
Stipa occidentalis Thurb. ex Wats. (Western needlegrass)						C		311	O
Stipa occidentalis var. *minor* ((Vas.) Hitchc. *S. columbiana* Macoun) (Columbia needlegrass)						R		66	O/F
Trisetum canescens Buckl. (tall trisetum)							R	280, 392	O
HYDRANGEACEAE									
Whipplea modesta Torr. (whipple vine)	R	C	A	A	C			21	O/F
HYDROPHYLLACEAE									
Hydrophyllum fendleri (Gray) Heller (Fendler waterleaf)							C	192	O/F
Nemophila parviflora Benth. (smallflower nemophila)		C						192	O/F

Species	S	H	W	D	I	R	M	Voucher number	Herbaria
	Vegetation types								
Phacelia hastata Lehm. (whiteleaved phacelia)						R		98	0/F
IRIDACEAE									
Iris chrysophylla Howell (slender-tubed iris)	R	C	C	C	R			25	0/F
JUNCACEAE									
Juncus orthophyllus Cov. (straight-leaved rush)							R	139	0/F
Luzula comosa E. Mey. (hairy woodrush)							C	207, 243	F
Luzula parviflora (Ehrh.) Desv. (millet woodrush)		C					C	17, 316	0/F
LABIATAE									
Agastache urticifolia (Benth.) Kuntze (nettle-leaved giant-hyssop)						R		212, 300	0/F
Monardella odoratissima Benth. (western balm)							R	292	0/F
Scutellaria antirrhinoides Benth. (snapdragon skullcap)							R	107	0/F
Stachys cooleyae Heller (Cooley's hedge nettle)		R						351A, 356	0/F
Stachys rigida Benth. (rigid hedge nettle)		R						351	0/F
LEGUMINOSAE									
Lathyrus polyphyllus T. & G. (Pacific peavine)		R						4	0/F
Lotus formosissimus Greene (Seaside lotus)							R	137	0/F
Lotus nevadensis (Wats.) Greene (Nevada lotus)						R		99	0/F
Lupinus albifrons Lindl. (white-leaved lupine)						R		94	0/F
Lupinus argenteus Pursh (silvery lupine)				R				217	0/F
Lupinus latifolius Agardh (broadleaf lupine)	C							213	0
Lupinus laxiflorus Lindl. (spur lupine)				R				93	0/F
Trifolium howellii Wats. (bigleaf clover)							C	344	0/F
Vicia americana var. *villosa* (Kell.) F. J. Herm. (American vetch)	C	C	A	C	R			7	0/F
LILIACEAE									
Allium siskiyounense Owns. (Siskiyou onion)						R		203, 204	0
Brodiaea congesta Smith							R	251	0/F
Brodiaea pulchella (Salisb.) Greene (purplehead brodiaea)						R		74	0/F
Calochortus elegans Pursh (elegant mariposa lily)						R		32	0/F

Species	Vegetation types S	H	W	D	I	R	M	Voucher number	Herbaria
Disporum hookeri (Torr.) Nichols. (Hooker's fairybells)	C	C	C	R	R			62	O
Erythronium grandiflorum Pursh (lambstongue fawnlilly)								201	O/F
Fritillaria atropurpurea Nutt. (purple fritillaria)							R	58	O
Lilium columbianum Hanson (Columbia lily)							R	157	O/F
Lilium washingtonianum Kell (Washington lily)							R	329	O
Smilacina racemosa (L.) Desf.	C	C	R					358	O
Smilacina stellata (L.) Desf. (starry solomonplume)	C	C	R					55	O/F
Trillium ovatum Pursh (white trillium)	C	A	R					51, 52	O/F
Veratrum viride Ait. (American false hellebore)							C		
Xerophyllum tenax (Pursh) Nutt. (common beargrass)							R	234	O/F
LINACEAE									
Linum Lewisii Pursh (Lewis flax)						R		293	
ONAGRACEAE									
Circaea alpina L. (alpine circaea)	A	R	R	C	C			169, 222	O/F
Clarkia rhomboidea Hook. (common clarkia)				R		R		90	O/F
Epilobium angustifolium L. (fireweed)						R		294	O/F
Epilobium glaberrimum Barbey (smooth willowweed)		C						5, 362	O/F
Epilobium minutum Hook. (small-flowered willowweed)						C		69, 106	O/F
Gayophytum humile Juss. (dwarf gayophytum)						R		127	O
Gayophytum nuttallii Piper (Nuttall's gayophytum)						C		75, 395	O/F
ORCHIDACEAE									
Calypso bulbosa (L.) Oakes (calypso)		R							
Corallorhiza maculata Raf. (spotted coralroot)		C	C					261	O
Corallorhiza mertensiana Bong. (Mertens' coralroot)		C	C					121, 225	O/F
Goodyera oblongifolia Raf. (rattlesnake plantain)		C	R					275	O/F
Habenaria dilatata var. *leucostachys* (Lindl.) Ames (boreal bogorchid)							R	333	F
Habenaria elegans (Lindl.) Boland. (California hillside habenaria)		R						242	O/F
Habenaria saccata Greene (slender bog orchid)							R	346	O/F
Listera caurina Piper (western twayblade)								386	O

Species	S	H	W	D	I	R	M	Voucher number	Herbaria
	Vegetation types								
PINACEAE									
Abies concolor Lindl. & Gord. (white fir)	A	C	A	A	C				
Abies magnifica var. *shastensis* Lemm. (Shasta red fir)	A								
Pinus lambertiana Dougl. (sugar pine)		R	R	R	C				
Pinus monticola Dougl. (western white pine)		R							
Pinus ponderosa Dougl. (ponderosa pine)				R	R				
Pseudotsuga menziesii (Mirb.) Franco (Douglas-fir)		C	A	A	A				
Tsuga heterophylla (Raf.) Sarg. (western hemlock)	R	A	C	R	R				
POLEMONIACEAE									
Collomia grandiflora Dougl. (large-flowered collomia)						R		256	O/F
Collomia heterophylla Hook. (varied-leaved collomia)				R	C			23	O/F
Gilia aggregata (Pursh) Spreng. (scarlet gilia)							R	305	O/F
Gilia capitata Sims (globe gilia)						R		36	O/F
Linanthus harknessii (Curran) Greene (harkness linanthus)						R		100	O/F
Navarretia divaricata (Torr.) Greene (short-stemmed navarretia)						C		43	O
Phlox adsurgens Gray (woodland phlox)								125	O/F
Phlox diffusa Benth. (sens. E. Wherry) (spreading phlox)						R		205	O/F
Polemonium pulcherrimum Hook. (showy polemonium)		R						53, 206	O/F
POLYGONACEAE									
Eriogonum compositum Benth. var. *compositum* (northern buckwheat)						C		88	O/F
Eriogonum nudum Benth. (naked eriogonum)						C		78	O/F
Eriogonum umbellatum Torr. var. *umbellatum* (sulfur buckwheat)						C		130	O/F
Polygonum bistortoides Pursh (American bistort)							C	336	O/F
Polygonum cascadense W. H. Baker (Cascade knotweed)						C		42	O/F
Polygonum majus (Meisn.) Piper (wiry knotweed)						R		70	O/F
Rumex acetosella L. (sheep sorrel)							C	250	O/F

Species	Vegetation types S	H	W	D	I	R	M	Voucher number	Herbaria
POLYPODIACEAE									
Athyrium filix-femina (L.) Roth (ladyfern)	R	R						346, 364	O/F
Cheilanthes gracillima D.C. Eat. (lace-fern)						R		76	O/F
Cryptogramma densa (Bracknr.) Diels (Oregon cliffbreak)						R		82	O/F
Pellaea glabella Kuhn (cliffbreak)						R		73	O/F
Polystichum munitum (Kaulf.) Presl. (swordfern)	C	C						352	O/F
Pteridium aquilinum (L.) Kuhn (bracken fern)	A	C	R				A		
PORTULACACEAE									
Claytonia lanceolata Pursh (lance-leaved spring beauty)							A	45	O/F
Montia parvifolia (Moc.) Greene (Miner's lettuce)		R						96	O/F
Montia sibirica (L.) Howell (western spring beauty)	A	C						9	O/F
Spraguea umbellata Torr. (pussypaws)						R		64	O/F
PRIMULACEAE									
Trientalis latifolia Hook. (starflower)	A	A	A	A	A			117	O/F
RANUNCULACEAE									
Actaea rubra (Ait.) Willd. (baneberry)							C	47, 313	O/F
Anemone deltoidea Hook. (threeleaf anemone)	C	C	R					1	O/F
Aquilegia formosa Fisch. (western columbine)						R		135	O/F
Delphinium glaucum Wats. (pale larkspur)							R	304	O/F
Delphinium menziesii DC. (Menzies' larkspur)	R						R	54	O/F
RHAMNACEAE									
Ceanothus integerrimus H. & A. (deerbrush)						C		80	O/F
Ceanothus prostratus Benth. (squawcarpet)					A	C		378	O/F
Ceanothus velutinus Hook. (varnishleaf ceanothus)					A	C		133	O/F
RIBESACEAE									
Ribes binominatum Heller (Siskiyou gooseberry)	A					R		171	O/F
Ribes cruentum Greene (shiny-leaved gooseberry)	R							132, 266	O/F
Ribes lacustre (Pers.) Poir. (prickly currant)	R							166	O/F
Ribes lobbii Gray (pioneer gooseberry)						R		181, 257	O/F
Ribes sanguineum Pursh (winter currant)						R		150	O/F
Ribes viscosissimum Pursh (sticky currant)	C				R	R		60, 174	O/F

Species	Vegetation types S	H	W	D	I	R	M	Voucher number	Herbaria
ROSACEAE									
Amelanchier alnifolia Nutt. (Saskatoon serviceberry)	R							272	O/F
Fragaria vesca L. (western wood strawberry)	R	C	R					20, 175	O/F
Holodiscus discolor (Pursh) Maxim. (creambush oceanspray)	C						R	108	O/F
Osmaronia cerasiformis (T. & G.) Greene (Indian plum)		R						387	O/F
Potentilla glandulosa Lindl. (gland cinquefoil)								81	O/F
Prunus emarginata (Dougl.) Walp. (bitter cherry)								63	O/F
Rosa gymnocarpa Nutt. (baldhip rose)	C	A	A	C	R			115	O/F
Rosa nutkana Presl. (Nootka rose)	R							273	O
Rubus lasiococcus Gray (dwarf blackberry)	R							228	O/F
Rubus leucodermis T. & G. (western blackcap)						R		122, 264	O/F
Rubus nivalis Hook. (snow dewberry)	C	R	C					360	O/F
Rubus parviflorus Nutt. (thimbleberry)	R							160, 302	O/F
Sorbus scopulina Greene (Greene mountain-ash)		R					R	384	O/F
Sorbus sitchensis Roemer (Sitka mountain-ash)							R	274	O/F
RUBIACEAE									
Galium oreganum Britt. (Oregon bedstraw)	A	C						176, 310	O/F
Galium triflorum Michx. (sweetscented bedstraw)	A	C	C					13, 343	O/F
Kelloggia galioides Torr. (kelloggia)						C		247	O/F
SALICACEAE									
Populus tremuloides Michx. (quaking aspen)							C	186	O/F
Salix scouleriana Barratt (Scouler's willow)		R					C	8, 188	O/F
SAXIFRAGACEAE									
Boykinia major Gray (large-flowered boykinia)		R						365	O/F
Lithophragma sp. cf. *L. tenella* Nutt.									
Tellima grandiflora (Pursh) Dougl. (Alaska fringecup)		R					R	6, 191	O/F
Tiarella unifoliata Hook. (western coolwort)							C	126, 229	O/F
SCROPHULARIACEAE									
Castilleja miniata Hook. (scarlet paintbrush)						R		208, 303	O/F
Castilleja pruinosa Fern. (frosted paintbrush)						R		85	O/F
Collinsia parviflora Lindl. (littleflower collinsia)								18, 44	O/F

Species	S	H	W	D	I	R	M	Voucher number	Herbaria
Nimulus breweri (Greene) Rydb. (Brewer monkeyflower)						R		129	O/F
Mimulus guttatus DC. (common monkeyflower)		R						125	O/F
Mimulus pulsiferae Gray							R	103	O/F
Mimulus tilingii Regel (clustered monkeyflower)		R						136	O/F
Orthocarpus imbricatus Wats. (mountain owlclover)							C	195	O/F
Pedicularis bracteosa Benth. (bracted pedicularis)							R	314	O
Pedicularis racemosa Hook. (sickletop pedicularis)							C	288	O/F
Penstemon davidsonii (Greene) var. *davidsonii* Piper (Davidson penstemon)						R		97	O/F
Penstemon deustus Lindl. (scabland penstemon)						R		91	O/F
Synthyris reniformis (Dougl.) Benth. (snowqueen)		C	R					155	O/F
TAXACEAE									
Taxus brevifolia Nutt. (western yew)		C							
UMBELLIFERAE									
Heracleum sphondylium L. (cowparsnip)	R					C		189	O
Ligusticum apiifolium (Nutt.) Gray (parsleyleaf licoriceroot)							C	209	O
Ligusticum grayi C. & R. (Gray's lovage)							C	209, 312	F
Lomatium nudicaule (Pursh) C. & R. (barestem lomatium)						C		72	O/F
Lomatium triternatum (Pursh) C. & R. (nineleaf lomatium)						R		111	O/F
Osmorhiza chilensis H. & A. (mountain sweetroot)	C	C					A	19	O/F
Osmorhiza occidentalis (Nutt.) Torr. (sweet anise)							C	190	O/F
Oxypolis occidentalis C. & R. (western oxypolis)								348	O/F
Perideridia bolanderi (Gray) Nels. & Macbr. (mountain false caraway)						A		39	O/F
Sanicula graveolens Poepp. ex DC. (Sierra snake-root)						R		56, 134	O/F
Sphenosciadium capitellatum Gray (range wolleyhead-parsnip)							C	339	O/F
VALERIANACEAE									
Valeriana sitchensis Bong. (Sitka valerian)							R	221, 308	O/F
VIOLACEAE									
Viola glabella Nutt. (wood violet)	C	A	R	R				49, 226	O/F
Viola sheltonii Torr. (Shelton violet)	R							22	O/F

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PNW-342 NOVEMBER 1979

EMPLOYMENT:WOOD CONSUMPTION RATIOS FOR THE FOREST PRODUCTS INDUSTRY IN SUBAREAS OF OREGON AND WASHINGTON, 1976

by

Brian R. Wall, *Economist*

Abstract

Presents and discusses employment:wood ratios for analyzing impacts on employment in forest products industries.

KEYWORDS: Employment (forest products industries), forest product output, mill operations/products.

This note presents employment:wood consumption ratios for major segments of the forest products industry in Oregon and Washington for the year 1976. These ratios can be used to estimate the impact of changes in levels of timber products output on employment in local areas (subareas); they also may be used to prepare management plans and environmental statements and to evaluate proposed legislation.

Employment:wood consumption ratios are based on several sources of data. Employment data by county, obtained from the Employment Security Department of the State of Washington and the Department of Human Resources of the State of Oregon, are for workers covered by unemployment insurance, segregated by four-digit standard industrial classification (SIC) codes.[1] Timber harvest data by county are from Lloyd (1978a, 1978b). Wood consumption data by industry and by county came from 100-percent canvasses of mills in 1976 by Howard and Hiserote (1978) and Bergvall et al. (1977).

Data were arrayed by subareas, which were the same as those used in the mill surveys:

Washington	Oregon
Puget Sound	Northwest
Olympic	West central
Lower Columbia	Southwest
Central	Central
Inland Empire	Blue Mountain

The counties in each subarea are listed in the appendix.

Employment data were summarized by subarea for the following categories:

(a) SIC 2411--logging
(b) SIC 2421--sawmills and planing mills
(c) SIC 2435 and 2436--veneer and plywood plants.

Employment:consumption ratios are calculated by dividing the employment in each SIC category by the roundwood consumption for that industry. For example, there are 900 employees in eastern Oregon veneer and plywood plants. In 1976 these plants consumed 297.9 million board feet of timber. The resulting ratio is 3.02 employees per million board feet.

The calculations are based on consumption of roundwood. Thus, when other wood materials are used in the manufacturing process, and hence support employment, the resulting ratios are too high and cannot be used for impact analysis.

DISCUSSION OF RESULTS

Table 1 shows the logging employment:timber harvest and the employment:wood consumption ratios by subarea for Oregon and Washington. The degree of manufacturing affects the ratios. The more processing lumber and plywood receive, the higher the ratio tends to be.

The highest logging employment ratio is 2.32 in the Puget Sound area of western Washington. The lowest logging employment ratio is 0.86 in the central part of eastern Oregon. Although why the ratios are so different is uncertain, logging methods differ in the two areas because of differences in timber types and sizes and in terrain.

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[1] Source of SIC codes: Statistical Policy Division (1972).

Table 1--Logging employment:timber harvest and employment:wood consumption ratios by area and type of manufacturing process, 1976

(Number of employees per million board feet, Scribner scale)

Half-State and subarea	Logging (SIC 2411)[1]	Sawmills and planing mills (SIC2421)[1]	Veneer and plywood plants (SIC 2435 and 2436)[1]
Western Washington:			
Puget Sound	2.32	6.59	NA
Olympic Peninsula	2.19	4.50	NA
Lower Columbia	2.25	5.51	9.40
Average	2.23	5.71	NA
Eastern Washington:			
Central	1.58	5.59	NA
Inland Empire	1.16	5.35	NA
Average	1.42	5.49	NA
Western Oregon:			
Northwest	2.00	4.49	[2]6.94
West central	1.59	4.50	7.05
Southwest	1.67	4.96	6.86
Average	1.71	4.65	6.94
Eastern Oregon:			
Central	.86	5.90	3.27
Blue Mountain	1.41	4.65	2.87
Average	1.07	5.39	3.02

NA = not applicable.

[1]SIC = Standard Industrial Classification.

[2]Multnomah County has been deleted.

The sawmill and planing mill employment ratio also shows variation among the subareas. No single variable appears to account for the variation. Differences can be expected because sizes of mills differ and some plants have operated longer than others. There is a higher degree of manufacturing in some subareas. And more company headquarters with their sizable staffs are located in some subareas than in others. Size of timber, types of machines, and productivity of labor are also factors that can affect the ratios and lead to real differences by subregion.

Variation was also found in the veneer and plywood employment ratios. How long a plant has been operating and the degree of manufacturing are important factors affecting the ratios. The low ratio in eastern Oregon reflects the fact that most plants produce only veneer and do not employ as many people as is usually associated with the plywood layup process.

The employment:wood consumption ratios for veneer and plywood in the Puget Sound and Olympic Peninsula and the average for western Washington are not shown because they appeared meaningless. Investigation of the wood consumption of the mills in these areas showed that the mills purchase veneer and lay it up; thus, roundwood is not the source of all wood consumed. The number of people employed depends in part on the amount of veneer purchased.

The veneer and plywood ratios for eastern Washington are not shown because employment data for one county were not available.

Over the past several decades, employment ratios have tended toward fewer employees per million board feet, primarily because of increases in labor productivity (Wall and Oswald 1975). A comparison with 1972 data for western Oregon shows that the logging employment ratio for 1976 (1.71) is higher than for 1972 (1.41) and the sawmill and planing mill ratio for 1976 (4.65) is higher than the 1972 ratio (3.84). The 1972 veneer and plywood ratio (7.85) is higher, however, than the 1976 ratio of 6.94.

Higher 1976 ratios for logging and sawmills and planing mills probably do not indicate a new upward trend in employment requirements, but they do show that labor productivity was lower in 1976 than 1972. The industry production level was lower in 1976 than in 1972. Firms use labor inputs differently, depending on whether the economy is expanding or contracting--1972 was a high production year, and 1976 was a recovery year after a recession. Thus, a difference in productivity is not surprising.

When employment ratios are used for impact analysis, one must assume that the marginal changes in harvest or consumption require the same labor inputs as the average. This is usually not the case; but unless detailed mill studies are made, the average must be used to approximate change.

CONCLUSION

Employment:wood consumption ratios can be calculated from the mill surveys.

Employment ratios vary considerably by subarea, representing differences in the industry, the timber, and the logging techniques. The exact cause of the variation could not be determined from this study. Some variation could be due to reporting errors in the mill surveys.

The subarea ratios can be used for employment impact analysis for local areas, but the distribution of the mix of wood consumption to sawmills and veneer and plywood plants must be estimated. The ratios by industry segment for a local area are not additive to get a composite ratio for the area.

Labor productivity dropped in western Oregon logging and sawmills and planing mills between 1972 and 1976; productivity in veneer and plywood plants rose.

These ratios are average ratios, and their use assumes they are the same as the marginal ratios. These ratios probably give the approximate magnitude of change in employment when the amount of timber harvested is changed.

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APPENDIX

Subareas in Counties of Washington and Oregon

Washington

Puget Sound
- Island
- King
- Kitsap
- Pierce
- San Juan
- Skagit
- Snohomish
- Whatcom

Olympic Peninsula
- Clallam
- Grays Harbor
- Jefferson
- Lewis
- Mason
- Pacific
- Thurston

Lower Columbia
- Clark
- Cowlitz
- Klickitat
- Skamania
- Wahkiakum

Central Washington
- Chelan
- Kittitas
- Lincoln
- Okanogan
- Yakima

Inland Empire
- Asotin
- Columbia
- Ferry
- Pend Oreille
- Spokane
- Stevens
- Walla Walla

Oregon

Northwest
- Clackamas
- Clatsop
- Columbia
- Hood River
- Marion
- Multnomah
- Polk
- Tillamook
- Washington
- Yamhill

West Central
- Benton
- Lane
- Lincoln
- Linn

Southwest
- Coos
- Curry
- Douglas
- Jackson
- Josephine

Central
- Crook
- Deschutes
- Jefferson
- Klamath
- Lake
- Wasco
- Wheeler

Blue Mountain
- Baker
- Grant
- Harney
- Morrow
- Umatilla
- Union
- Wallowa

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PNW-343 November 1979

GRASS SEEDING AND SOIL EROSION IN A STEEP, LOGGED AREA IN NORTHEASTERN OREGON

by

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W. B. Fowler, *Principal Meteorologist*

Abstract

This case study tested the common belief that grass seeding is needed to prevent erosion after areas are clearcut in the Blue Mountains. Changes in the soil surface height at about 500 points each in a seedbed and an unseeded area were measured on four dates covering a 20-month period. Average vertical displacement was not consistently related to seeding nor to degree of disturbance. Variability of vertical displacement within areas treated alike was almost as great as variability between treatments.

Size-graded fluorescent material (Willemite) was placed on 10 sites to characterize downslope soil movement. The maximum movement (240 centimeters) occurred on a severely disturbed area.

KEYWORDS: Seeding (erosion control), herbaceous plants, erosion control, erosion -)vegetation, Oregon (Blue Mountains).

INTRODUCTION

The High Ridge evaluation area was described in detail by Fowler et al. (1979). The objective of the High Ridge study is to evaluate the effects of timber harvest on the ecosystem, including the effects on various attributes of the soil and water resource.

In one of the preharvest conferences on the cutting prescriptions, it became apparent that a conflict would arise between operational and research objectives if the standard practice of seeding grass on all cutting units was allowed. Studies of successional trends of understory vegetation and comparisons of animal activity before and after harvest required that a substantial portion of the area be left unseeded. A compromise--essentially half of the disturbed area would be left unseeded--was agreeable especially when it was proposed that this would allow an additional test of the efficiency of seeding on local erosion.

We agreed to examine soil movement by two methods that have been used elsewhere (Leonard and Whitney 1977, Fowler and Berndt 1969). The objectives of this note are to report the results of our erosion measurements and to compare the development of vegetation in seeded and unseeded areas.

THE STUDY AREA

The study area is located in the Blue Mountains of northeastern Oregon on the Pendleton District of the Umatilla National Forest. It is about 22 km northwest of Elgin and 8 km southwest of the Spout Springs Recreation Area. Soil displacement was intensively measured within a 3.64-ha clearcut (fig. 1) which has a northeastern aspect and a 30-percent average slope. Average elevation is about 1 500 m.

Precipitation at High Ridge averaged 142 cm between 1967 and 1976. On the average, 87 percent of the annual precipitation fell between October 1 and May 31 and 13 percent in the summer months (July through September). Intense thunderstorms, which cause the most severe erosion problems are possible during the summer months. Although intense thunderstorm paths may be up to 60 km wide (Morris 1934), amount of precipitation normally declines rapidly with distance from thunderstorm cell centers. Records indicate that at least one storm in 10 years will deliver 2 cm of rainfall per hour and one storm in 100 years will deliver 2.5 cm of rainfall per hour (Pacific Northwest River Basins Commission 1969).

Figure 1.--A view of the study area. The area in the foreground was seeded; the background, unseeded.

Soils in the general area of the study site were probably of the Tolo or Helter Series, which are classified as Typic Vitrandepts or Entic Cryandepts (Geist and Strickler 1978). According to these authors, these soils are characterized by a layer of volcanic ash over an older buried soil. The ash layer is often 50 cm or more thick, with an A1 horizon of up to 15 cm. Texture is classified as silt loam throughout the ash overburden, and it grades into loam and finer textures in the buried soil. These soils contain a high percentage of organic matter relative to other soils in the Blue Mountains. Organic matter averaged 7.89 percent in the 0- to 15-cm layer; 4.70 percent in the 15- to 30-cm layer; 2.34 percent in the 30- to 60-cm layer; and 1.02 percent in the 60- to 90-cm layer. Geist and Strickler (1978) and Hall (1973), who classified the area as belonging to the *Abies grandis* - *Linnaea* - forb plant community, concluded that the soils are erodible by wind when exposed and that they have capacities for rapid infiltration.

Before logging, the area was densely stocked with grand fir (*Abies grandis* (Dougl.) Lindl.), Engelmann spruce (*Picea engelmannii* (Parry)), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), western larch (*Larix occidentalis* Nutt.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

METHODS

Logging

Trees were felled, bucked into log lengths, then skidded to landings where they were loaded on trucks. Skidding with tractors left trenches up to 50 cm deep in several places (fig. 2). After the merchantable material was removed, the large residue was piled by tractors and a fireline was constructed around the clearcut; the residue was later burned. Residue too small for piling was broadcast burned. After the burning, tractors were again used to scatter unburned fuels and to construct water bars in the skid trails and firelines.

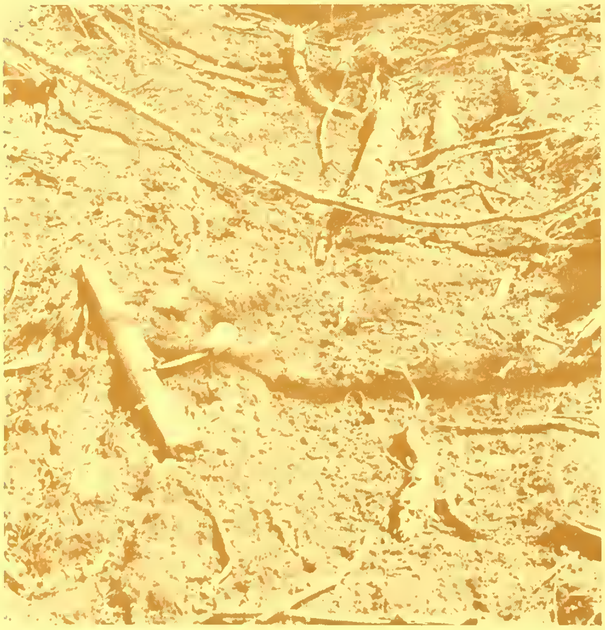

Figure 2.--A skid trail running up and down the slope. Note the severe soil disturbance.

Seeding

The clearcut was divided in half at right angles to the slope contour. The northwestern half was seeded in October 1976 with 1.14 kg/ha hard fescue (Festuca ovina duriuscula), 0.87 kg/ha intermediate wheat grass (Agropyron intermedium), 1.34 kg/ha orchard grass (Dactylis glomerata, and 0.56 kg/ha white clover (Trifolium repens). The other half of the clearcut was not seeded. In April 1977, 370 Engelmann spruce and 475 western larch seedlings per hectare were planted in the entire clearcut.

Soil Surface Changes

Two methods were used to index displacement of soil. The first method, described by Fowler and Berndt (1969), consisted of "salting" 10 plots with size-graded fluorescent material (Willemite). Our intention was to index movement of particles of various sizes, not to test control of erosion by grass seeding. Within each plot, three 25-cm-diameter spots were covered with Willemite: one each with 1-mm particles, 1- to 3-mm particles, and 3- to 25-mm pieces. The plots were chosen to represent the following conditions of surface disturbance caused by logging and residue treatment: (1) none (the forest floor was still intact); (2) slight (the litter layer was burned, but the humus layer was not disturbed); (3) moderate (the humus layer was churned up, but the subsoil was not exposed); and (4) severe (disturbance of subsoil; i.e., a 20-cm-deep trench running upslope caused by log skidding).

Movement of the Willamite from the original location was determined by visiting the sites at night and using a black light to find the current location of the fluorescent material. A meter stick was used to measure maximum displacement of the material, and each site was examined for evidence of animal activity or rills made by running water associated with disturbance of the Willemite.

Variations of our second method for indexing soil displacement have been used for many years by hydrologists and soil conservationists to document changes in stream channel cross sections and land surfaces over time. More recently, Leonard and Whitney (1977) used essentially the same method reported here for documenting changes in forest trails caused by people and animals. Our method was as follows: (1) A numbered nail was driven vertically into each of several stumps along three contours across the study site. About 2 mm of space was left between the underside of the nail head and the top of the stump. Distance between stumps varied from 3 to 24 m. (2) A thin, nylon string was stretched tightly between two stumps and tied to the nails. (3) The distance from the nylon string to the soil (or residue) surface was measured at 30-cm intervals (fig. 3) and recorded to the nearest millimeter. (4) The same procedure was followed for all transects.

The Willemite plots were established and the first survy made on October 8, 1976, after all activity with machinery was finished. During the first survey, each sample point was rated according to disturbance by the categories Klock (1975) used. Areas where litter and topsoil were still in place were rated as having little or no disturbance, areas where the topsoil was well mixed were rated as moderately disturbed, and areas where the subsoil was exposed were rated as severely disturbed.

Vertical soil displacement was determined at about 500 points each in the seeded and unseeded portions of the clearcuts. To test the precision of the measurement method, we measured 24 points on one transect twice on 1 day. The average difference in the two sets of data was only 0.8 mm.

Figure 3.--Measuring vertical displacement of soil.

Vegetation Sampling[1/]

At the end of the 1978 growing season, 14 randomly located plots, each with an area of 0.4 m^2, were established in each half of the clearcut. Species of plants growing on each plot were recorded, and the vertical projection of foliar material onto the ground surface was measured for all plants present by Tiedemann and Klock's (1973) methods. An ocular estimate was made of the percent of ground covered by litter and logging debris in each plot.

Data Analysis

Because this is a case study without replication, a rigorous statistical analysis of variance is not possible. We chose to present average values, express data variability for vertical displacement, and draw conclusions from these values.

[1/]Vegetation sampling was by Dr. A. R. Tiedemann, formerly Range Scientist at the Forest Hydrology Laboratory, Wenatchee, Washington, now project leader at the Shrub Sciences Laboratory, Provo, Utah. His contribution to this study is gratefully acknowledged.

RESULTS AND DISCUSSION

Soil Displacement on the Willemite Plots

The maximum soil movement, as indicated by the largest size of Willemite, was 240 cm downslope in a severely disturbed skid trail. The smallest size material was rapidly (within the first sample period) dispersed and included within the mineral soil and was not detected. Frost heaving, raindrop impact, and settling appeared to be partially responsible. The material was scattered across the slope by deer or elk when they occasionally stepped on a plot.

Vertical Changes in the Soil Surface

The results of the measurements (table 1) represent average differences (declined soil surface) between the initial measurement on October 8, 1976, and the later measurements. Average surface decline was slightly greater in the seeded area than in the unseeded. Variation around the mean values, as defined by end points of the 95-percent confidence interval[2/] in table 1, indicates that values for seeded and unseeded areas usually overlap for a given measurement date. One exception was on July 12, 1978: The surface reduction of seeded area was 2.84 cm, with a range of 2.43 to 3.26 cm; the average for the unseeded area was 1.63 cm, with a range of 1.29 to 1.97 cm.

We classed 55 percent of the point samples as having little or no disturbance; 45 percent, moderate to severe disturbance. There was no consistent difference in displacement between the two disturbance classes.

The trend toward decreased soil surface location between October 8, 1976, just after the logging and residue treatments were completed, and July 12, 1978, is real. This effect could be the result of several processes. When our first measurements were made (October 8, 1976), the soil surface in many parts of the area was fluffed up, much like a plowed field. The combined impact of raindrops and pressure exerted by the snowpack tended to compact the surface soils during the 21 months (two winters) between the first and last measurements. Decomposition of the litter layer would also make the surface recede relative to the benchmarks.

Vegetation Development

Results of the vegetation survey are presented in table 2. Average plant cover was 56 percent on the seeded area, 20 percent on the unseeded. Native species included Ross sedge (*Carex rossii*), *Ribes* species (*Ribes* spp.), and elderberry (*Sambucus glauca* Nutt.). The most frequently encountered seeded species were orchard grass and hard fescue.

[2/] 95-percent confidence interval = $\bar{x} \pm t_{0.05}\, S_{\bar{x}}$. This interval includes 95 percent of the measurement values.

Table 1--The average cumulative difference (decrease) in the elevation of the soil surface ($\overline{x}$) between October 8, 1978, and the survey dates[1]

Survey date	Little or no disturbance				Moderate to severe disturbance			
	Seeded		Unseeded		Seeded		Unseeded	
	Centimeters							
6/8/77	0.51	(0.25-0.77)	0.42	(0.22-0.62)	1.00	(0.72-1.28)	0.60	(0.32-1.64)
10/12/77	1.29	(.92-1.65)	1.15	(.89-1.42)	.92	(.54-1.30)	1.06	(.48-1.64)
7/12/78	2.84	(2.43-3.26)	1.63	(1.29-1.97)	2.31	(1.87-2.75)	1.72	(1.28-2.16)

[1] The 95-percent confidence interval (in parentheses) = $\overline{x} \pm t_{0.05} S_{\overline{x}}$.

Table 2--Vegetation and litter cover on sample plots located in a clearcut in the Blue Mountains of Oregon[1/]

Plot No.	Seeded area			Unseeded area		
	Native plants	Seeded plants	Litter cover	Native plants	Seeded plants	Litter cover
			Percent			
1	10	20	70	10	0	35
2	40	10	80	5	0	25
3	0	40	40	30	0	55
4	2	35	50	5	0	65
5	5	80	25	20	0	42
6	5	80	10	25	0	45
7	7	25	30	45	0	35
8	5	75	25	10	0	80
9	50	20	50	45	0	70
10	10	25	5	10	0	30
11	2	70	20	25	0	10
12	5	30	10	35	0	20
13	5	85	10	10	0	20
14	0	50	25	10	0	55
Mean	10.4	46.1	32.1	20.4	0	41.9

[1/]Size of sample plots was 0.4 square meter.

Average ground cover by native species on the unseeded plots was double that on the seeded plots. This may indicate that seeded species initially tend to crowd the native plants out.

CONCLUSIONS

Since this study was not replicated, observations apply only to the conditions of soil, topography, and climate in the study area. With these limitations in mind, the following conclusions can be stated. First, grass seeding had little or no effect on soil surface changes in this clear-cut. This conclusion is based on our measurements, as well as our observations of places where overland flow occurred. We observed evidence of overland flow only in the deep skid trails; and even there, soil movement was limited to a few meters. The greatest daily rainfall measured during the study was 3.2 cm. A difference in erosion between the seeded and unseeded areas might have occurred if an intense rainstorm had hit the area during the 1st year after seeding.

Grass seeding appeared to have a negative effect on the rate that native plants developed on the cutover land. We did not attempt to evaluate the effect of grass seeding on survival or growth rate of planted seedlings. Because the effects of seeding in other combinations of soil type, slope steepness, and precipitation regime are not known, a replicated study is needed to evaluate the effects of seeding on soil erosion for the common soil types and topography of the Blue Mountains.

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English Equivalents

1 centimeter = 0.394 inch
1 meter = 1.094 yards
1 hectare = 2.471 acres
1 kilogram/hectare = 0.892 pound/acre
1 kilometer = 0.62 mile
1 millimeter = 0.04 inch
1 square meter = 10.76 square feet

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LUMBER RECOVERY FROM LIVE AND DEAD LODGEPOLE PINE IN SOUTHWESTERN WYOMING

by

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Abstract

A sample of 120 live and 147 dead lodgepole pine (Pinus contorta Dougl.) trees was selected in southwestern Wyoming to represent stands many timber managers and mill operators are processing. The trees were processed through a conventional circular headsaw sawmill to determine lumber yield and relative differences in product recovery. Of the total lumber volume for all live trees in the sample, 47 percent was graded Standard and Better, 17 percent Utility, and 8 percent Economy; for the dead trees, only 24 percent was graded Standard and Better, whereas 37 percent was graded Utility and 13 percent Economy. Based on the gross cubic volume of the log, the average cubic volume of lumber recovered was nearly the same for both live and dead trees--32 and 31 percent, respectively.

KEYWORDS: Lumber recovery, lumber yield, dead timber, lodgepole pine, Pinus contorta, Wyoming.

INTRODUCTION

The States of Utah and Wyoming contain an estimated 8-1/2 billion board feet (International 1/4-inch log rule) of commercial lodgepole pine (*Pinus contorta* Dougl.) sawtimber. Many stands include overmature and decadent trees, as well as dead trees; and many stands are overstocked. These stands present difficult problems to timber managers and timber buyers.

Many small mills in the Intermountain Region depend on lodgepole pine for a large proportion of their annual lumber production. With today's emphasis on environmental concerns and the Nation's increasing need for lumber, the vast volume of dead timber in these stands can no longer be ignored. Managers, buyers, and sellers of timber need reliable product recovery information to make sound evaluations in harvesting dead sawtimber.

Lack of information about this resource prompted a cooperative study between the Pacific Northwest Forest and Range Experiment Station, the Intermountain Region (R-4) of the National Forest System, and the Kamas Valley Lumber Company. The purpose of the study was to estimate the amount of lumber from a typical stand of live and dead lodgepole pine and to compare product recovery of live and dead trees.

METHODS

From a 10-acre area in Wyoming, 120 live and 147 dead trees were selected. About 55 percent of the trees were dead, probably since before 1960. Down trees were not included in the sample. The area was clearcut in 1976, and tree-length logs were skidded to the landing. At the landing, tops were bucked to a diameter of 4.5 to 5.0 inches, and broken tops and forks were cut off. This resulted in some larger top diameters. A sample of the tree length from the bucking point to the top was taken for each d.b.h. (diameter at breast height) class as the trees were yarded. An average length was later applied to the bucked trees for an estimate of total height.

All the trees were trucked to the millyard, and the sample to be processed was selected. A card with a number identified each sample tree. The intent was to select 20 dead and 20 live trees by 1-inch d.b.h. classes. This was easily accomplished in the smaller classes, but at the upper limits of the stand size it was more difficult. Therefore, the sample above 13-inch d.b.h. contains fewer than 20 trees per class since the stand did not contain many trees above that diameter.

Diameter and length of each log were measured so that both Scribner volume and cubic-foot volume could be calculated. Scribner scale was determined on the long logs (both live and dead) according to Forest Service Scaling Handbook rules. The dead logs were also scaled by deducting only soft rots, voids, and chars, and the reasons shown. The gross cubic volume of the log was calculated by Smalian's formula,

$$(0.002727)\ L(D_S^2+D_L^2);$$

where:

L = log length in feet,
D_S = diameter of the small end of the log in inches, and
D_L = diameter of the large end of the log in inches.

With these log volume calculations and the lumber tally volumes, the lumber recovery ratio (total lumber tally/net log scale) and the lumber recovery factor (LRF)[1] for logs and trees could be calculated.

Various curve forms using transformations of diameter correlated with cubic recovery percent were tested. The curve form selected was:

$$\text{Cubic recovery percent} = b_0+b_1D+b_2(1/D)+b_3(1/D^2);$$

where $b_0 \ldots b_3$ are the regression coeffieients, and D is the small end diameter of the log in inches.

The model chosen was based on the coefficient of determination and the standard deviation from regression, with the restriction that the same model be used for both live and dead logs.

Lumber Manufacturing

Equipment for processing lumber in the sawmill included a circular headsaw, two-saw scragg, double arbor edger, and trim saws. This equipment and the sawing, drying, and surfacing practices were representative for mills in the area. Identity of each log was maintained throughout the manufacturing process so that each piece of lumber tallied could be related back to the log from which it was derived. The lumber was tallied by its shipping dimension and grade. All lumber was graded under the supervision of a Western Wood Products Association grading inspector.

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[1]LRF = lumber recovery in board feet/gross cubic log volume.

RESULTS AND DISCUSSION

Lumber recovery is presented by log scaling diameter in tables 1 and 2 for the woods-length, live and dead logs, and in tables 3 and 4 by d.b.h. class for live and dead trees. When scaled by current USDA Forest Service methods, net scale of logs from dead trees was 17 percent of the gross scale (table 2); when sawn, the average cubic volume of lumber recovered was 32 percent for live logs and 31 percent for dead. The average cubic volume lumber recovery ratio for the dead logs and trees was only 1 percent less than that for the live. This ratio was calculated by dividing the sum of the cubic volumes of lumber by the sum of the cubic volumes of logs. Figure 1 shows curves of the cubic volume recovery ratio over diameter for live and dead logs.

Table 1--Log scale, lumber recovery, and cubic volume by scaling diameter for live lodgepole pine logs

Log scaling diameter	Number of logs	Log scale: Gross	Log scale: Net	Lumber tally: Volume	Lumber tally: Recovery ratio	Cubic volume: Log	Cubic volume: Lumber	Cubic volume: Lumber recovery ratio[1]	Cubic volume: Sawdust	Cubic volume: Residue
Inches		Board feet	Board feet	Board feet	Percent	Cubic feet	Cubic feet	Percent	Cubic feet	Cubic feet
4	14	360	350	636	179	120.49	34.36	29	10.43	75.50
5	38	1,310	1,170	2,267	194	421.55	125.67	30	34.04	261.84
6	53	2,960	2,730	4,636	170	832.61	260.32	31	66.40	505.89
7	8	650	590	957	162	160.80	53.95	34	12.93	93.92
8	5	440	430	783	182	118.71	44.52	38	10.67	63.52
9	5	390	370	571	154	89.06	32.27	36	7.36	49.43
10	--	--	--	--	--	--	--	--	--	--
11	--	--	--	--	--	--	--	--	--	--
12	1	120	50	119	238	20.04	6.77	33	1.67	11.96
Total or average	124	6,230	5,690	9,959	175	1,763.62	557.86	32	143.50	1,062.26

[1]Based on gross cubic-foot volume of the log.

Table 2--Log scale, lumber recovery, and cubic volumes by scaling diameter for dead lodgepole pine logs

Log scaling diameter	Number of logs	Log scale			Lumber tally			Cubic volume				
		Gross	Actual net	Net, after deductions for rots, voids, and chars	Volume	Recovery ratio: Actual net[1]	Recovery ratio: Net, after deductions for rots, voids, and chars	Log	Lumber	Lumber recovery ratio[2]	Sawdust	Residue
Inches		Board feet	Board feet	Board feet	Board feet	Percent	Percent	Cubic feet	Cubic feet	Percent	Cubic feet	Cubic feet
4	7	160	20	150	292	1,460	195	48.54	16.22	33	4.96	27.36
5	23	1,190	210	1,110	1,777	846	160	378.82	98.54	26	27.77	252.31
6	64	3,770	760	3,590	5,704	751	159	1,039.22	320.45	31	80.77	637.96
7	25	1,800	200	1,730	2,449	1,224	142	435.65	138.45	32	33.54	263.66
8	5	390	110	380	598	554	157	106.75	33.78	32	8.33	64.68
9	8	840	70	810	1,353	1,933	167	199.64	76.86	38	17.89	104.89
10	7	740	120	740	1,151	959	156	183.93	65.45	36	15.48	103.00
11	1	120	0	100	122	--	122	22.14	6.89	31	1.71	13.54
12	1	150	50	140	171	342	122	30.54	9.71	32	2.31	18.52
Total or average	151	9,160	1,540	8,750	13,617	884	156	2,445.27	766.39	31	192.76	1,486.12

[1]Calculations should not be based on actual net for dead timber.

[2]Based on gross cubic-foot volume of the log.

Table 3--Tree scale, lumber recovery, and cubic volume by diameter class for live lodgepole pine trees

Tree d.b.h.	Number of trees	Tree scale		Lumber tally		Cubic volume				
		Gross	Net	Volume	Recovery ratio	Total tree	Lumber	Lumber recovery ratio[1]	Sawdust	Residue
Inches		- - - Board feet		- - -	Percent	- Cubic feet -		Percent	- - Cubic feet - -	
7	2	40	40	77	192	16.14	4.11	25	1.28	10.75
8	19	470	400	720	180	138.72	39.60	29	11.74	87.38
9	31	960	880	1,572	179	286.81	86.53	30	24.96	175.32
10	21	970	910	1,502	165	293.93	83.79	29	22.20	187.94
11	18	1,090	1,030	1,829	178	330.04	102.74	31	25.58	201.72
12	19	1,420	1,210	2,320	192	409.99	131.20	32	31.25	247.54
13	2	260	240	416	173	63.95	23.63	37	5.69	34.63
14	7	920	860	1,332	155	233.47	75.55	32	17.90	140.02
15	--	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--	--	--
18	1	130	50	119	238	35.13	6.77	19	1.67	26.69
Total or average	120	6,260	5,620	9,887	176	1,808.18	553.92	31	142.27	1,111.99

[1]/Based on gross cubic-foot volume of the tree.

Table 4--Tree scale, lumber recovery, and cubic volume by diameter class for dead lodgepole pine trees

Tree d.b.h.	Number of trees	Tree scale: Gross	Tree scale: Net	Tree scale: Net, after deductions for rots, voids, and chars	Lumber tally: Volume	Lumber tally: Recovery ratio: Actual net[1]	Lumber tally: Recovery ratio: Net, after deductions for rots, voids, and chars	Cubic volume: Tree	Cubic volume: Lumber	Cubic volume: Lumber recovery ratio[2]	Cubic volume: Sawdust	Cubic volume: Residue
Inches		- - - - - - - Board feet	- - - - - - -			- - - Percent	- - -	- Cubic feet	-	Percent	- - Cubic feet	- -
7	5	100	50	100	136	272	136	24.35	7.37	30	2.33	14.65
8	16	330	40	270	498	1,245	134	99.29	27.28	27	8.45	63.56
9	24	870	190	850	1,070	563	126	239.20	58.95	25	17.19	163.06
10	21	950	190	850	1,412	743	166	298.67	79.21	27	21.31	198.15
11	23	1,220	310	1,100	1,840	594	167	375.60	103.70	28	25.71	246.19
12	19	1,340	230	1,300	2,008	873	154	349.96	113.12	32	27.47	209.37
13	17	1,530	190	1,430	2,344	1,234	164	404.84	132.72	33	32.16	239.96
14	9	1,020	300	940	1,526	509	162	256.63	86.54	34	20.44	149.65
15	7	1,120	370	920	1,493	404	162	284.02	84.64	30	20.20	179.18
16	1	140	30	140	172	573	123	32.73	9.62	29	2.23	20.88
17	2	280	50	230	396	792	172	67.86	22.44	33	5.53	39.89
18	3	470	140	420	670	479	160	128.55	38.06	30	8.90	81.59
Total or average	147	9,370	2,090	8,550	13,565	649	159	2,561.70	763.65	30	191.92	1,606.13

1/Calculations should not be based on actual net for dead timber.

2/Based on gross cubic-foot volume of the log.

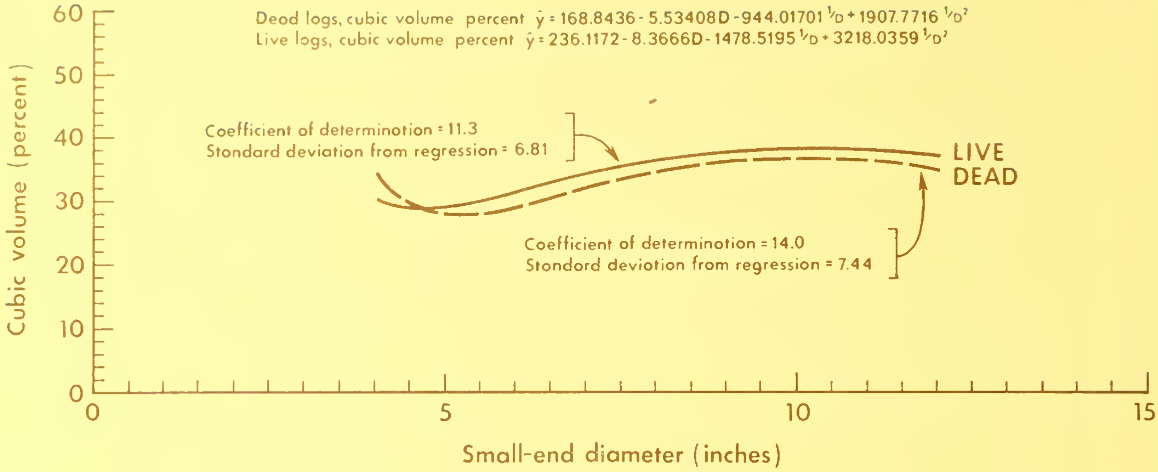

Figure 1.--Recovery of cubic volume curved over diameter for live and dead lodgepole pine logs.

Apparently, defect deductions for checks under the scaling rules do not adequately reflect the potential for recovery of lumber from dead timber. The reduction in lumber volume was much less than land managers and operators might expect. I think one reason the percentage of the lumber recovered from live and dead logs was so similar at a mill producing 4/4 and 8/4 lumber is that lumber no wider than 8 inches was produced. Another factor may be that the amount of spiral checking in these logs was less severe than in some stands of lodgepole pine. These factors would contribute to maximizing recovery from these logs.

Both the actual net volume and the net volume with deductions for soft rots, voids, and chars are shown for the dead logs in table 2. The corresponding recovery ratios for the two net volumes show that when the deductions for rots, voids, and chars are made, the recovery ratio is only slightly less than that for the live logs. For instance, table 2 shows an average recovery ratio of 156 when dead logs are scaled with deductions only for soft rots, voids, and chars compared with 175 for live logs (table 1) scaled by conventional methods. A similar relationship can be seen for the trees. Some recovery ratios exceed 1,000 percent when scaled by conventional methods. Such values are not valid functions of potential recovery from dead timber; I have shown them to stress the defect deduction method used on dead timber.

The cubic volumes of lumber shown in the tables are based on actual dimensions of the surfaced, dry lumber taken from the planer settings. Cubic volumes of sawdust were calculated from an average saw kerf of 0.25 inch and the computed surface area of the surfaced dry lumber; therefore, the volume of sawdust is conservative. Volume of residue was calculated by subtracting the volumes of lumber and sawdust from the gross cubic volume of the log. It then included the volume attributed to shrinkage and planer shavings plus a small amount of sawdust produced from slabs, edging, and trim ends.

This study produced 79-percent dimension lumber, all 2x4, 2x6, or 2x8; the other 21 percent was 1-inch lumber not over 8 inches wide. Tables 5 and 6 show lumber grade recovery as a percentage of lumber tally volume by 1-inch diameter classes for the live and dead logs; similar data are shown for live and dead trees in tables 7 and 8.

The average LRF, based on the surfaced dry lumber tally, for this study was 5.64 for the live logs and 5.57 for the dead. This is consistent with cubic-volume recovery percents for the live and dead logs.

Even though the cubic recovery ratios for the live and dead logs and trees are nearly alike, the differences in recovery by lumber grade are important, particularly in the dimension grades because of the loss in value from deterioration of the dead timber. The live logs and trees produced 47 percent of the total lumber tally volume as Standard and Better grade lumber, whereas only 24 percent of the lumber was graded Standard and Better for the dead logs and trees. The major reason for the difference is that the checking inherent in the dead material resulted in more Utility or No. 3 and Economy grade lumber; 17 percent of the recovered volume from live logs and trees was Utility or No. 3 and 8 percent Economy; the yield for dead logs and trees was 37 percent Utility or No. 3 and 13 percent Economy. Yield in stud grades was 6 percent for the live logs and trees and 5 percent for the dead. These relationships are depicted by diameter class in the histograms in figures 2 and 3.

Table 5--Lumber grade recovery by diameter class for live lodgepole pine logs

Log scaling diameter	Number of logs	Total lumber tally	Lumber grade: Moulding	No. 1 Common	No. 2 Common	No. 3 Common	No. 4 Common	No. 5 Common	Select structural	Construction or No. 1	Standard or No. 2	Utility or No. 3	Economy	Stud	Economy stud
Inches		Board feet	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	Percent of total lumber tally volume	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -
4	14	626	0.48	0.96	4.95	16.45	10.38	8.95	6.71	5.59	16.77	10.06	2.24	11.82	4.63
5	38	2,267	.35	.66	3.75	10.67	6.09	5.21	10.50	12.92	17.73	13.19	7.54	7.32	4.06
6	53	4,636	.24	1.23	1.19	9.04	4.85	3.71	16.76	12.36	19.67	17.49	8.09	3.47	1.90
7	8	957	--	.73	3.03	5.54	4.60	1.46	24.66	7.84	15.99	25.29	9.93	.42	.52
8	5	783	--	.38	3.83	5.62	2.68	4.85	32.18	10.34	10.22	23.50	5.11	1.28	--
9	5	571	.70	--	--	4.20	3.15	2.63	35.55	21.54	7.01	12.61	9.11	3.50	--
10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	1	119	--	4.20	2.52	3.36	10.08	3.36	26.89	--	26.89	13.45	9.24	--	--
Total or average	124	9,959	.26	.93	2.34	8.93	5.25	4.19	17.87	11.85	17.31	16.94	7.61	4.37	2.15

Table 6--Lumber grade recovery by diameter class for dead lodgepole pine logs

Log scaling diameter	Number of logs	Total lumber tally	Lumber grade												
			Moulding	No. 1 Common	No. 2 Common	No. 3 Common	No. 4 Common	No. 5 Common	Select structural	Construction or No. 1	Standard or No. 2	Utility or No. 3	Economy	Stud	Economy stud
Inches		Board feet	- - - - - - - -	- - - - -	- - - - -	- - - - -	- - - - -	Percent of total lumber tally volume	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -
4	7	292	--	--	7.53	18.15	10.27	6.51	--	2.40	2.40	13.70	8.22	23.97	6.85
5	33	1,777	--	0.56	2.59	13.51	7.60	7.65	4.95	3.94	15.76	19.25	9.90	11.25	3.04
6	64	5,704	0.12	.05	1.28	7.42	5.94	5.43	4.68	4.70	16.09	35.83	14.13	3.28	1.03
7	25	2,449	--	.33	.29	4.74	5.23	5.19	7.51	4.08	14.90	44.47	10.45	2.04	.78
8	5	598	--	--	--	4.52	12.21	3.18	5.52	12.71	10.54	41.97	7.69	1.67	--
9	8	1,353	.22	.22	--	2.59	6.73	5.40	5.32	11.68	9.09	44.86	13.16	.74	--
10	7	1,151	.70	--	.26	5.65	5.13	6.69	5.04	7.65	7.04	41.44	20.42	--	--
11	1	122	--	--	--	8.20	13.11	3.28	--	--	--	54.92	17.21	3.28	--
12	1	171	--	--	5.26	2.34	8.77	2.34	--	--	8.19	49.71	20.47	--	2.92
Total or average	151	13,617	.13	.18	1.18	7.15	6.51	5.65	5.16	5.63	13.59	36.73	13.05	3.90	1.15

Table 7--Lumber grade recovery by diameter class for live lodgepole pine trees

Tree d.b.h.	Number of trees	Total lumber tally	Lumber grade												
			Moulding	No. 1 Common	No. 2 Common	No. 3 Common	No. 4 Common	No. 5 Common	Select structural	Construction or No. 1	Standard or No. 2	Utility or No. 3	Economy	Stud	Economy stud
Inches		Board feet	Percent of total lumber tally volume												
7	2	77	--	3.90	7.79	11.68	12.99	7.79	--	20.78	9.09	--	--	25.97	--
8	19	720	0.42	3.75	2.64	13.89	8.75	9.31	--	4.31	14.31	7.78	15.00	12.22	7.64
9	31	1,572	1.21	1.59	4.07	15.46	6.23	5.73	8.02	10.94	14.69	13.99	7.12	7.25	3.69
10	21	1,502	--	1.00	2.80	9.45	5.99	3.73	22.10	12.98	16.55	12.52	3.99	6.72	2.26
11	18	1,829	--	.44	1.37	6.62	5.25	2.95	14.00	10.11	25.86	22.58	7.49	2.08	1.26
12	19	2,320	.17	--	1.12	5.26	3.19	4.35	21.64	16.25	15.73	21.03	8.66	1.51	1.08
13	2	416	--	--	5.53	5.77	5.05	.72	35.10	8.41	19.95	8.89	6.01	2.16	2.40
14	7	1,332	--	.75	1.43	8.18	3.45	2.70	28.98	12.69	13.06	20.20	7.81	.75	--
15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	1	119	--	4.20	2.52	3.36	10.08	3.36	26.89	--	26.89	13.45	9.24	--	--
Total or average	120	9,887	.26	.94	2.30	8.84	5.16	4.22	18.00	11.93	17.35	17.06	7.67	4.20	2.07

Table 8--Lumber grade recovery by diameter class for dead lodgepole pine trees

Tree d.b.h.	Number of trees	Total lumber tally	Lumber grade: Moulding	No. 1 Common	No. 2 Common	No. 3 Common	No. 4 Common	No. 5 Common	Select structural	Construction or No. 1	Standard or No. 2	Utility or No. 3	Economy	Stud	Economy stud
Inches		Board feet	- - - - - - - - - -	- - -	- - -	- - -	- - -	- - - Percent	of total	lumber tally volume	- - -	- - -	- - -	- - -	- - -
7	5	136	--	--	12.50	22.79	8.82	2.21	--	5.15	--	--	11.03	30.15	7.35
8	16	498	--	1.41	5.42	19.88	5.62	10.64	--	5.42	13.25	11.85	3.41	18.07	5.02
9	24	1,070	--	.47	2.62	16.82	10.19	5.89	0.93	5.05	14.86	19.72	12.34	8.88	2.24
10	21	1,412	--	--	2.34	11.05	7.22	6.02	10.76	6.02	18.34	18.06	13.46	5.31	1.42
11	23	1,840	--	--	.33	4.62	6.52	4.62	3.70	4.08	19.51	33.97	15.33	5.43	1.90
12	19	2,008	--	--	.80	5.18	5.28	4.23	5.33	3.54	16.78	42.03	12.30	3.88	.65
13	17	2,344	0.30	.26	.43	5.25	6.10	5.67	9.56	3.37	9.47	45.78	12.46	1.37	--
14	9	1,526	.72	--	.20	3.93	5.24	6.16	4.00	15.07	13.30	43.45	7.27	.33	.33
15	7	1,493	--	--	.87	4.55	8.37	5.02	2.88	6.43	8.71	48.36	14.13	.33	.33
16	1	172	--	--	--	3.49	3.49	2.91	--	6.40	9.30	43.60	25.00	2.91	2.91
17	2	396	--	--	1.26	4.29	6.82	9.60	--	--	15.91	38.64	22.22	--	1.26
18	3	670	--	--	--	6.12	4.18	5.67	5.52	4.78	4.48	48.06	21.19	--	--
Total or average	147	13,565	.13	.13	1.16	7.15	6.53	5.58	5.18	5.65	13.59	36.87	13.05	3.88	1.08

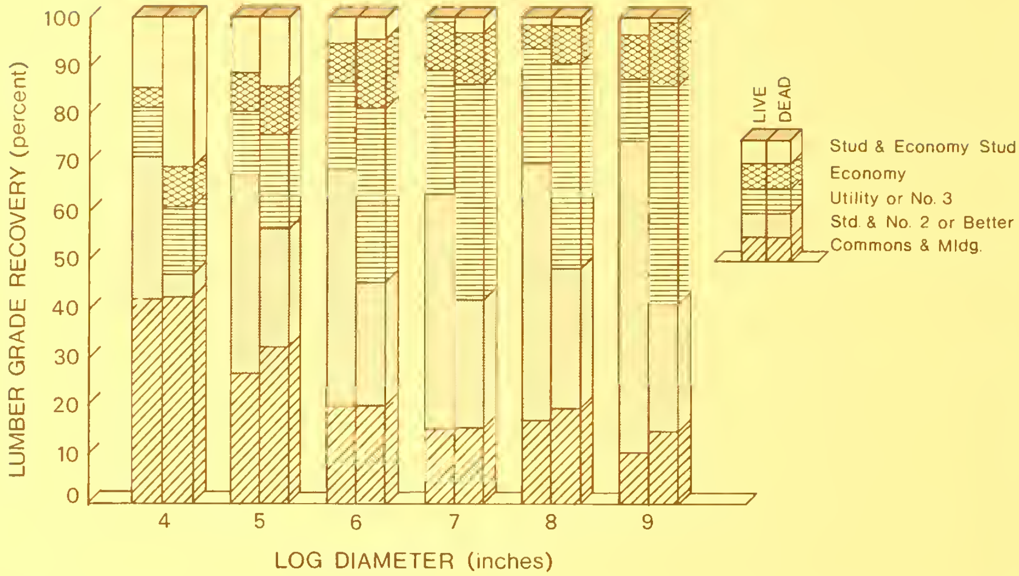

Figure 2.--Percent lumber grade recovery by diameter class for live and dead lodgepole pine logs in Wyoming.

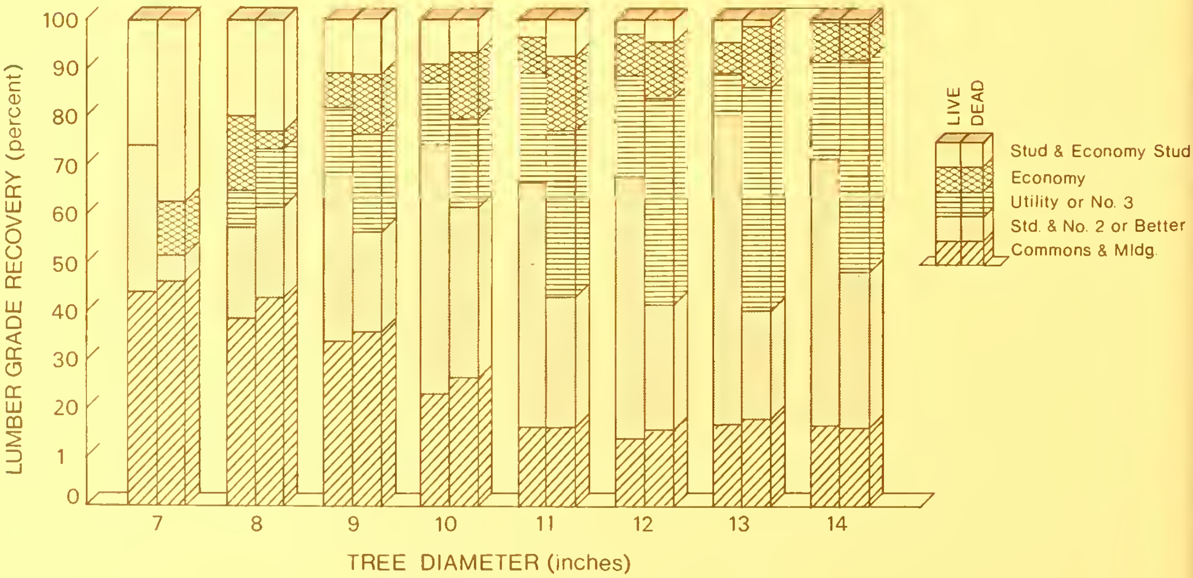

Figure 3.--Percent lumber grade recovery by diameter class for live and dead lodgepole pine trees in Wyoming.

SUMMARY

Standing dead lodgepole pine presents an opportunity for utilization of a resource that can extend the Nation's timber supply, but there are potential problems because of defect, small timber, and reduced grade yields. In this study, nearly the same amount of lumber was recovered from dead material as from live material, but the dead material showed a marked reduction in grade recovery compared with the live. The amount of checking present in the logs was the primary reason for the lower grade of dead logs.

Metric Equivalents

1 inch = 2.54 centimeters
1 cubic foot = 0.028 3 cubic meter
1 acre = 0.404 7 hectare

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AN INSTRUMENT TO MEASURE STREAM CHANNEL GRADIENT AND PROFILES

by

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ABSTRACT

A waterlevel to measure streambed profiles and gradients is described. Line of sight is not required for accurate (to 1 cm) measurements. Assembly and use are discussed.

KEYWORDS: Measuring equipment, channel erosion.

Stream channel morphometry and gradient are important factors in determining the quality of salmonid habitat. Although several methods are available to measure profiles and gradients, they require line of sight and are frequently cumbersome in small stream measurements. We adopted a builders level to measure gradients and channel profiles, which eliminates many of the requirements of other methods.

The instrument is easy to use, inexpensive, and simple to build. Based on the principle that water seeks its own level, it is precise and accurate to 1 cm. The instrument we describe will measure a vertical drop up to 1 m. Larger drops and distances can be measured by constructing a larger instrument than the one described here.

The waterlevel (fig. 1) is constructed from a pair of 2-m x 1/2-in[1] type "L" or "M" copper water pipes, a pair of 1-m x 1/2-in O.D., 1/4-in I.D. plastic tubes, pipe fittings, and 1/4-in flexible plastic tubing. Each pipe is cut into a 1-m upper scale assembly section and a 1-m lower support section. The scale assembly receives the scale and the clear plastic pipe. The scale assemblies are prepared by removing two thirds of the diameter of 1-m length of each pipe with a table saw. Use a non-ferrous cutting blade and the fence set to guide the pipe.[2] The finished pipe is cleaned with a file to remove all sharp edges.

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[1]English measurements are used to correspond to commonly available materials on the U.S. market.

[2]Caution: A face shield and heavy gloves should be worn during this operation. The cutting generates heat and metal chips; and until filed, the cut edges are very sharp.

Figure 1.--The waterlevel device.

We used a calcomp plotter to draw the 1-m scale strip in 1-cm increments from 0 to 100 cm on waterproof mylar paper. The strip is placed inside the 1-m opening cut out of the copper pipe.

We sealed the scale strip between the clear plastic tube and the open copper pipe with a clear leak-tight sealer to maintain a closed water system inside the pipe and tube. The pipe and tube are clamped together until the sealer is set. Enough sealer should be used to insure a good bond between components. Excess sealer is easily removed from the face of the scale sight tube.

The scale assembly (1) is soldered into a tee connection (2) (fig. 2). A 1/2-in sweat to a 3/4-in NPT (National Pipe Thread) fitting (3) is soldered into the tee. A 3/4-in to 1/4-in NPT bushing (4) is connected to the 3/4-in NPT fitting. A 1/4-in thermoplastic tube fitting is mounted in the 1/4-in NPT bushing (5). The thermoplastic fitting is fitted with a short length of 1/4-in polyethylene tubing (6). The two level tubes are connected with a length of 1/4-in I.D. flexible plastic tubing. The length is optional, but we use a 10-m length. The flexible tubing is clamped onto the polyethylene tubing. The lower copper support section is sealed water tight and connected to the lower opening of the tee fitting. A threaded adapter between the tee and the support allows the two sections to be separated for transportation and storage.

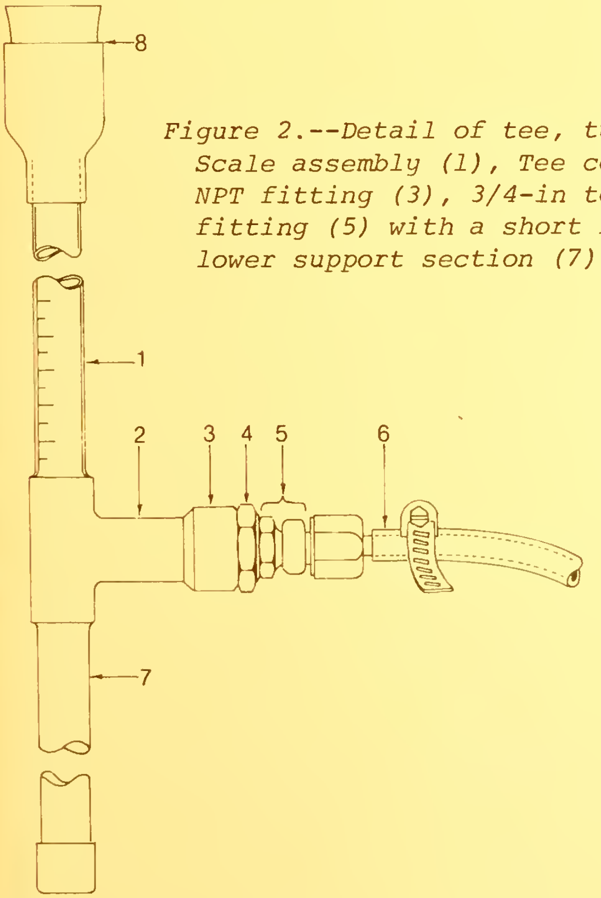


Figure 2.--Detail of tee, tubing connection, and top of waterlevel. Scale assembly (1), Tee connection (2), 1/2-in sweat to 3/4-in NPT fitting (3), 3/4-in to 1/4-in NPT bushing (4), thermoplastic fitting (5) with a short length of 1/4-in polyethylene tubing (6), lower support section (7), top fitted with a rubber stopper (8).

Both scale tubes must be the same height when finished so readings will be the same when the water tube assembly is vertical. Care must be taken to insure that all parts are made the same length and the scale strips are matched for each pair of scale tubes.

The water level system is filled with water to 40 or 50 centimeters on both sight tubes with both tubes held vertically on the same level. The water filled tubes must be free of air bubbles. An uneven water level indicates air bubbles, plugged or restricted tubes, or stoppers left in the top of the level tube. Stoppers are placed in the reducers (8) in the top of each level tube after filling and are removed during use (fig. 2). The connecting tube may be coiled for transportation to the stream site.

To calculate gradient, the horizontal distance (d) and the vertical drop (v) must be measured. The length of the flexible plastic tube represents horizontal distance (d), and the difference between the water level in the two scales h_1 and h_2 represent vertical drop (v). For example, let d = 10 m, the downstream reading h_1 = 87 cm, and the downstream reading h_2 = 17 cm, then gradient in percent (g) can be calculated from the general equation:

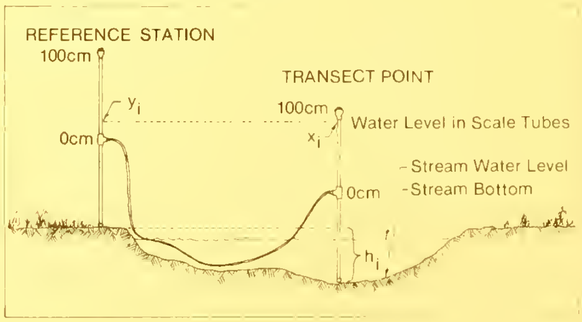
$$g = \frac{(h_1 - h_2)}{d_{cm}} \times 100$$

$$\text{where } d_{cm} = d \times 100$$

In the above example the gradient is 7.0 percent.

Stream cross-sections are measured in the same manner, but the water level on the bank (reference station) will change as the depth across the transect changes because there is a constant volume of water in the tube (fig. 3). The difference between the two readings is the vertical drop from the streambank to the stream bottom h_i (fig. 3). Let y = reference station reading, x = transect station reading, h = actual depth with respect to the reference station, and i = transect point. For the first transect point depth (h_i, i = 1) take both readings on the bank. At this point $x_i - y_i = 0$; thereafter $h_i = x_i - y_i$.

Figure 3.--Stream channel cross-section showing operation of a waterlevel device to measure channel profile.



The stoppers should be replaced to prevent water loss during transportation. After the stoppers are removed, the water will oscillate for a few seconds. Oscillations are also set up if the flexible tube is placed in a turbulent current. Readings can be taken with the tubing over, under, and around obstructions, even if the tubing is higher than the sight tubes. Line of sight is not necessary. The limit for vertical drop to be measured is 1 m.

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EFFECT OF DATE OF CONE COLLECTION AND STRATIFICATION PERIOD ON GERMINATION AND GROWTH OF DOUGLAS-FIR SEEDS AND SEEDLINGS

by

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Abstract

Low-elevation seeds collected 6 and 2 weeks before assumed natural seed fall were stratified 1, 2, 4, 8, 16, 32, 64, and 128 days and germinated in the laboratory. Germinated seeds from all stratification periods were sown at the same time in the nursery bed. Germination and seedling measurements were taken over two growing seasons.

Early collection gave smaller seeds, reduced germination percentage, and yielded smaller seedlings. Reduced seedling size appeared to be related to reduced seed weight.

Germination rates of both early- and late-collected seeds increased with increased stratification, but the response of late-collected seeds was greater. When time to 50 percent of total germination and length of stratification both were expressed in logs, the response was linear over the range of stratification periods. Stratification beyond about 30 days was detrimental to total germination of early-collected seeds.

Total height of 1st-year seedlings was linearly related to the log of stratification period only for late-collected seeds. The effect was small and not present by the end of the 2d year. Stratification appeared to increase 1st-year seedling size through its effect on hypocotyl extension. Epicotyl elongation rates during the exponential phase of elongation and elongation period were not affected by stratification period.

KEYWORDS: Germination (seed), seeding date, stratification (seed), cone collection, seed weights, seedling growth, Douglas-fir, Pseudotsuga menziesii.

INTRODUCTION

Exposure to low, but above freezing, temperatures during a resting phase often increases the potential rate of development during subsequent growth periods. Chilling of seeds previously brought to the proper moisture content (stratification) may affect germination rate (Allen 1958, McLemore and Czabator 1961, Mergen 1963), and chilling of seedlings may affect rate of bud-burst (Wommack 1964, Nienstaedt 1967, Campbell and Sugano 1979).

The low-temperature effects may be limited to a relatively short time during plant development, for example to the elongation of embryos prior to germination or to elongation of buds prior to flushing; however, it may also extend to processess of longer duration. Rohmeder (1962) and Kriek (1976) present evidence that speed of germination, which can be influenced by chilling, also affects seedling size. Others have observed that absence of low-temperature treatment continues to influence stem elongation processes after germination (Flemion 1934, Pollock 1959) or after bud burst (Schwabe 1973, R. K. Campbell, USDA Forestry Sciences Laboratory, Corvallis, Oreg., personal communication 1979).

In most germination and growth tests, the speed of germination has been confounded with other factors such as genetic composition, seed size, or onset of germination so that causal relations between germination rate and other factors could not be positively identified. The purpose of the present study was to investigate the effects of germination rate on growth of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings using a known source of seeds and timing germination to occur together. Samples from a single lot of seeds were stratified for different periods ranging from 1 to 128 days, germinated seeds were sown at the same time, and seedling size was measured periodically. As the maturity of seed is known to affect germination rate, seed weight, and possibly chilling response (Maki 1940, Cram and Worden 1957, Allen 1958, Ching and Ching 1962, Rediske 1969), seeds of two maturities were also included. Specific objectives were:

1. Relate germination rate and seedling size through 2 years in the nursery to maturity of seed and eight stratification periods.
2. Determine the mathematical relationships between stratification period and both germination rate and seedling size.

The purpose of the first objective was to further evaluate the extent and ways in which seed maturity and stratification might confound genetic comparisons (Olson and Silen 1975). The second objective was important because of ongoing and planned work relating seed germination and seedling bud-break patterns of different geographic sources of Douglas-fir to climate at the seed origin.

MATERIALS AND METHODS

Cone Collection and Handling

Cones were collected in 1976 from five trees growing in a low-elevation stand in the western Oregon Cascades (latitude 44° 35'N, longitude 120° 42'W, 275-m elevation). An "early" collection of approximately 50 cones per tree was made August 11 when cone scales were green to slightly brown. A "late" collection of similar size was made September 9 when cones were brown to opening, depending upon the tree. Fresh weights of five-cone samples from each tree were determined. The cones were then dried 72 hours at 80°C in a circulating-air oven, reweighed, and moisture percentage determined on a dry weight basis.

The remaining cones were allowed to dry at 22°C (room temperature) until the cone scales flared. Seeds were extracted by striking the basal ends of individual cones with a stick. After extraction, seeds were de-winged and X-rayed. Filled seeds from each tree were weighed and placed in cold storage (-10°C) until required for stratification treatments and sowing the following spring.

Seed Stratification and Germination

Seeds soaked in water for 24 hours at 22°C were stratified at 3°-4°C. Eight stratification periods, 1 to 128 days, were used and were arranged such that each stratification period doubled the length of the previous period, e.g., 1, 2, 4, 8 days, etc. In this way, stratification periods were closer together when the most response to stratification could be expected, and also the periods were equally spaced on a logarithmic scale. After stratification, seeds were germinated on moistened filter paper in covered sandwich boxes in a controlled environment chamber at a constant 20°C with a 12-hour light period. Seeds from each tree were germinated in separate boxes placed at random in the growth chamber.

Sample size for each of the 16 pregermination treatments (2 seed maturities and 8 stratification periods) consisted of 156 filled seeds (35 seeds from 4 trees and 16 seeds from 1 tree which had low numbers of filled seeds).

Germination was observed for 4 months, after which ungerminated seeds were cut. Seeds with decayed gametophytes and embryos were considered nongerminable, and germination rate and percent for each dish was based on the number of germinated + firm filled seeds in the dish (Allen 1960).

Mean rate of germination for each dish was determined by plotting cumulative percentage against $days^{-1}$ on probit paper (Campbell and Sorensen, in prep.). A straight line was visually fitted to the points and mean germination rate, R, read as $days^{-1}$ at which observed germination equaled 50 percent of total germination. Germination rates for each stratification period and seed maturity were based on the average rate of all five families. Families were not replicated within treatments, and no test was made of family differences.

Log Transformation of Germination Rate

Germination is the culmination of many processes and cannot be attributed to one event or treatment. Nevertheless, as the basis for the log transformation, I assumed that a change in the length of stratification was accompanied by some proportional change in the concentration of a reactant critical to the germination process. From this assumption, the relationships of chemical kinetics could be used to describe the response of germination rate to stratification period (Chang 1977).

The velocity of an nth order reaction is proportional to the nth power of the concentration of the reactant, thus

$$v = k[A]^n,$$

where,

v = velocity,
k is a constant,
[A] is the concentration of the reactant, and
n is the proportionality coefficient.

The value of n may be obtained by measuring v at several concentrations of A and plotting log v versus log [A]. Generally, initial velocities (V_o) are used because the accumulation of reaction products can affect subsequent velocities. In the case of germination, mean rates were used rather than initial rates because individual seeds within a family constituted a population and their rates were normally, or very close to normally, distributed when time to germination was expressed as t^{-1} (Campbell and Sorensen, in prep.).

If reaction velocity is equated to germination rate and concentration of the reactant equated to length of stratification, the above equation becomes,

$$R = k[S]^n,$$

where,

R = mean germination rate ($days^{-1}$ to 50 percent total germination),
k = constant,
[S] = duration of stratification (days), and
n = slope of the line relating R and [S].

Taking the common logarithms gives,

$$\log R = \log k + n \log [S]. \quad \text{(Eq. 1)}$$

When regression lines were compared statistically, the method of Snedecor and Cochran (1967, p. 432) was used.

Seedling Characters

Preliminary tests had indicated the total stratification + germination time needed to have germination of each treatment peak the last week in April, the time set for sowing. In actuality, three replications were sown April 26, one April 28, and one May 2. The delay was due to slow germination in seedlots with less stratification. This had two consequences. First, germinated seeds from faster germinating treatments (e.g., 64- and 128-day stratification) had to be returned to the cooler after germination to prevent further radicle development. Second, the slower germinating seeds in the short stratification treatments were not included in the seedling test. That is, the germinated seeds from the short-stratification treatments represented the portion of the population which had the greatest response to stratification. This was not true of the long-stratification treatments, because their seeds had essentially completed germination by the sowing dates.

The seedling test was established using germinated seeds from each of the 16 treatments in the germination test. Seeds were sown in eight-seedling rowplots.

The following traits were measured and analyzed,

1. Hypocotyl length.
2. Elongation rate between June 15 and August 24. Total height was measured every 2 weeks during the 1st year starting June 15. Plots of log height against time were linear between June 15 and August 24. The slope of this line (elongation rate) was determined for each rowplot.
3. Date of final budset, 1st year. Observations of the terminal growing point were made weekly, and a bud was considered set when green scales could first be seen at the base of the needles.
4. Total 1st-year height.
5. Total height after 2 years.
6. Diameter below the cotyledons after 2 years.

Seedling data was analyzed as a 2x8 factorial in a randomized complete block design with five replications. Rowplot means were used as the unit of observation. All treatments were fixed. Expected mean squares are:

Sources of variation	d.f.		Expected mean squares
Total	79		
Replication (R)	4		
Collection date (C)	1		$\sigma^2 + rs\ \sigma^2_C$
Stratification period (S)	7		$\sigma^2 + cr\ \sigma^2_S$
Linear		1	
Nonlinear		6	
C x S	7		$\sigma^2 + r\ \sigma^2_{CS}$
C x S linear		1	
C x S nonlinear		6	
Remainder	60		σ^2

RESULTS

Cone and Seed Measurements

Fresh and dry weights and moisture percentages of cones from the early collection were somewhat greater than for late-collected material (23.9 versus 21.2 g, 10.4 versus 10.1 g, and 128 versus 110-percent H_2O, respectively). Comparing moisture percentages with those reported in Ching and Ching (1962) indicates that the cones in the late collection were still about 2 weeks from full maturity. The time of natural seedfall was not observed, but it was assumed that the early collection was about 6 weeks and the late collection about 2 weeks prior to seedfall.

Filled seed weights from early and late collections were 10.2 and 12.6 mg, respectively.

Germination

Both stratification period and seed maturity affected percent germination of full firm seeds after 4 months in the germinator (fig. 1). For late-collected seeds, the relationship was linear with log [S]--each doubling of the stratification period increased total germination by an average of about 3 percent. Full germination (98 percent for this material), however, appeared to be achieved with about 30 days of stratification. For early-collected seeds, total germination was lower and the relationship to stratification period was curvilinear. Germination percentage increased for up to 16 days of stratification; stratification periods longer than 32 days appeared to be detrimental.

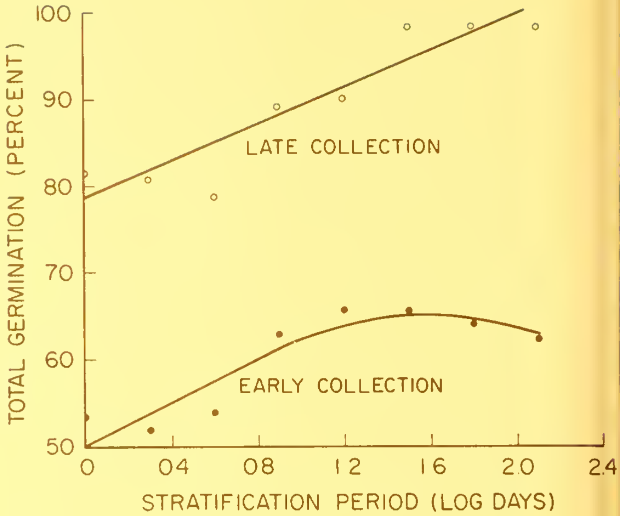

Figure 1.--Effect of stratification period on total germination percent of full, firm Douglas-fir seeds collected approximately 6 and 2 weeks before natural seed fall. ● = early collection; o = late collection.

The effects of seed maturity and length of stratification period on germination rate are shown in fig. 2. With short stratification, the early-collected seeds germinated more rapidly than the late-collected seeds. As length of stratification was increased, the difference in rates due to collection date decreased.

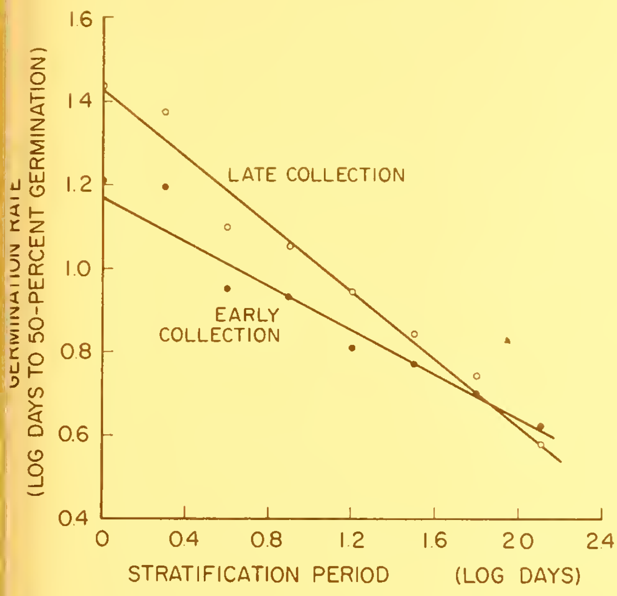

Figure 2.--Regression of germination rates of Douglas-fir seeds collected approximately 6 and 2 weeks prior to natural seed fall on stratification period. ● = early collection; o = late collection. The slopes of the lines are significantly different ($F=19.31$; d.f.=1, 12; $p < 0.01$).

Seedling Traits

The effect of cone collection date on seedling size was significant for early measurements but did decrease with age (table 1). At the end of 2 years in the nursery, significant height differences had disappeared but significant diameter differences were still present.

Length of stratification affected size of seedlings grown from late-collected seeds but had little or no effect on seedlings grown from early-collected seeds. The relationship to 1st-year total height is shown in fig. 3. This relationship between stratification period and height was no longer significant for either seed maturity by the end of the 2d year in the nursery.

Table 1--Effect of date of cone collection on Douglas-fir seed and seedling traits. Early collection was made approximately 6 weeks and late collection approximately 2 weeks before natural seed fall

Trait (unit)	Cone collection date		Percent of decrease	Significance
	Early	Late		
Filled-seed weight (mg)	10.2	12.6	19	[1]0.01
Hypocotyl length (cm)	1.41	1.51	7	.01
Elongation rate[2]	.176	.176	0	n.s.
1-year total height (cm)	15.5	16.8	8	.01
1-year bud set (date)	Oct. 3	Oct. 3	0	n.s.
2-year total height (cm)	34.3	35.5	3	n.s.
2-year diameter (mm)	6.07	6.45	6	.01

[1]Significance of 0.01 indicates that the probability of no difference due to date of cone collection 0.01, n.s. = nonsignificant.

[2]Cm/cm per 2 weeks between June 15 and August 24 of the 1st year in nursery.

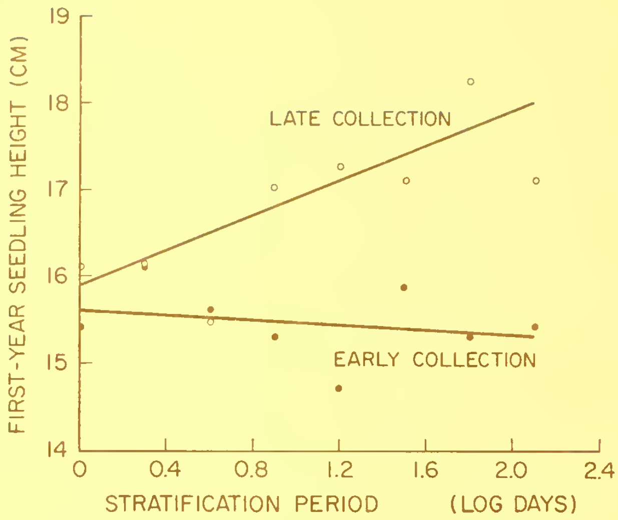

Figure 3.--Effect of seed collection date and stratification period on 1-year heights of Douglas-fir seedlings. ● = early collection; o = late collection. Each point is the mean of five replications. The slopes of the two lines are significantly different ($F=5.91$; d.f.=1, 60; $p < 0.05$).

DISCUSSION

Germination

Total germination of filled late-collected seeds was 78 percent or better following all lengths of stratification; nevertheless germination improved significantly when seeds were stratified for periods up to 1 month. Thirty days of cold, moist storage was sufficient to raise total germination of mature seeds to 98 percent.

Total germination of filled early-collected seeds was lower. Also, early-collected seeds responded to longer stratification periods differently than late-collected seeds. Although Allen (1958) reported that stratification appeared to have a detrimental effect on most of the "immature" seed in "immature" lots, Ching and Ching (1962) found stratification to be beneficial to seeds of all maturities. They suggested that differences in stratification procedures might explain why their results differed from those of Allen. My results indicate one aspect of stratification procedure, length of stratification, does influence total germination percentage of immature seeds--short stratification periods being beneficial and periods beyond about 30 days detrimental.

The log of days to 50 percent germination was closely correlated with log of stratification period (fig. 2). Examination of a limited amount of other data (Allen 1962, Sorensen, unpubl.) indicated that the relationship may be general but that the slope of the line may vary for seeds of different geographic origins as well as for seeds of different maturities. The lines in fig. 2 indicate that four to six stratification periods equally spaced on the log time scale, starting with a short stratification period and extending to about 10 weeks stratification should characterize the relationship between stratification period and germination rate for Douglas-fir seeds.

Germination rates of early-collected seeds were not affected by stratification as much as were the germination rates of late-collected seeds. If germination rates after little or no stratification indicate degree of embryo dormancy or rest, then the early-collected seeds in this study were less dormant initially than the late-collected seeds. Since dormancy may deepen in cold storage for loblolly pine (<u>Pinus taeda</u> L.) (McLemore and Barnett 1966), storage time may also affect the response to stratification period.

Seedling Growth

In this test, weights of early-collected seeds were 19 percent less than weights of late-collected seeds and seedlings grown from early-collected seeds averaged 8 percent shorter than seedlings grown from late-collected seeds (table 1). In previous studies in which Douglas-ir seedlings were raised from seeds of different weights (Sorensen 1973 nd unpubl.), it was estimated that 10-percent difference in seed weight was accompanied by a dif-erence in 1st-year height of about -5 percent. Thus, there was no vidence that the reduction in eedling vigor associated with arly cone collection was due to actors other than seed size.

The results indicated that the direct effect of stratification on late-collected seeds continued during epicotyl extension but not thereafter. Although the relation between stratification period and 1st-year height was significant, this was apparently the result of the relationship between stratification period and hypocotyl length, because stratification period did not influence either elongation rate during the exponential phase of stem extension or length of the growing season.

It is probable that stratification period would usually have a greater indirect effect on seedling size through its effect on onset of germination than it does through its direct effect on hypocotyl extension. In this test, pregerminated seeds were sown. Consequently, all seedlings started nursery growth at the same time. The germination rate results show, however, that if ungerminated seeds with different stratification periods had been sown in the nursery, they would have germinated and started growth at greatly different times. Further, our germination test was conducted at 20°C. Nursery soils are often cooler than this at the time of sowing. Allen (1960) reported that decreasing the length of stratification decreased the rate of low-temperature germination (10°C) of Douglas-fir seeds even more than it did the rates of germination at higher temperatures. Because the date at which seedling growth starts can influence both the length of the growing season and the relationship of particular developmental phases with the annual climatic cycle, the date of germination could have a large effect on seedling size and form (Sorensen 1978).

McLemore also concluded that the differences in size of seedlings from stratified and unstratified loblolly pine seed was due to earlier germination of the former.[1/] Lavender[2/] has made similar observations in a Douglas-fir nursery. Lavender also noted that there appeared to be an interaction between the effects of stratification period on germination rate and date of sowing in the nursery. This was apparently due to the change in nursery soil temperature during the spring (Lavender, unpubl.) and is in line with the experimental results of Allen (1960) and with other observations on the interacting effects of stratification period and germination temperature on germination rate (Vegis 1963).

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LOGGING COSTS FOR A TRIAL OF INTENSIVE RESIDUE REMOVAL

by

Thomas C. Adams, *Economist*

Abstract

Logging costs were developed in a study of residue removal to specified levels in each of three size classes: 1/4 to 3, 3.1 to 9, and over 9 inches in diameter. These levels were determined by an interdisciplinary team during initial sale planning and represented levels that would be desired to attain without slash burning. Cable yarding was specified. This trial was conducted on the Wind River Experimental Forest near Carson, Washington.

KEYWORDS: Logging enterprise costs, residue management, intensive management.

INTRODUCTION

Forest managers are seeking ways to reduce the need for broadcast slash burning. Residue removal is one alternative. Accordingly, a trial of intensive residue removal was conducted on the Wind River Experimental Forest, Gifford Pinchot National Forest, near Carson, Washington, during 1975-77. This trial was on three clearcut units of the Trout Creek Hill timber sale, at about 1,800-foot elevation, in old-growth western hemlock, Douglas-fir, and Pacific silver fir (fig. 1).

The purpose of this trial was to test the practicability of residue-level prescription by an interdisciplinary team, with the timber sale purchaser responsible for achieving the desired end result. This note covers production rates and logging costs for the three levels of residue removal tested. Residue management aspects of this timber sale are reported in another research note.[1]

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[1]Thomas C. Adams, Managing logging residue under the timber sale contract. USDA For. Serv. Res. Note PNW-348, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Figure 1.--High-lead tower yarding to residue pile on Unit 1, Trout Creek Hill timber sale.

TIMBER SALE SPECIFICATIONS

Yarding Specifications

Three residue levels were specified, one on each of three clearcut units of this sale. The residue level selected for Unit 2 was determined by an interdisciplinary team who examined the area during sale preparation. Residue specifications for Unit 1 were set at approximately 30 percent less than on Unit 2, and for Unit 3 about 30 percent more (table 1). The specified residue levels were to be met through cable yarding, without burning.

Table 1--Specified and actual residue levels by diameter class (actual residue levels after logging shown in parentheses)

Cutting unit	Diameter class (inches)			
	1/4-3	3.1-9	Over 9	Total
	Tons per acre			
1	4-6 (5.6)	4-8 (2.9)	0 (0)	8-14 (8.5)
2	5-9 [1](9.1)	6-11 (5.2)	<10 (4.4)	<30 (18.6)
3	8-13 (8.5)	8-14 (8.4)	<20 (9.3)	<47 (26.2)

[1]Actual residue level of 9.1 tons per acre was not a meaningful deviation from the specified level.

Residue Measurement

The timber sale contract specified that the Forest Service would measure residue levels frequently, with volume of residue on each sampling area required to be under the maximum amount specified, for each of the three size classes 1/4 to 3, 3.1 to 9, and over 9 inches in diameter. No rearrangement of residue was required if minimum specified levels were not met, as in the 3.1 to 9-inch diameter class in two cutting units.

Residue volumes were measured by the planar intersect method and calculated in both cubic feet and tons per acre.[2] All weights represent ovendry tons.

RESULTS

Yarding was by the high-lead cable system. Most of the initial yarding was with a 90- or 100-foot tower; later a smaller yarder with a 70-foot tower was used for some of the yarding.

After trying several methods of yarding tops and small residue concurrently with regular yarding of merchantable logs, the operator shifted to two-stage yarding, with cull logs and other residue material yarded in a separate second stage. Some of the large cull logs were yarded during the first stage.

Tops were mostly broken up in felling or during the first-stage yarding. These and the many branches and short chunks slowed production (fig. 2). Small pieces were often choked in bundles, some of which were prepiled to avoid delays. Much breakage occurred, however, as these bundles traveled along the ground.

Table 1 shows resulting residue levels in parentheses below each entry for the specified levels. Attained levels were generally well under the maximums allowed, chiefly because of the need to be within specified limits on each sampling unit and because extra quantities in the 3.1- to 9-inch diameter class were yarded in order to reach specified levels for the smaller material attached to those pieces.

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[2]Brown, James K. 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16, 24 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Figure 2.--Two turns of residue material being yarded to piles on landing.

Time and Production Data

Daily time sheets were prepared by the operator, showing man- and machine-hours worked on each unit. These were summarized by the two stages, main yarding and residue yarding (table 2). In this report, man-hours cover total time on the job including travel time; machine-hours include operating time minus delays over 15 minutes.[3] Crew size varied at times, and was generally smaller for the residue yarding stage.

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[3]Tractor time is shown separately for operating time and standby time when machine is available on the site but not operating. Loader machine time attributable to piling residue material and keeping landing clear was included only for the first few days on Unit 1 before the shift to two-stage yarding. Yarder and loader fixed costs are considered amortized over annual machine-hours; hence, fixed costs for these machines are not charged for delay times of more than 15 minutes.

Table 2--Man-hours and machine-hours for yarding Units 1, 2, and 3

Stage of yarding	Unit 1	Unit 2	Unit 3
		Hours	
A. Main yarding			
Man-hours:			
Straight time	2,755	3,460	3,567
Overtime	30	0	0
Machine-hours:			
100' yarder	273	126	304.5
90' yarder	186	403	283.5
70' yarder	64.5	0	0
Tractor, 180-flywheel hp:			
Standby time	244	341	0
Operating time	23.5	9	0
Tractor, 235-flywheel hp:			
Standby time	97.5	62.5	248.5
Operating time	6.5	1.5	20.5
B. Residue yarding			
Man-hours:			
Straight time	5,510	2,865	2,156
Overtime	115	64	70
Machine-hours:			
100' yarder	11	0	222
90' yarder	748	376.5	182.5
70' yarder	324	170	0
Loader	27	0	0
Tractor, 180-flywheel hp:			
Standby time	183.5	0	0
Operating time	7.5	0	0
Tractor, 235-flywheel hp:			
Standby time	5	70	118
Operating time	3	6	18

The three cutting units in this trial were sold on a cubic-foot basis. A total of 22,473 cunits[4] were removed (table 3).

Table 3--Yarding production data

Item	Unit 1	Unit 2	Unit 3	Total
		Cunits[1/]		
A. Scaled net volume removed	5,766	8,002	8,704	22,472
		Tons		
B. Tons of residue yarded in residue yarding stage	4,697	3,904	3,600	12,201
		Tons per acre		
C. Tons per acre yarded in residue yarding stage	70.1	64.0	51.4	--

[1/] One cunit equals 100 cubic feet.

Yarding Costs

Per-hour yarding costs were estimated using a modification of the 1974 Bureau of Land Management Schedule 19 timber appraisal cost guide.[5] A factor of 1.15 was used to convert the 1974 cost data to a 1976 base. Adjusted wage rates used in this application include additions for workmen's benefits (19 percent), direct supervision (10 percent), and employer's contributions for unemployment compensation, industrial accident insurance, and social security (22 percent) (table 4).

Applying these rates to the production data of table 2 gave total costs for yarding (table 5), excluding fire protection and moving costs.

Residue yarding accounted for 65, 46, and 42 percent of total yarding cost for Units 1, 2, and 3, respectively. Residue yarding on the three units combined accounted for 53 percent of total yarding cost.

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[4] One cunit equals 100 cubic feet.

[5] U.S. Bureau of Land Management. 1974. Timber appraisal production cost schedule 19, U.S. Bureau of Land Management, Oregon State Office, var. pages, illus. Portland, Oreg.

Table 4--Wage rate summary for yarding crew

Crew member	1974 basic wage	1976 basic wage	1976 adjusted wage
		Dollars per hour	
Hook tender	$5.97	$6.87	$10.37
Rigging slinger	5.12	5.89	8.89
Choker setters (2 x $4.58)	9.16	10.52	15.90
Chaser	4.75	5.46	8.23
Yarder engineer	5.50	6.32	9.54
Total, 6 people	30.50	35.06	52.93
Average	5.08	5.84	8.82

Source: Developed from Bureau of Land Management Timber appraisal production cost schedule 19, U.S. Bureau of Land Management, Oregon State Office, Portland, Oreg., 1974.

Residue yarding costs per acre were estimated at $1,365 on Unit 1, $768 on Unit 2, and $550 on Unit 3, with the three units together averaging $893 per acre (table 6).

Estimated yarding costs per cunit of scaled volume removed on Unit 1 were $8.60 for main yarding and $15.88 for residue yarding. On Unit 3 these costs were $6.19 for main yarding and $4.42 for residue yarding.

Residue yarding cost per ton of residue amounted to $19.47 on Unit 1, $11.99 on Unit 2, and $10.69 on Unit 3, with the three units averaging $14.49 per ton.

From table 3 and 6, residue yarding on Unit 2 removed 12.6 more tons per acre than on Unit 3, at an extra cost of $218 per acre, or $17.30 per extra ton of removal. In the same fashion residue yarding on Unit 1 removed 6.1 more tons per acre than on Unit 2, at an extra cost of $597 per acre, or $97.87 per extra ton of removal.

Table 5--Cost of main yarding and residue yarding, Units 1, 2, and 3

Stage of yarding	1976 hourly rate[1]	Unit 1	Unit 2	Unit 3
		Dollars		
A. Main yarding				
Labor:				
Straight time	$8.82 (av.)	$24,299	$30,517	$31,461
Overtime	13.23	397	0	0
Total labor cost		24,696	30,517	31,461
Equipment:				
100' yarder	34.83	9,509	4,389	10,606
90' yarder	29.96	5,573	12,074	8,494
70' yarder	24.82	1,601	0	0
Tractor, 180-flywheel hp:				
Standby time	7.75	1,891	2,643	0
Operating time	23.47	552	211	0
Tractor, 235-flywheel hp:				
Standby time	10.82	1,055	676	2,689
Operating time	31.64	206	47	649
Total equipment cost		20,387	20,040	22,438
Total equipment and labor cost		45,083	50,557	53,899
Total including 10-percent overhead		49,591	55,613	53,900
B. Residue yarding				
Labor:				
Straight time	8.82 (av.)	48,598	25,269	19,016
Overtime	13.23	1,521	847	926
Total labor cost		50,119	26,116	19,942
Equipment:				
100' yarder	34.83	383	0	7,732
90' yarder	29.96	22,410	11,280	5,468
70' yarder	24.82	8,042	4,219	0
Loader	16.13	436	0	0
Tractor, 180-flywheel hp:				
Standby time	7.75	1,422	0	0
Operating time	23.47	176	0	0
Tractor, 235-flywheel hp:				
Standby time	10.82	54	757	1,277
Operating time	31.64	95	190	570
Total equipment cost		33,018	16,446	15,047
Total equipment and labor cost		83,137	42,562	34,989
Total including 10-percent overhead		91,451	46,818	38,488
C. Total		$141,042	$102,431	$92,388

Source: Developed from Bureau of Land Management, Timber appraisal production cost schedule 19, U.S. Bureau of Land Management, Oregon State Office, Portland, Oreg., 1974. Hourly rates for yarders are estimates derived from data given for 110- and 65-ft towers.

[1] Hourly equipment rates include fixed costs plus operating costs, except for tractor standby time which includes fixed costs only.

Table 6--Summary costs of main yarding and residue yarding, Units 1, 2, and 3[1]

Item	Unit 1 67 acres	Unit 2 61 acres	Unit 3 70 acres	Total or average 198 acres
		Dollars		
A. Yarding cost				
Main yarding	$49,591	$55,613	$53,900	$159,104
Residue yarding	91,451	46,818	38,488	176,757
Total	141,042	102,431	92,388	335,861
		Dollars per acre		
B. Cost per acre				
Main yarding	740	912	770	804
Residue yarding	1,365	768	550	893
Total	2,105	1,680	1,320	1,697
		Dollars per cunit[2]		
C. Yarding cost per cunit of scaled net volume removed in main yarding				
Main yarding	8.60	6.95	6.19	7.08
Residue yarding	15.88	5.85	4.42	7.87
Total	24.48	12.80	10.61	14.95
		Dollars per ton		
D. Residue yarding cost				
Residue yarding	19.47	11.99	10.69	14.49

[1]Attained residue levels: Unit 1 8.5 tons per acre.
Unit 2 18.6 tons per acre.
Unit 3 26.2 tons per acre.

[2]One cunit equals 100 cubic feet.

DISCUSSION

Excessive Yarding Costs

The high residue yarding costs indicate that in the absence of compelling reasons to avoid burning, broadcast burning or machine piling and burning should probably be retained as a preferred alternative for this kind of site. Conventional YUM yarding[6] to 8-inch diameter inside bark at the large end, to 10-foot length, combined with a light spring burn of fine material could have saved a considerable amount of time and money. However, this trial was intended to provide experience and cost information applicable to situations where an alternative to burning would be desired.

Alternative Logging Systems

The second-stage yarding costs could have been reduced with lighter equipment and a smaller crew; however, this would have required yarding all the large cull material in the first pass with the large equipment, and using a grapple skidder or some other means to keep the landing area cleared.

Minimum bucking-out of breaks or cull segments might have reduced yarding costs where these pieces also were yarded later; but a brief trial of tree-length yarding resulted in congestion, delays, and less efficient bucking at the landing.

CONCLUSIONS

1. This trial of intensive residue removal by high-lead system in an old-growth forest was a rather costly procedure in relation to management goals. Additional site preparation was judged necessary for replanting on this site.
2. High costs of yarding small residue by standard high-lead equipment suggests that such equipment is not suitable for such small material.
3. In absence of a market for small residue material, some form of slash burning on this site will continue to be the favored treatment on old-growth clearcut units to reduce small residue to acceptable levels.

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[6] YUM yarding is an acronym for yarding of unutilized material.

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MANAGING LOGGING RESIDUE UNDER THE TIMBER SALE CONTRACT

by

Thomas C. Adams, Economist

ABSTRACT

Management of logging residue is becoming an important part of timber sale planning. This involves controlling the amount of residue remaining on the ground and its distribution by diameter size class. Some residue is beneficial.

An interdisciplinary team specified a desired residue level for one clearcutting unit of this trial. For comparison another cutting unit was given a specified residue level approximately 30 percent greater, and another unit 30 percent lower.

KEYWORDS: Residue management, stumpage sales arrangement.

INTRODUCTION

Forest managers are giving increased attention to management of logging residue. This includes not only reduction of residue to a manageable level, but also recognizes the need to leave some of the biomass on the ground for nutrient recycling, soil protection, seedling protection, and wildlife use.

Two steps were involved in this residue management trial; first, determining the desired residue level and second, carrying out the residue reduction to the desired level through the timber sale contract. The trial was undertaken during 1975-77 on the Wind River Experimental Forest, Gifford Pinchot National Forest, near Carson, Washington.

The trial sale was also designed to develop comparative production rates and costs for residue yarding. Those results are reported in another research note.

DESCRIPTION OF TRIAL SALE OFFERING

This trial was a part of the experimental Trout Creek Hill timber sale, in old-growth western hemlock, Douglas-fir, and Pacific silver fir, at an elevation of approximately 1,800 feet and on nearly level ground.

SALE BY CUBIC-FOOT MEASURE

Timber on the three cutting units of this sale covered by the residue level prescription was sold on a cubic-foot basis. All logs removed were scaled by the Columbia River Log Scaling and Grading Bureau at the High Bridge scaling station, under cubic-foot scaling instructions developed for this sale.

DETERMINING THE DESIRED RESIDUE LEVEL

An interdisciplinary team was assembled during timber sale preparation to determine a desired residue level in each of three diameter classes, designed to meet prescribed forest land management objectives. Team members were guided by a photo series illustrating a wide range of residue levels.[1] The team consisted of staff specialists from the Regional Forester's Office (Region 6) and the Gifford Pinchot National Forest Supervisor's Office, having skills in landscape management, soils, silviculture, wildlife management, and fire management. Each person was asked to specify a desired residue level, by diameter class. These residue levels were then reviewed by the team as a whole, and a consensus reached for a single prescription in each of the three diameter classes, expressed in tons per acre. These levels, with minor adjustment, were specified for Unit 2 of the timber sale. Levels approximately 30 percent lower were specified for Unit 1, and approximately 30 percent higher for unit 3 (table 1, fig. 1).

Prospective purchasers were advised that reaching the specified residue levels in the 1/4 to 3-inch diameter class on Units 1 and 2 might require stage logging, minimum bucking, and/or yarding of up to 100 percent of tops concurrent with regular log yarding, and on Unit 3 might require yarding of 50 percent of tops concurrent with regular yarding.

Specifications were shown in both cubic feet per acre and tons per acre, although in practice tons per acre became the primary reporting unit. Tons per acre were calculated by an adaptation of the planar intersect method for measuring forest residues.[2] All weights represent oven-dry tons.

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[1]Maxwell, Wayne G., and Franklin R. Ward. 1976. Photo series for quantifying forest residues in the: coastal Douglas-fir-hemlock type and coastal Douglas-fir-hardwood type. USDA For. Serv. Gen. Tech. Rep. PNW-51, 103 p., illus., Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

[2]Brown, James K. 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16, 24 p., illus. Intermtn. For. & Range Exp. Stn., Ogden, Utah.

Table 1--Specified residue level by diameter class

Unit	Diameter class			
	1/4-3"	3.1-9"	Over 9"[1]	Total
		Cubic feet per acre (Tons per acre)		
1	290-440 (4-6)	290-580 (4-8)	0 (0)	580-1,020 (8-14)
2	360-660 (5-9)	440-800 (6-11)	<730 (<10)	<2,190 (<30)
3	580-950 (8-13)	580-1,020 (8-14)	<1,460 (<20)	<3,430 (<47)

[1] Material in this size class is defined as those pieces firm enough to permit lifting and moving by choker and cable systems.

Figure 1.--Unit 1 (a), Unit 2 (b), and Unit 3 (c) after yarding to specified residue levels.

CONDUCT OF OPERATIONS

A study plan was made a part of the timber sale contract. This explained the residue management aspects and outlined responsibilities of both purchaser and Forest Service in carrying out the studies.

In cutting Units 1, 2, and 3 it was the purchaser's responsibility to remove material down to the specified residue levels, by cable yarding, without burning. The study plan called for unutilized material 6 inches and larger in diameter inside bark and 8 feet or more in length to be piled at the landing. Unutilized smaller pieces, whose removal was required to meet the specified residue levels, were yarded to the outer edge of the landings.

The Forest Service had responsibility to inventory residue levels every few days and to inform the purchaser of results. Each sampling area was expected to meet compliance with the upper limit of the specified residue level, but lower level limits were used only as a guide. That is, if the upper limit were exceeded, the purchaser would have to return and remove more material from the same sampling area; but if there was less than the minimum, no action was required.

Purchaser of the sale was Stevenson Co-Ply, Inc., of Stevenson, Washington. From the start it was recognized that meeting the specified residue levels on Units 1 and 2 would require yarding of some or all of the tops, with the main branches still attached. The operator, Ober Logging Company, commenced yarding with 90- and 100-foot towers, using the standard high-lead cable system. Later, a smaller yarder with a 70-foot tower was added so as to release the larger equipment for other use.

Terrain was nearly level, and the towers provided little or no lift beyond about 200-foot yarding distance. This resulted in tops being broken up during the yarding operation. Species composition was mostly western hemlock, and the brittle branches tended to break off either in felling or yarding. Yarding tops or branches along with regular logs slowed production and caused congestion and delays at the landing.

Several methods were tried to improve operations. These included using a crawler tractor to provide a short elevated tail hold, tight-lining within limits of the high-lead yarding equipment, rigging the tail block 30 to 40 feet high in a green tree, tree-length logging with tops left attached, and use of a brush grapple for tops and branches. None of these methods were satisfactory.

For a 2-week period a timber cutter was added to the landing crew to buck off tops and branch stubs. It was not possible to keep this man fully occupied, so bucking and limbing were shifted back to the stump area as in regular operations.

Even when tops and branches were yarded separately, additional delays occurred as this material accumulated at the landing area. Operations then had to be halted while the area was cleared, either with the loader or with a crawler tractor.

After a number of these trials, the operator shifted to two-stage yarding, and completed the three units. In this method all the regular logs were yarded first; then the entire setting was relogged for the cull logs, tops, chunks, and branches. Some of the larger cull logs were yarded during the first stage. Most of the second stage yarding was done by a separate yarder and a separate crew.

Short pieces and branches were choked in bundles, and at times a second crew was used to pile this material ahead to speed up yarding. However, much breakage of these bundles occurred during inhaul, and some pieces had to be handled two or three times before they reached the landing.

The operator proposed yarding the unutilized material with a mobile yarder positioned in the unit to permit smaller piles and shorter yarding distances. This proposal was not approved because of the fear of soil compaction and its effect on planned reforestation and silvicultural research.

In hindsight, some form of skyline operation would have reduced breakage of tops and branches during yarding, especially if this material were yarded concurrently with regular logs. Also, smaller chokers, including nylon chokers, might have increased efficiency in yarding small material.

RESULTS

Residue Levels

Resulting residue levels for pieces over 9 inches in diameter were mostly well under the maximums allowed (table 2). This was partly due to the requirement that each sampling area meet the specifications--low residue levels could not be balanced with high levels to give an acceptable average. Also, the operator did not want to go back and relog areas not meeting specifications. A third reason was that neither cubic feet nor tons per acre could be adequately visualized nor measured by the operator or crew, and they could not judge their performance until results of the Forest Service measurements were known. For this reason they tended to be conservative and made extra effort to be sure the amount of residue removal was adequate.

Residue levels attained in the 3.1- to 9-inch size class were below the minimum specified on Units 1 and 2 because of the need to meet specified levels for material in the smaller 1/4- to 3-inch size class. Most of these smaller pieces yarded were those attached to larger pieces in the 3.1- to 9-inch size class.

Table 2--Specified and measured residue levels by diameter class

Cutting unit	1/4 - 3 inch			3.1 - 9 inch			Over 9 inch			Total		
	Specified volume	Measured volume	Standard error 1/	Specified volume	Measured volume	Standard error 1/	Specified volume	Measured volume	Standard error 1/	Specified volume	Measured volume	Standard error 1/
	--Tons per acre--		Percent	--Tons per acre--		Percent	--Tons per acre--		Percent	--Tons per acre--		Percent
1	4-6	5.6	5.6	4-8	2.9	11.6	0	0	--	8-14	8.5	6.1
2	5-9	2/ 9.1	4.1	6-11	5.2	8.5	<10	4.4	11.9	<30	18.6	5.0
3	8-13	8.5	4.4	8-14	8.4	7.0	<20	9.3	13.2	<47	26.2	6.2

1/ Standard error is an estimate of sampling precision. The probablility is approximately 95 percent that the sample mean is within plus or minus twice the standard error from the population mean.

2/ Measured residue level of 9.1 tons per acre was judged not a meaningful deviation from the specified level.

Measured residue levels shown in table 2 are the means of 40-point planar intersect samples of the individual sectors of each cutting unit, which ranged from 15 to 20 sectors per unit. Standard errors of the data in individual diameter classes ranged from 4.1 to 13.2 percent. Each sector covered the area yarded by at least one cable yarding road, and all yarding roads were included.

Some of the larger unutilized material was yarded in the main yarding stage, but most was left for the residue yarding stage. The volume of residue was also measured on each unit after the main yarding but before residue yarding; these levels, in material 1/4-inch and larger diameter, were 78.6, 82.6, and 77.7 tons per acre on Units 1, 2, and 3, respectively.

Post-Harvest Reevaluation

The reevaluation team consisted of the same disciplines and nearly the same team members that had made the presale evaluation. After harvest, the team agreed that the desired level represented by Unit 2 should have been slightly lower for the small material and slightly higher for the larger material. They added a recommendation for leaving two or three large pieces per acre 20 inches in diameter or larger not over 10 feet in length, for wildlife use (table 3). They also recommended leaving one or two isolated snags or green trees that could become snags. This recommendation was not included in the consensus due to commitment of the area to research on intensive timber management, and to the presence of many other snags in the adjoining green timber.

The landscape management representative recommended leaving no large residue pieces (over 20 inches in diameter) in the first 100 or 200 feet from main roads, with a gradual increase in amount of all residue sizes permissible beyond the foreground area. He also recommended leaving patches of reproduction where possible, especially to temper the sharp visual effect of abrupt cutting edges as seen from the roads.

Table 3--1977 interdisciplinary team consensus of desired residue level

Diameter class, inches				Slash depth	Duff-litter depth	Duff-litter ground cover
1/4-3	3.1-9	9.1-20	20.1+			
- - - Tons per acre - - -			Pieces per acre <10 ft long	Feet	Inches	Percent
3-6	4-6	5-9	2-3	<0.3	<2-3	<60

Team members expressed concern that the duff-litter layer was surprisingly undisturbed, and that this layer, ranging up to 12-inch depth, was laced with roots which would make planting and hand fire line construction difficult. The team felt that machine piling and burning or broadcast burning would still be desirable additional treatment for these areas. They added to their consensus report a recommendation that average slash depth be not over 0.3 foot, that duff-litter depth be not over 2 or 3 inches, and that the duff-litter ground cover be not over 60 percent.

DISCUSSION

This trial was an effort to focus timber sale planning on land management needs as identified by an interdisciplinary team and to make an operational trial of achieving the specified residue levels, by size class, through the yarding process. These objectives were achieved, but only at considerable expense, as contrasted with alternative treatment by broadcast burning or by machine piling and burning.

Operational Problems

The chief operational problem was the inefficiency of yarding tops, short chunks, and branchwood with large, powerful high-lead equipment. Too many turns broke as they traveled along the ground to the landing. Some form of skyline system would have been able to yard tops intact, with less breakage and rehandling of branches.

The large volume of residue precluded concurrent yarding of residue with the regular logging, unless some means were available to remove each piece of residue as it reached the landing. The possibility of hauling residue to a disposal site was considered in the sale planning stage, but the decision was made to avoid extra handling and to dispose of the residue on its original site.

Lack of Market for Residue

More of the residue might have been utilized for pulpwood chips if the market had remained at its high level existing at the time of sale planning. The chip log market, however, was extremely poor during the operation period; and residue piles at the landings became quite large.

Some use was made of the residue piles by issuing firewood permits to individuals for home use. Commercial firewood dealers inspected the piles but were not interested, partly because most of the material was western hemlock and Pacific silver fir, not very desirable species for commercial firewood.

With no prospect of a market for the residue piles, they were disposed of by burning in late fall of 1976.

Land Management Aspects

An important objective of this trial was to see if the land could be prepared for regeneration without burning. In some places, concentrations of material 1/4 to 3 inches in diameter were too much to plant through; in other places, material 3 to 9 inches in diameter would be a nuisance to planting crews. Also, due to the heavy duff and litter layer of this old-growth timber type a site-preparation treatment before planting was prescribed.

Either broadcast burning or machine piling and burning would have prepared the ground for regeneration with much less effort and expense. Even though results on this site were less than satisfactory from a regeneration standpoint, perhaps conditions would be more favorable for regeneration on other sites having less of a duff-litter layer.

Focusing attention on land management needs brings out the favorable influence of forest residue in giving protection to the soil, protecting seedlings from excessive heat and drying, providing cover for wildlife, and recycling nutrients.

Administration

It is recommended that on an operational basis the interdisciplinary team be made up chiefly of Ranger District personnel, but supplemented where needed to obtain qualified specialists in a particular discipline.

In future sales, residue measurement, too, could be made a responsibility of Ranger District personnel.

CONCLUSIONS

These three study units are case histories; the following conclusions apply only to these units:

1. Yarding of small residue was very inefficient with standard high-lead equipment not designed for this type of service. Operations were slowed by the need for hand piling of broken tops, chunks, and limbs in preparation for yarding, and by such material breaking up as it traveled along the ground during yarding.

2. Residue management had an important role in planning and operation of this timber sale. It focused attention on soil protection, seedling protection, nutrient recycling, provision of cover for wildlife, and reduction of the need for burning.

3. An interdisciplinary team gave an important input to timber sale planning. Their value was in helping to accomplish land management objectives in a positive way, rather than just being concerned with planning treatment after a timber harvest job is done.

4. More trials are needed, especially on steeper ground. Different logging methods and equipment more suitable for handling small material could result in less breakage and less costly yarding.

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POSTSEASON HUNTING TO REDUCE DEER DAMAGE TO DOUGLAS-FIR IN WESTERN OREGON

by

Glenn L. Crouch, Principal Research Wildlife Biologist[1]

Abstract

Effects of two successive postseason deer hunts on deer browsing of Douglas-fir seedlings in the Coast Ranges in western Oregon were evaluated. Terminal browsing was significantly lower on the area subjected to more hunting compared with other areas.

Keywords: Browse damage, wildlife management, hunting.

[1] At the time this research was conducted, the author was with the Pacific Northwest Forest and Range Experiment Station, Olympia, Washington. He is now stationed at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

By the late 1960's, sizeable acreages had been clearcut, many of the blocks were poorly stocked, or tree growth was slow, partly because of damage by deer. Although no population data were available, periodic spotlight counts and pellet group inventories showed that deer activity was high in the clearcut blocks, especially at Randall Saddle and in the Corvallis Watershed. Periodic tree examinations indicated that the terminal shoots of large percentages of trees were being browsed each year on these areas (Crouch 1974 and unpublished[2]).

The Study

Effects of three different hunting regimes were evaluated by semi-annual examinations of marked samples of trees on clearcut blocks in each study area. The effort was originally designed to evaluate only the 1971 hunting season, but a second postseason hunt was added at Randall Saddle in 1972, which prolonged the period of assessment.

Five clearcut blocks ranging in size from 20 to 40 acres (8.1 to 16.2 ha) and in age from 1 to 5 years since logging and planting were selected at each study site. In each block, three samples in plots of 20 trees each were marked and measured in April 1971. Hunting effects on incidence of deer browsing of terminal shoots were determined by examining the same trees in April and September 1971 through 1974.

It was expected that measureable effects of the postseason hunting would be reflected in the years immediately following the added hunting efforts (1972 and 1973) and that effects would be undetectable by 1974, unless the added harvest was unexpectedly large.

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[2]Unpublished data in the author's files at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

1971 HUNTING SEASONS

In the Denzer area, hunting followed the regulations for the general deer season common to other Coast Ranges Management Units except that the Alsea Unit was allocated more either-sex permits. A 1-month archery season allowing the taking of one deer of either sex was scheduled before and after the general season (Oct. 2-31), in which the bag limit was one buck deer having at least one forked antler. Also, 3,000 permit-holders were allowed one deer of either sex from October 16 through 31 if they had not taken a buck earlier.

The Corvallis Watershed was closed to hunting in 1971. At Randall Saddle, the hunting seasons were the same as at Denzer except that two additional weekends of postseason hunting were allowed holders of unfilled either-sex permits. The added dates were 1 week and 3 weeks after the general season, respectively. Hunters were checked on and off the Randall Saddle area during the postseason hunts. About 45 mi^2 (116.6 km^2) were included in the postseason hunts, but only 20 mi^2 (51.8 km^2) were included in the study.

1972 HUNTING SEASONS

Hunting regulations at Denzer were similar to those in 1971 except that 4,000 either-sex permits were issued for the total Alsea Big Game Management Unit. The Corvallis Watershed was open to hunting in 1972 under the same regulations as at Denzer.

Hunting regulations for Randall Saddle were the same as for the other study areas except that two additional postseason weekends of hunting were allowed. For the late hunts, 600 permits were issued each weekend for hunters who were unsuccessful during the general season.

DATA ANALYSES

Effects of the different hunting regimes on incidence of terminal shoot browsing among years, within locations, were compared by analyses of variance following arcsin transformation of percentage data. Tukey's test was used for mean separations among years.

Results and Discussion

DEER HARVEST

Estimated deer harvests during the study are shown in table 1. The values are based mainly on returns from hunter questionnaires assembled by the State management agency from 1971 through 1975. A 30-percent crippling loss was added, and information from check stations supplied the numbers harvested in the postseason hunts at Randall Saddle.

Although no deer population data exist for the study areas, spotlighting and pellet group counts in clearcuts suggested that the general hunting seasons removed only a small proportion of the total number of deer each year, if the published harvest estimates are reasonably accurate.

Harvest data from check stations on the Corvallis Watershed show that more than 10 deer per mi^2 (2.6 km^2) were taken annually during special hunting seasons between 1957 and 1965.[3] Also, nearly 17 deer per mi^2 (2.6 km^2) were harvested annually from the nearby McDonald-Dunn Forests from 1958 to 1968 (Hines 1975).

[3]Adapted from unpublished data on file at the Albany office of the Oregon Fish and Wildlife Department.

Table 1--Estimated hunter deer kill on selected areas in the Alsea Big Game Management Unit, Oregon, 1970-74

Location	1970	1971	1972	1973	1974
	Number per $mile^2$ (2.6 km^2)[1/]				
Denzer	1.2	2.7	3.5	5.5	3.8
Corvallis Watershed	1.2	0.0	3.5	5.5	3.8
Randall Saddle	1.2	5.5	10.5	5.5	3.8

[1/]Adapted from the Oregon State Game Commission Bulletin, 1971-72, and its successor, Oregon Wildlife, 1973-75. Thirty percent crippling losses were added. Randle Saddle values include deer from postseason hunts in 1971 and 1972.

BROWSING

Terminal browsing incidence is shown in table 2. Initial values representing browsing occurring from April 1970 through April 1971 indicate that the incidence was highest at Randall Saddle, intermediate in the Corvallis Watershed, and lowest on the Denzer blocks. This is the same order that was established in the late 1960's in another study in the same areas (Crouch unpublished (see footnote 2)).

Browsing incidence was not different among years on the Denzer area, where similar hunting season regimes were maintained through the study period. On the Watershed, browsing increased significantly in 1972, following no hunting the previous year, and increased again in 1973 despite hunting in 1972. Browsing incidence declined in 1974, the 3d year after no harvest, to a level comparable to that determined in 1971 (table 2).

At Randall Saddle, browsing declined significantly following the first postseason hunt, and remained at a similar lower level the next year, after the second added season. Browsing incidence was similar to the initial 1971 level in 1974, 2 years after the second postseason hunt.

The reduction in browsing incidence in the years following the postseason hunts at Randall Saddle appear to have resulted primarily from added harvest during the late seasons. It is likely that the attention focused on Randall Saddle through publicizing of the postseason hunts also increased the hunting effort during the general seasons both years.

Table 2--Incidence of terminal shoot browsing on young Douglas-fir under three different hunting regimes in western Oregon

Location	1971	1972	1973	1974
		Percent Browsed		
Denzer	34	32	30	31
Corvallis Watershed[1/]	39a	48b	62c	36a
Randall Saddle[1/]	54a	36b	34b	50a

[1/]Within each location, yearly means followed by the same or no letter are not significantly different (P=0.05).

Conclusions

Results indicate that increasing deer harvests by hunting regulations can reduce browsing by deer, at least on a relatively small, well-roaded area like the Randall Saddle tract. Whether the effort was worthwhile in terms of the protection achieved can only be assessed by long-term monitoring of tree growth.

Justifying, planning, and administering extra-season hunts is laborious and costly; and the efforts offer no assurance that hunter response will fulfill expectations in terms of deer harvest and tree protection.

For success, extra-seasons must be devised that have the best chance to accomplish their protective goals and also assure safe and satisfactory hunting experiences for participants. Such efforts must be properly justified; and their purpose, to protect trees, must be emphasized and publicized well in advance of the proposed seasons.

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AN IMPROVED TRI-TUBE CRYOGENIC GRAVEL SAMPLER

by

Fred H. Everest, Carl E. McLemore, and John F. Ward[1]

ABSTRACT

The tri-tube cryogenic gravel sampler has been improved, and accessories have been developed that increase its reliability and safety of operation, reduce core extraction time, and allow accurate partitioning of cores into subsamples. The improved tri-tube sampler is one of the most versatile and efficient substrate sampling tools yet developed.

KEYWORDS: Forestry equipment, stream environment, sedimentation.

[1]Fred H. Everest is Research Fisheries Biologist and Carl E. McLemore and John F. Ward are Fisheries Technicians at the Forestry Sciences Laboratory, Corvallis.

Introduction

Methods for sampling and analyzing the textural composition of gravels used by spawning salmonids have evolved slowly during the past 20 years. The first quantitative samplers to receive general use were metal tubes, open at both ends, that were forced into the substrate. Sedimentary material within the tubes was removed by hand for analysis. A variety of samplers using this principle have been developed, but one described by McNeil and Ahnell (1960) has become widely accepted for sampling streambed sediments.

More recently, scientists began experimenting with cryogenic devices to obtain sediment samples. These devices, generally referred to as "freeze-core" samplers, consist of a hollow probe driven into the streambed and then cooled with a cryogenic medium. After a prescribed time of cooling, the probe and a frozen core of sediment adhering to it are extracted. Liquid nitrogen, liquid oxygen, solidified carbon dioxide ("dry ice") and acetone, dry ice and alcohol, and liquid carbon dioxide (CO_2) have been used experimentally as freezing media. Several years of development have produced a reliable sampler (Walkotten 1976) that uses liquid CO_2. The freeze-core sampler, like the "McNeil sampler," has become widely accepted.

Figure 1. Tri-tube sampler in operation.

The accuracy and precision of the freeze-core and McNeil samplers have been compared in laboratory experiments.[2] Samples collected by both devices were found to be representative of a known sediment mixture, but the freeze-core sampler was more accurate (Walkotten 1976). It is also more versatile, functioning under a wider variety of weather and water conditions, but it has a disadvantage. The gravel cores obtained by the single-tube, freeze-core sampler are often too small to allow the core to be stratified into representative subsamples.

[2]Koski, K. Victor, and William J. Walkotten, Unpublished data on file at the Forestry Sciences Laboratory, Corvallis, Oreg.

To alleviate problems caused by the size of the cores, the single-tube sampler has been modified by Lotspeich and Reid (in press). The modified freeze-core sampler uses a triangular array of three probes driven into the substrate through a template which keeps the probes in a fixed relation to each other. The "tri-tube" sampler (fig. 1) retains all of the advantages of the single freeze-core sampler, but it extracts larger cores--often more than 20 kilograms--which are probably more representative of substrate composition than cores obtained by either the single freeze-core or McNeil samplers.

We have used the tri-tube freeze-core sampler to investigate the effects of spawning by anadromous salmonids on the spatial and temporal distribution of fine sediments in redds. During the study, we made several improvements in the sampler and developed accessories that have increased reliability and safety of operation, reduced core extraction time, and allowed accurate partitioning of cores into subsamples. The tri-tube sampler described by Lotspeich and Reid (in press), with the addition of improvements described in this paper, is the most versatile and efficient substrate sampling tool yet developed.

Description of Improvements

CARBON DIOXIDE DELIVERY SYSTEM

Liquid CO_2 for freeze-core sampling is stored and transported in 20-pound (9-kg) capacity aluminum fire extinguisher bottles. The standard valves on the extinguishers are pressure activated and therefore must be tended (hand-squeezed or clamped) while CO_2 is metered through manifolds into probes in the substrate. Note that the pressure-activated valves are subject to dangerous accidental discharge of high pressure CO_2. We have found that Kidde[3] aluminum fire extinguisher bottles equipped with plastic carrying handles, siphon tubes, and hand-wheel valves (fig. 2) offer two advantages. The hand-wheel valves can be opened and left unattended while CO_2 is flowing to the probes, and accidental discharge of CO_2 through the hand-wheel valves is nearly impossible.

A second improvement in the CO_2 delivery system is a hex nut-gland coupler between the tri-tube manifold and the tank valve (fig. 2). The coupling allows the manifold to be moved quickly from one CO_2 bottle to another and prevents twisting of the delivery hoses.

[3]Trade names mentioned are for the convenience of the readers and do not imply endorsement by the U.S. Department of Agriculture.

Figure 2. Carbon dioxide storage tank with hand-wheel valve and three-way delivery manifold with nut-gland attachments.

PROBES

We have used probes constructed of rigid copper, monel, and stainless steel tubing, none of which were fully satisfactory. Although all three metals successfully conduct heat away from the substrate, the thin-walled tubes tend to bend and deform when driven into coarse gravel. We have constructed more rigid probes from 1-inch (2.5-cm) O.D. stainless steel pipe tipped with stainless steel points of the dimensions described by Walkotten (1976). The open end of each probe is fitted with a 3/16-inch (4.8-mm) thick stainless steel collar 2 inches (50.8 mm) long (fig. 3). The collar is scarf-welded around the rim and plug-welded at 180° intervals on the side. Welded surfaces are subsequently smoothed on a lathe. The collars provide a broad flat surface, which does not bend or deform when the probes are driven, and a shoulder to pull against when the probes are extracted from the substract.

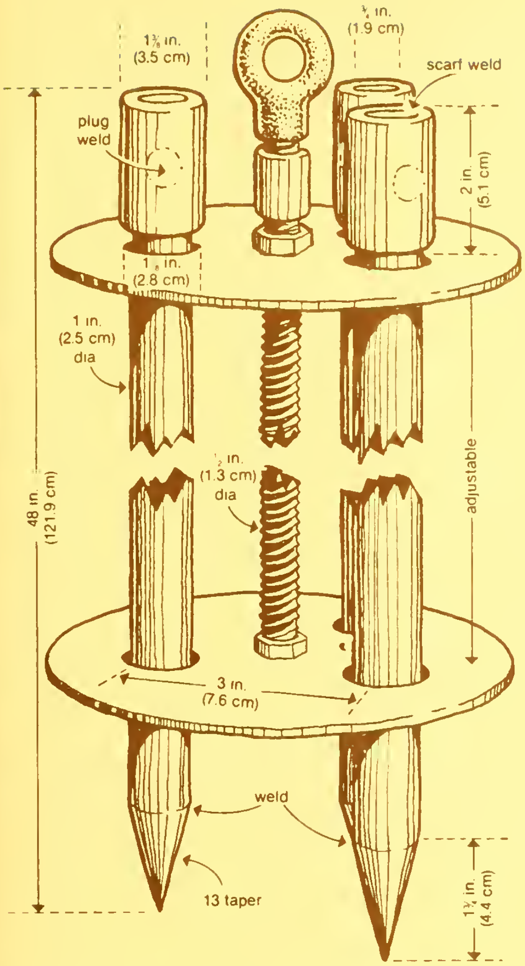

Figure 3. Detail of stainless steel pipe probes and adjustable depth-gage/template.

TEMPLATE

The probe template has been modified to serve three purposes. In addition to holding three probes in a fixed triangular array, our template serves as an adjustable depth-gage for the probes and as the extractor for removing probes with frozen samples from the substrate. The template is constructed from two circular steel plates 1/4 inch (6.4 mm) thick and 5-3/4 inch (14.6 cm) in diameter. Each plate has a triangular array of 1-1/8-inch (28.6-mm) diameter holes spaced 3.5 inches (8.9 cm) on center, and a center hole of 1/2-inch (12.7-mm) diameter. The plates are mounted on a 3-foot (91.4-cm) length of 1/2-inch (12.7-mm) diameter threaded steel rod. The lower plate is fixed on the rod, but the distance between the upper and lower plates can be adjusted by moving hex nuts up or down the threaded rod. This feature allows the template to function as a depth gage and ensures that each probe can only be driven a prespecified distance into the substrate before the probe collar contacts the upper plate of the template.

The upper end of the threaded rod is fitted with a pulling eye that will accept a hook from a small chain hoist (fig. 3). When a sample has been frozen, it can be removed from the substrate in a few seconds with this pulling arrangement. Pulling mechanisms used previously often took several minutes to extract a sample and sometimes permitted surface thawing before extraction.

FLOW SHUNT

We have also developed a flow shunt to improve the size and shape of cores removed from riffles with rapid current and warm water. Swift-flowing water causes incomplete freezing in the upper layers of the core, and some material is often lost during extraction. To eliminate the problem, a shunt constructed from a 2- x 5-ft (61- x 152-cm) piece of 20-gage galvanized sheet metal formed into a teardrop shape (fig. 1) is placed around the probes to divert the current. The shunt functions well in water up to 2 feet (61 cm) deep and at velocities up to 3.5 feet/ second (1.1 m/s); it facilitates consistent freezing throughout the core, especially at the water-substrate interface.

CORE SUBSAMPLER

A major advantage of the freeze-core sampler is that it provides opportunity for vertical stratification of substrate cores. We have developed a subsampler that consists of a series of open-topped boxes made of 26-gage galvanized sheet metal. The boxes are 12 inches (30.5 cm) long, 8 inches (20.3 cm) high, and either 3 or 4 inches (7.6 or 10.2 cm) wide, depending on the depth stratification desired. The individual boxes are held together on an aluminum-framed plywood tray, 12.5 by 28 inches (31.8 x 71.1 cm) with an elastic strap (fig. 4). A 16 x 28-inch (40.6- x 71.1-cm) plywood backboard is placed upright on the tray along one end of the boxes. A core is laid horizontally on the boxes of the

Figure 4. Diagram of core subsampler.

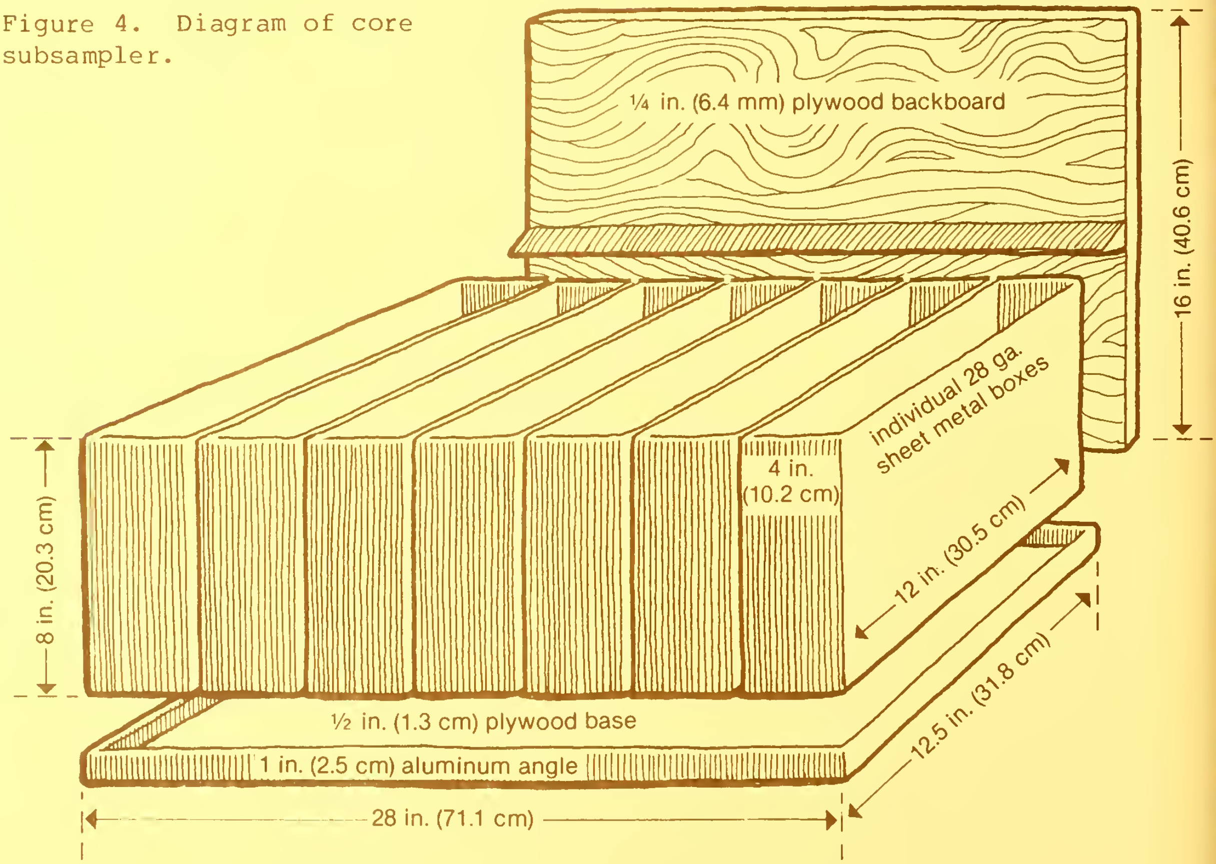

Figure 5. Thawing sample with a blowtorch (note subsampling tray).

subsampler and thawed with a blowtorch fueled with white gasoline (fig. 5). Sediments freed from the core drop directly into the boxes below. Large particles in the sample can be dislodged with a cross-peen or rock hammer and placed in the appropriate boxes.

SAFETY

Liquid CO_2 released in the probes changes to a solid and is forcefully ejected as snow-like pellets of dry ice. Because the operator of the equipment must jiggle the manifolds frequently to prevent solid CO_2 from accumulating in the probes, precautions must be taken to protect exposed skin and eyes from dry-ice pellets. This is accomplished with a deflector that directs dry-ice pellets away from the operator, safety glasses to protect the eyes, and insulated rubber gloves to protect the hands (see fig. 1). Safety glasses are also used when samples are being thawed, to protect the eyes from flying rock chips caused by differential heating of rock surfaces.

APPRAISAL

The tri-tube freeze-core sampler with the changes described in this paper is an improved device for sampling streambed sediments in the field. The equipment is portable, reliable, versatile, safe, and only moderately expensive to purchase and operate. Capital outlay for the equipment needed to collect 12 samples without refilling CO_2 cylinders was $2,000 in early 1979. Cost of materials per sample was $10--the cost of refilling one CO_2 cylinder. With a crew of three, up to four samples per hour can be collected, thawed, and stored for analysis.

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FORMATION OF ECTOMYCORRHIZAE FOLLOWING INOCULATION OF CONTAINERIZED SITKA SPRUCE SEEDLINGS

by

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and

R. Molina, Botanist

ABSTRACT

Containerized Sitka spruce, [*Picea sitchensis* (Bong.) Carr.] were inoculated at sowing with pure cultures of either *Pisolithus tinctorius* (Pers.) Coker & Couch, *Laccaria laccata* (Scop. ex Fr.) Berk. & Br., *Astraeus pteridis* (Shear) Feller, *Amanita pantherina* (D. C. ex Fr.) Schumm., or *Cenococcum geophilum* Fr. Seedlings were grown in 66-cubic centimeter cells for 6 months in greenhouses at Corvallis, Oregon, and Petersburg, Alaska, and environmental growth chambers at Juneau, Alaska. At Corvallis, Petersburg, and Juneau, respectively, 100, 85, and 100 percent of the seedlings inoculated with *L. laccata* and 100, 80, and 98 percent, of those inoculated with *C. geophilum* formed mycorrhizae. Percentage of short roots on colonized seedlings that were mycorrhizal at Corvallis, Juneau, and Petersburg, respectively, were 92, 38, and 77 for *L. laccata*, and 91, 7, and 12 for *C. geophilum*. Positive mycorrhizal formation by the other test fungi could not be confirmed at any location.

KEYWORDS: Mycorrhizal inoculation, container nursery stock, Sitka spruce, *Picea sitchensis*.

INTRODUCTION

Over 100 000 hectares of old-growth Sitka spruce-western hemlock, *Picea sitchensis* (Bong.) Carr. - *Tsuga heterophylla* (Raf.) Sarg., forest have been clearcut on the Tongass National Forest in southeast Alaska. Usually, natural regeneration of both spruce and hemlock has been dense and thrifty on these areas with little need for supplementary planting. With increasingly intensive management, however, areas with inadequate regeneration have become more apparent and the establishment of conifers thereon more desirable.

To supply seedlings for planting on these sites, Region 10 (USDA Forest Service) is developing a greenhouse nursery at Petersburg, Alaska. The facility is scheduled for completion by 1981 and has a projected yearly output of 1,000,000 to 1,500,000 containerized seedlings, largely Sitka spruce. With an abundant supply of planting stock available, some reforestation will also be conducted on routine sites as well as problem sites.

In recent years, production of containerized seedlings has increased rapidly (Tinus et al. 1974). Typically, the potting mixture used to grow these seedlings lacks inoculum of mycorrhizal fungi (Trappe 1977). Mycorrhizae are generally required for woody plants to survive and grow in soil not artificially enriched with nutrients (Marks and Kozlowski 1973, Zak 1977). A lack of mycorrhizae on nursery seedlings may prevent their establishment on mycorrhizae-deficient forest sites or delay establishment until mycorrhizae can form in soils that do not contain natural inocula of mycorrhizal fungi. A cursory examination of containerized Sitka spruce seedlings in the greenhouse nursery at Petersburg showed no development of mycorrhizae.

Techniques are now being refined for inoculating potting mixtures used for growing containerized seedlings with pure cultures of mycorrhizal fungi (Marx and Barnett 1974, Ruehle and Marx 1977, Molina 1979). Such procedures use specific mycorrhizal fungi that may aid establishment and survival of outplanted seedlings on both normal and "problem" reforestation sites (Marx 1977).

Literature dealing with mycorrhizae on Sitka spruce is limited (Trappe 1964, Levisohn 1965, Alexander 1971, Guadray 1973, Thomas and Jackson 1979), and reports no previous attempts to artificially establish mycorrhizal fungi on the roots of container-grown seedlings. The objective of this study was to determine if fungi known to form mycorrhizae could be established on containerized Sitka spruce seedlings through controlled inoculations.

METHODS

Sitka spruce were grown in 66-cm^3 Ray Leach[R] Cells[1] in greenhouses at Corvallis, Oregon, and Petersburg, Alaska, and environmental growth chambers at Juneau, Alaska. The cells were inoculated at sowing with pure cultures of either Pisolithus tinctorius (Pers.) Coker & Couch (S-216)[2], Laccaria laccata (Scop. ex Fr.) Berk. & Br. (S-238), Astraeus pteridis (Shear) Feller (S-237), Amanita pantherina (D. C. ex Fr.) Schumm. (S-331), or Cenococcum geophilum Fr. (A-176). Control seedlings received no fungus inoculum. The isolate of C. geophilum was obtained in Alaska while the others were from Oregon. The ability of all fungus species to form ectomycorrhizae with Sitka spruce had been confirmed previously by pure culture synthesis (Molina, unpublished).

Fungus inocula were prepared at the Forestry Sciences Laboratory in Corvallis, Oregon, by procedures similar to those described by Marx and Bryan (1975) and Molina (1979). After leaching, inocula for use in Alaska were placed in plastic bags, cooled to 5°C, air-freighted in an ice chest to Juneau, and stored at 5°C until use (up to 3 weeks).

[1]The use of trade, firm, or corporation names does not constitute an official endorsement by U.S. Department of Agriculture.

[2]Reference numbers for the PNW culture collection maintained at the Forestry Sciences Laboratory, Corvallis.

A nonsterilized peat-vermiculite mix (approximately 1:1) was used as a potting medium. Inoculum was thoroughly mixed with the potting medium at a ratio of 1:7. Planting cells were filled firm with the medium, each sown with three stratified Sitka spruce seed from Juneau, and covered with perlite. Seeds were sown in late May at Corvallis and Petersburg and early June in Juneau. All cells were later thinned to one seedling each. Corvallis and Petersburg seedlings were harvested in late December and Juneau in early January, 6 months after planting.

In Petersburg and Corvallis six treatments (five fungi and control) were planted in a randomized block design, 20 trees per treatment with four replications (480 total seedlings). In Juneau 30 trees were planted per treatment with two replications, one in each environmental chamber (360 total seedlings).

In Petersburg seedlings were grown under natural light supplemented with "grow lites" during three intervals of 6 minutes duration every hour. Air temperature varied from 15° to 27°C. Trees were watered by hand each or every other day. A commercial preparation of soluble 20-20-20 (NPK) fertilizer amended with trace elements was applied every 2d or 3d day after the 1st month at a nominal rate of 0.2 g/liter of water for each 2 m^2 of bench area. This was approximately one-half the standard fertilization rate then in use for Sitka spruce at the Petersburg nursery.

In Corvallis seedlings were reared under a 16-hour photoperiod with air temperatures varying from 15° to 27°C. They were watered with an automatic misting system and fertilized by hand with approximately 3.1 mg of solubilized 20-19-18 (NPK) per seedling, twice monthly.

In Juneau, seedlings were reared under a 16- to 18-hour photoperiod of approximately 1 000 lux with air temperatures varying from 15° to 27°C. The same fertilizer as used in Petersburg was mixed at 0.1 g/liter of water and applied to each 0.28-m^2 chamber area once a week after the 1st month.

At all three locations iron chelate was also applied at roughly one-half the fertilization rate, and water, temperature, and lighting were reduced in late October to induce bud set.

After harvest, roots were gently washed free of the potting mix and each root system was examined microscopically for mycorrhizae. Ten seedlings showing successful inoculation and no contaminant mycorrhizae were selected at random from each treatment-replication. The degree of mycorrhizal formation was calculated by removing three to four large lateral roots and classifying each short root thereon as mycorrhizal or nonmycorrhizal. One hundred or more short roots were examined and classified on each seedling. Height, root collar diameter, and ovendry weights of tops and roots were recorded for each of the 10 seedlings. From within each area, results were examined by analyses of variance and differences between treatment means were compared with Tukey tests. All tests were performed at $P < 0.05$.

RESULTS

At all locations 80 to 100 percent of the seedlings inoculated with *Laccaria laccata* and *Cenococcum geophilum* formed mycorrhizae (table 1). These mycorrhizae are distinct and easily separated from contaminant mycorrhizae that were also present. The low percentage of mycorrhizae formed, inconsistency between replications and areas, and the presence of contaminant mycorrhizae--one of which appeared quite similar to *Amanita pantherina*--precluded confirming successful inoculation by *Pisolithus tinctorius*, *Amanita pantherina*, or *Astraeus pteridis*.

The percentage of short roots that were mycorrhizal on seedlings colonized by *L. laccata* and *C. geophilum* was very high (approximately 90 percent) at Corvallis, but dropped markedly for *C. geophilum* at Juneau and Petersburg and *L. laccata* at Petersburg (table 1). At all locations, some basidiocarp primordia of *L. laccata* developed on colonized seedlings and mature basidiocarps formed at Corvallis. Mycorrhizal short roots formed by *C. geophilum* at Juneau and Petersburg were concentrated on the upper few centimeters of the root system.

Table 1--Mycorrhizal formation on inoculated seedlings at Corvallis, Juneau, and Petersburg

Fungus	Corvallis		Juneau		Petersburg	
	Percent of seedlings colonized[1]	Percent of mycorrhizal short roots[2]	Percent of seedlings colonized[1]	Percent of mycorrhizal short roots[2]	Percent of seedlings colonized[1]	Percent of mycorrhizal short roots[2]
Pisolithus tinctorius	10	--	2	--	[3]44	--
Laccaria laccata	100	91	100	77	85	38
Astraeus pteridis	0	--	2	--	[3]25	--
Amanita pantherina	16	--	0	--	18	--
Cenococcum geophilum	100	90	98	12	80	7
Control	6	--	0	--	11	--

[1]Mean of all seedlings.

[2]Mean of 10 colonized seedlings per replication.

[3]Appeared to be contaminant mycorrhizae.

Analyses of variance for top height, top weight, root collar diameter, root weight, total weight, and root-shoot ratio were performed within each location for seedlings colonized by L. laccata, C. geophilum, and uninoculated controls. Significant differences occurred only at Corvallis for root collar diameter, root weight, and total weight. Tukey tests for differences among treatment means for these variables at Corvallis were not significant; however, for all three variables, mean values for control seedlings were greater than those for seedlings colonized by either L. laccata or C. geophilum (table 2). Seedlings colonized by L. laccata also had a markedly larger but marginally nonsignificant (P=0.065) root shoot ratio (table 2).

Disregarding inoculation, Petersburg seedlings were significantly taller but had significantly less root weight and a smaller root shoot ratio than Corvallis (table 2). Differences in experimental design at Juneau, Corvallis, and Petersburg did not allow statistical comparisons among the three areas; but overall, Juneau seedlings were the smallest (table 2).

Table 2--Growth of Sitka spruce seedlings at Corvallis, Juneau, and Petersburg

Treatment location	Growth measurements[1]					
	Top height (cm)	Top weight (g)	Root col. diameter (mm)	Root weight (g)	Ratio (Root weight/ top weight)	Total weight (g)
Laccaria laccata, Corvallis	6.7	0.29	1.4	0.35	1.26	0.64
Cenococcum geophilum, Corvallis	6.8	.28	1.3	.26	.95	.54
Control, Corvallis	7.6	.38	1.6	.36	.99	.74
Control, Juneau	12.4	.20	1.3	.073	.35	.28
Control, Petersburg	13.3	.39	1.6	.15	.38	.54

[1]Mean of 10 seedlings per replication.

DISCUSSION

Successful inoculation with Laccaria laccata and Cenococcum geophilum indicates the potential for artificial establishment of selected mycorrhizal fungi on containerized Sitka spruce nursery stock. The failure of the remaining isolates to colonize seedling roots consistently, however, indicates that not all mycorrhizal fungi are suitable to use with this inoculation technique. The reasons for these failures are largely unknown and are probably a combination of many factors. For example, the age and original host associate of the fungus isolate may markedly influence its ability to form mycorrhizae (D. H. Marx, personal communication). Some fungi may not be able to tolerate the rigorous mechanical handling involved in inoculum preparation or the lag period between inoculation and feeder root production. Also, different fertility regimes can affect the performance of fungus inoculum (Marx and Barnett 1974, Trappe and Molina, unpublished data). Clearly, more research is needed to determine if these potentially useful fungi could be introduced onto the roots of container-grown seedlings.

Both L. laccata and C. geophilum are distributed worldwide and are able to form mycorrhizae with most trees that host ectomycorrhizae (Trappe 1962 and 1964, Molina, unpublished data). Both isolates used in this study performed well over a variety of growing conditions, often colonizing entire root systems. Molina recently found similar excellent performance by both fungi on inoculation of containerized Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco, western larch, Larix occidentalis Nutt., western hemlock, ponderosa pine, Pinus ponderosa Laws., and lodgepole pine, Pinus contorta Dougl. Thus, it appears these fungi could be used for wide scale inoculations in container nurseries growing west coast conifers.

Ectomycorrhizal inoculation of containerized seedlings rarely aids their growth in the nursery (Marx and Barnett 1974, Molina 1979 and 1980). With the use of soluble fertilizers, even at much reduced levels, uninoculated control seedlings obtain adequate nutrition to make comparable growth. A more important consideration is how inoculated seedlings will perform upon outplanting in comparison with uninoculated control seedlings. Outplanting studies with containerized Sitka spruce successfully inoculated with L. laccata and C. geophilum are currently in progress.

Finally the Alaskan inoculations show that fungus inoculum can be commercially transported over long distances and still maintain viability. This may be an important consideration for use of inoculum in isolated nurseries or production of inoculum for several nurseries at a single location.

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GENETIC VARIATION IN ROOTABILITY OF CUTTINGS FROM ONE-YEAR-OLD WESTERN HEMLOCK SEEDLINGS

by

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ABSTRACT

One-year-old western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seedlings from three open-pollination families from eight locations in the Washington and Oregon Coast Ranges were cultured under accelerated growth conditions in a glasshouse. Forty cuttings from each of five seedlings (open-pollination siblings) per family were then placed in a rooting box in a randomized block design with five replications. Percent of cuttings rooted after one year in the bed was analyzed in a hierarchal design.

Average rooting percentage was 72.4 percent. Significant effects were associated only with replication, siblings-in-families-in-provenances (S/F/P) and with the interaction, S/F/P x replication. The last two together accounted for 73 percent of the variance.

The results indicated that additive genetic effects were not important to rooting success, but that dominance and unique clone-effects probably were.

KEYWORDS: Heritability, provenance (-genetic traits, rooting ability, western hemlock, *Tsuga heterophylla*.

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INTRODUCTION

Numerous studies have shown large genetic variation in the rootability of cuttings taken from different individuals of the same tree species. This variation has been found in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) (Brix and Barker 1975) and in other species (Mergen 1962, Ooyama and Toyoshima 1965, Wilcox and Farmer 1968, Rauter 1971, Kleinschmit 1972, Kiang and Garrett 1974, Wilcox and others 1976).

Sometimes, significant stand or population-sample effects have also been indicated. Ooyama and Toyoshima (1965) reported large differences in rooting among races in *Pinus densiflora* and in *P. thunbergii*. Their results also indicated that the racial effect varied with years. Wilcox and Farmer (1968) observed that clonal variation in rooting of *Populus deltoides* Bartr. ex Marsh was strongly related to heritable differences in budflush date, which suggests geographic variation in rootability. Rauter (1971) found that the rooting success of cuttings taken from seedlings of 18 populations of *Picea mariana* (Mill.) B.S.P. ranged from 12 to 62 percent.

Conversely, Kiang and Garrett (1974) reported that seed source of the ortet was not an important factor in rooting response in *Pinus strobus* L. cuttings taken from a provenance planting; Brix and Barker (1975) did not find a significant stand effect on the rooting of western hemlock cuttings taken from 31 plus-tree stands, 42 years of age or older, in British Columbia.

We evaluated the genetic effects associated with three levels of genetic sampling: provenance, family-in-provenance and sibling-in-family. Particularly, we were interested in the possibility of provenance variation and whether it could be related to environment at the source. One-year-old seedlings, cultured under conditions for accelerated growth in a glasshouse, were the source of the cuttings.

MATERIALS AND METHODS

Open-pollination seeds were collected from three mature trees at each of eight locations in the Washington and Oregon Coast Ranges in 1975. These locations ranged from 44°00' to 48°08' N. latitude, from 20 to 126 km from the ocean, and from 30 to 640 m in elevation. In February 1976, pregerminated seeds from each of the 24 mature trees were sown, 3 seeds per pot, into gallon containers arranged in 10 randomized complete replications on a single bench in a glasshouse. Seedlings were watered with an overhead mist spray, fertilized regularly with a balanced complete nutrient solution, and provided with supplemental light. In early summer, pots with more than one surviving seedling were thinned to one per pot. Conditions for vigorous growth were maintained until late autumn, when day length and moisture supply were reduced to induce bud set.

In February 1977, the five most uniform replications, which were the center replications on the bench, were used as a source of twig cuttings. Seedlings were 40-50 cm tall (average), well branched, and dormant. Forty cuttings, taken from each seedling (sibling), were subdivided into five groups of eight and placed in eight-ramet rows in five randomized replications in a plastic- and shadecloth-covered rooting bed. Cuttings were 4-8 cm long and taken from all branch orders. Use of the shorter material was necessary to get the 40 cuttings.

The rooting medium was two parts peat and one part sand by volume. Cuttings and bed were kept moist with an automated overhead mist system activated by evaporation of moisture from a wire grid. Fungicide and liquid fertilizer were applied weekly. Soil temperature was maintained at approximately 21°C with subsoil heating cables. Air temperature was controlled by shadecloth and by raising the plastic sides of the frame over the rooting bed to increase ventilation. In general, air temperature around the cuttings followed the outside air temperature.

In January 1978, the number of cuttings with roots in each eight-ramet plot was determined. Although the quantity and vigor of roots varied, we tallied only the presence or absence of living roots.

Percentage of cuttings rooted was calculated for each plot, substituting 1/4n if the percentage was zero and 100-(1/4n) if the percentage was 100, where n = 8, the number of ramets per plot initially (Bartlett 1947). Percentages were transformed into arc sins in radians and analyzed according to ANOVA in table 1. Replications were considered to be random. Within-plot variance was estimated by 0.25/n (Steel and Torrie 1960, p. 158). Thirteen plots were inadvertently left out of the rooting bed and degrees of freedom for total and error (c) accordingly reduced. Because the genetic effects were random, approximate F-tests were made according to the method of Cochran (1951).

Additive genetic variance among families from open-pollination seeds is biased from natural inbreeding and an unknown proportion of full-sibs (Namkoong 1966, Squillace 1974). Based on the relationships given in Squillace (1974), we have assumed that the component of variance for families-in-provenances ($\sigma^2_{F/P}$ in table 1) estimates 1/3 of the additive variance. It may also include some of the dominance variance, but we have assumed that it did not. Heritabilities, narrow and broad sense, were estimated by the relationships

$$h^2_{ns} = \frac{\sigma^2_A}{\sigma^2_{F/P} + \sigma^2_{R(F/P)} + \sigma^2_{S/F/P} + \sigma^2_{R(S/F/P)} + \sigma^2_W} \quad \text{and}$$

$$h^2_{bs} = \frac{\sigma^2_{F/P} + \sigma^2_{S/F/P}}{\sigma^2_{F/P} + \sigma^2_{R(F/P)} + \sigma^2_{S/F/P} + \sigma^2_{R(S/F/P)} + \sigma^2_W},$$

where

$\sigma^2_{S/F/P}$ estimates 2/3 σ^2_A, σ^2_D, most genetic interaction variances (Bohren and others 1965), and some c-effects,

$\sigma^2_{F/P}$ estimates 1/3 σ^2_A ,

$\sigma^2_{R(F/P)}$ estimates plot effects,

$\sigma^2_{R(S/F/P)}$ estimates interaction variance of siblings-in-families-in-provenances with replication, and

σ^2_W estimates the within-plot variance (Steel and Torrie 1960, p. 158).

Nonadditive genetic variance was calculated based on the assumption that the variance among siblings-in-families-in-provenances was made up of additive genetic variance, nonadditive genetic variance, and the interaction variance of siblings-in-families-in-provenances with replication (Namkoong and others 1966). Assuming no epistasis, nonadditive genetic variance in this example would include dominance variance (Namkoong and others 1966) plus c-effects associated with:

a) each seedling being cultured in its own unique pot microenvironment, and
b) differences in the branching habit of the seedlings, particularly as it affects twig lengths and frequencies of branches of different order.

The effect associated with item (a) would be small because of the relative uniformity of the environmental regime in which the seedlings were cultured.

Because dominance effects could not be separated from effects of unique seedling-microenvironment collaboration and branch morphology, we had to treat all of this variance estimate as nonadditive genetic variance.

Table 1--Analysis of variance showing expected and observed mean squares for rootability of cuttings. (See text for further explanation)

Sources of variation	d.f.	M.S.	Estimated mean squares[1/]	EMS code	F	F^{1} [2/]
Replication (R)	4	.2770	$\sigma^2_{R(S/F/P)} + s\sigma^2_{R(F/P)} + sf\sigma^2_{RP} + sfp\sigma^2_{R}$	E_1	3.91*	
Provenance (P)	7	.5184	$\sigma^2_{R(S/F/P)} + r\sigma^2_{(S/F/P)} + s\sigma^2_{R(F/P)} + sr\sigma^2_{F/P}$ $+ sf\sigma^2_{RP} + sfr\sigma^2_{P}$	E_2		1.78[3/] n.s.
Error a (R x P)	28	.0709	$\sigma^2_{R(S/F/P)} + s\sigma^2_{R(F/P)} + sf\sigma^2_{RP}$	E_3		
Families/P	16	.2516	$\sigma^2_{R(S/F/P)} + r\sigma^2_{(S/F/P)} + s\sigma^2_{R(F/P)} + sr\sigma^2_{F/P}$	E_4		1.18[4/] n.s.
Error b (R x F/P)	64	.0582	$\sigma^2_{R(S/F/P)} + s\sigma^2_{R(F/P)}$	E_5		
Siblings/F/P	96	.2181	$\sigma^2_{R(S/F/P)} + r\sigma^2_{(S/F/P)}$	E_6	2.98**	
Error c (R x S/F/P)	371	.0733	$\sigma^2_{R(S/F/P)}$	E_7	2.35**	
Within plot	4109	.0312	$\sigma^2_W = 0.25/n$			

1/ σ^2_R = Variance component for replications;

σ^2_P = Variance component for provenances;

$\sigma^2_{F/P}$ = Variance component for families-in-provenances;

$\sigma^2_{S/F/P}$ = Variance component for siblings in families-in-provenances;

n = Number of cuttings per plot = 8;

r Number of replicates = 5;

p = Number of provenances = 8;

f = Number of families/provenance = 3;

s = Number of siblings/family/provenance = 5.

2/ Approximate F-test.

3/ $F^1 = (E_2 + E_5)/(E_3 + E_4)$

d.f. (numerator) $= (E_2 + E_5)^2/(\frac{E_2^2}{f_2} + \frac{E_5^2}{f_5}) = 8.6$

d.f. (denominator $= (E_3 + E_4)^2/(\frac{E_3^2}{f_3} + \frac{E_4^2}{f_4}) = 25.2$

4/ $F^1 = (E_4 + E_7)/(E_5 + E_6)$

d.f. (numerator) $= (E_4 + E_7)^2/(\frac{E_4^2}{f_4} + \frac{E_7^2}{f_7}) = 26.6$

d.f. (denominator) $= (E_5 + E_6)^2/(\frac{E_5^2}{f_5} + \frac{E_6^2}{f_6}) = 139.2$

5/ Probability of a larger F: n.s. > .05, * = .05, ** = .01.

RESULTS AND DISCUSSION

Rooting percentages (retransformed values) for the clones ranged from 33.2 to 96.9 and averaged 72.4 percent. Average rooting of provenances ranged from 65.2 to 81.9 percent. The range of average rooting percentages for families-in-provenances was less (66.5 to 77.8) and for siblings-in-families-in-provenances greater (52.5 to 84.9) than the range for provenances.

Components of variance are given in table 2. Neither provenance nor family-in-provenance variances were significant; siblings-in-family-in-provenance variance was highly significant. Coefficient of variation associated with error c (table 1) was high, 33 percent, even though the test included 40 cuttings per clone, which illustrates the difficulty of getting precision in a test of this type.

Additive genetic variance was estimated to be 0.0057, giving a narrow-sense heritability of 0.04 and a broad-sense heritability of 0.23. Non-additive genetic variance was estimated to be 0.0252, about four times the additive variance.

Given the sampling stratification we used, significant provenance-variance would have suggested an association between rootability and some geographically varying genetic factor, for example, phenological state of the plant. An excess of family-in-provenance variance over sibling-in-family variance would have indicated an additive heritable control of rootability. This test did not provide evidence that either of these factors was important in the rooting of cuttings taken during the dormant season from 1-year-old western hemlock.

Under near-optimal cultural conditions, 90+ percent rooting of cuttings from hemlock seedlings can be expected (Brix 1978, and Stephen Ross, Forest Research Center, Weyerhaeuser Company, Centralia, Washington, personal communication). Our conditions were less than optimal, probably because of lack of air temperature control over the rooting beds. At about 70 percent rooting success, comparatively large effects were associated with siblings-in-families and with interactions between siblings and replication. Statistically, these effects showed up as nonadditive genetic variance.

Variance from dominance alone is not normally expected to exceed additive genetic variance (Comstock and Robinson 1948), although it can for highly sensitive traits (Gene Namkoong, USDA Forest Service, Genetics Department, North Carolina State University, Raleigh, personal communication). In our test, nonadditive variance was about four times additive variance. Because growing conditions within the glasshouse were relatively uniform, the siblings-in-families-in-provenance variance probably reflects genetic differences to a much greater extent than it does environmental preconditioning. However, the genetic differences may also include clone- or c-effect associated with crown form, branching habit, and twig availability of the individual seedlings. Crown form and branching habit are under genetic control, but their effect would vary depending on the number of cuttings needed and the relative size of the seedling. If the crown characteristics of the seedling are included, most of the genetic variation in rootability of cuttings from these dormant hemlock seedlings was associated with the individual plants, and very little with the families and the provenances.

Table 2--Estimated components of variance for the three levels of sampling and their interaction with replication

Component	Estimate	Percent
Replication (σ^2_R)	.0017	1
Provenance (σ^2_P)	.0034	2
Replication x Provenance (σ^2_{RP})	.0008	1
Family/P ($\sigma^2_{F/P}$)	.0019	1
Replication x Family/P ($\sigma^2_{R(F/P)}$)	0	0
Sibling/F/P ($\sigma^2_{S/F/P}$)	.0290	21
Replication x sibling/F/P ($\sigma^2_{R(S/F/P)}$)	.0733	52
Within plot (.25/n) (σ^2_W)	.0312	22
	.1413	100

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PNW RESEARCH NOTE

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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ESTIMATING MERCHANTABLE VOLUMES OF SECOND GROWTH DOUGLAS-FIR STANDS FROM TOTAL CUBIC VOLUME AND ASSOCIATED STAND CHARACTERISTICS

by

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and

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ABSTRACT

Equations are given for estimating merchantable volumes of second-growth Douglas-fir stands to specified breast high and top diameter limits, in cubic feet or board feet, from total volume in cubic feet and certain associated stand characteristics.

KEYWORDS: Volume (merchantable), second-growth stands, cubic volume measure, conversion factors, Douglas-fir, Pseudotsuga menziesii

METRIC EQUIVALENTS

1 cubic foot per acre = .06998 cubic meter per hectare
1 square foot per acre = .22955 square meter per hectare
1 acre = .40469 hectare

Introduction

Research reports and data summaries concerned with growth of forest stands often present total stem cubic volumes, including volume of tops and stumps, and associated statistics for all trees. Land managers usually want to know merchantable volumes to specified breast high and top diameter limits, in both board and cubic feet. A method is needed to estimate merchantable volumes and associated merchantable stand statistics from total stand statistics.

This note gives estimation equations applicable to second-growth Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) stands, using customary measurement units. These equations were developed to provide conversions in a Douglas-fir stand simulator (DFSIM) now being developed as part of a cooperative effort by the USDA Forest Service's Pacific Northwest Forest and Range Experiment Station and by Weyerhaeuser Company, using permanent plot data contributed by a number of organizations.[1] These equations should also be useful to others with similar estimation problems concerning Douglas-fir.

[1]Cooperators are listed in an appendix.

The Data

The plot data used[2] were from even-aged second-growth stands of coastal Douglas-fir in western Washington, Oregon, and British Columbia. Stands included were at least 80-percent Douglas-fir by basal area, under 100 years of age, both thinned and unthinned, and of both natural and plantation origin. Plot sizes ranged from .1 to 1.0 acre.

Plot volumes in total cubic feet per acre for all stems over 1.5-inch d.b.h. were calculated using height-diameter functions and the Bruce-DeMars (1974) volume equation. Corresponding merchantable volumes were obtained by tree-by-tree conversion and summation, using the Washington Department of Natural Resources tarif system equations as given by Brackett (1973). For stems over 5.5-inch d.b.h., we calculated volume in cubic feet to a 4-inch top d.i.b. For stems over 7.5-inch d.b.h., we calculated cubic volume to 4- and 6-inch tops d.i.b., and also board-foot volumes in Scribner and International 1/4-inch Rules to a 6-inch d.i.b. top.

Separate analyses were made for (1) live stand--trees alive at a given measurement date, (2) the "cut component"--those trees removed in thinning, and (3) the "mortality component"--those trees dying between two successive measurements on a plot.

There were 3,299 plot measurements for the live stand, after omitting incomplete or unsuitable data and stands with quadratic mean d.b.h. (D) less than 5.6 inches. Included were 585 plot measurements for trees cut in thinnings, after omitting plots where less than 15 percent of the stand by basal area was cut. Included also were 1,407 plot measurements for trees lost as mortality, obtained as differences between successive plot measurements while omitting cases with zero mortality. No minimum diameter was specified for mortality. Some of these observations were serial in time.

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[2]This is the same data used as the basis for the stand simulation program DFSIM and will be described in more detail in a manuscript now in preparation.

Analysis

We considered three approaches to the estimation problem:

1. Diameter frequency functions in conjunction with individual tree merchantable volume tables or equations.
2. Individual tree merchantable volume tables or equations applied to mean trees.
3. Conversion ratios fitted as functions of available stand variables.

We adopted method 3, which requires no explicit assumptions about the d.b.h. frequency distributions in the "live," "cut," and "mortality" stand components (which are probably different). Estimation equations were derived for each of these three components.

Merchantability classes derived included:

1. Cubic volume, total stem, for stands with D greater than 5.5 inches ($CVTS_{5.6}$).
2. Cubic volume to 4-inch tops for stands with D greater than 5.5 inches ($CV4_{5.6}$).
3. Cubic volume, total stem, for stands with D greater than 7.5 inches ($CVTS_{7.6}$).
4. Cubic volume to 4-inch tops for stands with D greater than 7.5 inches ($CV4_{7.6}$).
5. Cubic volume to 6-inch tops for stands with D greater than 7.5 inches ($CV6_{7.6}$).
6. Scribner volume to 6-inch tops for stands with D greater than 7.5 inches ($SV6_{7.6}$).
7. International 1/4-inch volume to 6-inch tops with D greater than 7.5 inches ($IV6_{7.6}$).

Prediction equations were fitted using forward stepwise regression. The dependent variable used was either (1) the ratio of the specified merchantable volume to total cubic volume, or (2) merchantable volume (with total cubic volume as one of the predictor variables). Independent variables included D of live stand and of the cut component; mean height of the largest 40 stems per acre, live stand (H40); relative stand density[3] of live stand; whether the stand was of natural or planted origin; and whether or not the stand had been thinned prior to the date of measurement.

We list below our equations for estimating merchantable stand volume and associated stand statistics from stand volumes in total cubic feet in stems over 1.5-inches first, for live stand; next, for the cut portions of thinned stands; and last, for natural mortality. As would be expected, D was consistently, and by far, the most important predictor. Other variables, though significant and presumably representing differences in the underlying distributions, made much smaller contributions.

Some of these equations may be unreliable if extrapolated beyond the data. To avoid unreasonable estimates and inconsistencies between estimates to alternative merchantability limits, users should observe the stated restrictions.

The form of the dependent variable used in actual fitting was not the same in all cases and variances were usually not uniform across the range of stand diameters. As a result, multiple correlation coefficients and standard errors of estimate associated with these equations are not readily interpretable other than as an indication that quite close fits to the data were achieved in most cases. Multiple correlation coefficients were greater than 0.9 for most equations and greater than 0.95 for many. As would be expected from the erratic nature of mortality, the equations for the mortality component were much poorer in fit; and we give only those for total cubic volume in trees over 5.5- and over 7.5-inch d.b.h.

When comparing equations fitted with different forms of the dependent variable, we based our choices on Furnival's (1961) index of fit and on apparent reasonableness of behavior within and at the margins of the data.

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[3]Here expressed by the ratio of basal area to the square root of D, $(G/D^{\frac{1}{2}})$; which is nearly proportional to the ratio of observed basal area to the "normal" given by equation 1-0 in Bruce et al. (1977), as well as to other diameter-based stand density measures (Curtis 1971).

Variables appearing in these equations are as defined in table 1.

Table 1--Glossary of variables used for converting statistics for stands over 1.5-inch d.b.h. to statistics for stands over 5.5- and 7.5-inch d.b.h.

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1. CVTS = Cubic-foot volume of total stem, tops and stumps included, all trees over 1.5-inch d.b.h.
2. H = H40 before cut, where H40 is average height of the 40 trees per acre of largest d.b.h.
3. D = Quadratic mean diameter of trees over 1.5-inch d.b.h.
4. $D_{5.6}$ = Quadratic mean diameter of trees over 5.5-inch d.b.h.
5. $D_{7.6}$ = Quadratic mean diameter of trees over 7.5-inch d.b.h.
6. G = Basal area of trees over 1.5-inch d.b.h.
7. $G_{5.6}$ = Basal area of trees over 5.5-inch d.b.h.
8. $G_{7.6}$ = Basal area of trees over 7.5-inch d.b.h.
9. RD = Relative density = $G_{1.6}/(D_{1.6})^{\frac{1}{2}}$.
10. P = 1 if a plantation, otherwise 0.
11. T = 1 if stand had been thinned previous to measurement, any other = 0.
12. Unsubscripted variables refer to live stand. A variable with a "c" or "m" subscript refers to the "cut" or "mortality" component, respectively.

Equations for estimating statistics for stands over 5.5- and 7.5-inch d.b.h. from statistics for total stand over 1.5-inch d.b.h.

A. <u>Live Stand Before Cut</u>:

1. $$D_{5.6}/D = .984357 - .583464\ (P/D) + 1.89968\ (H/D^3) - 12.3567\ (H/D^5) - 30.8412\ (T/D^3) + 662.059\ (T/D^5) - .0115069\ (RD/D).$$

Restrictions:

If $\hat{y}$[4] < 1.0 or $D > 16.0$, $\hat{y} = 1.0$.

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[4]Here and later, $\hat{y}$ refers to the dependent variable in the equation in question.

2. $G_{5.6}/G = .893313 + 1.47633\ (1/D) - 3055.41\ (1/D^5)$
$+ .00983207\ (H/D) - 2.03654\ (H/D^3) + 63.6836\ (H/D^5)$
$+ 37.5119\ (P/D^3) - 1412.33\ (P/D^5)$.

Restrictions:

If $\hat{y} > 1.0$ or $D > 16.0$, $\hat{y} = 1.0$.

3. $CVTS_{5.6}/CVTS = .975949 + .255308\ (P/D)$
$+ .106148\ (H/D^2) - 2288.48\ (1/D^5)$
$- 21.9646\ (H/D^4) + 121.832\ (H/D^5)$
$+ 2685.35\ (1/HD^3) - 81974.7\ (1/HD^5)$
$- 435.843\ (P/D^5)$.

Restrictions:

If $\hat{y} > 1.0$ or $D > 16.0$, $\hat{y} = 1.0$.

4. $CV4_{5.6}/CVTS = .961397 - 768.661\ (1/D^4)$
$+ .138938\ (P/D) + .0330124\ (H/D^2) + 42.8285\ (1/D^3)$
$- 13.9873\ (H/D^4) + 99.8628\ (H/D^5) - 515.9\ (P/D^5)$
$- 1.09081\ (RD/D^4) - 34.8689\ (T/D^4)$.

Restrictions:

If $\hat{y} > 0.97(CVTS)$, $\hat{y} = .97(CVTS)$.

5. $D_{7.6}/D = 1.07445 - .609012\ (P/D) + 3.86485\ (H/D^3)$
$- 124.037\ (H/D^5) - 2.48009\ (1/D) + 8786.25\ (1/D^5)$
$- 20.0203\ (T/D^3) + 8368.65\ (1/HD^3)$
$- 448096.0\ (1/HD^5) - .00821434\ (RD/D)$.

Restrictions:

If $\hat{y} < 1.0$ or $D > 18.0$, $y = 1.0$.

6. $G_{7.6}/G = 1.36153 - .0237196\ (H/D) + 1.11498\ (P/D)$
$- 79.8001\ (P/D^3) - 53.6643\ (1/H) + 23409.5\ (1/H^3)$
$+ 4116.87\ (1/D^5) + 639.163\ (1/HD) - 41771.5\ (1/HD^3)$
$+ 556335.0\ (1/HD^5) - 687.478\ (T/D^5)$
$- .428632\ (RD/D^3)$.

Restrictions:

If $\hat{y} > 1.0$ or $D > 18.0$, $\hat{y} = 1.0$.

7. $CVTS_{7.6}/CVTS = .972557 + .37322\ (P/D) + 133.694\ (1/HD)$
$- 21229.9\ (1/HD^3) + 404110.0\ (1/HD^5)$
$- 1912.74\ (P/D^5) - .249844\ (RD/D^3)$.

Restrictions:

If $\hat{y} > 1.0$, $\hat{y} = 1.0$;

If $CVTS_{7.6} > CVTS_{5.6}$, $CVT\hat{S}_{7.6} = CVT\hat{S}_{5.6}$.

8. $CV4_{7.6}/CVTS = 1.23073 + 87.0257\ (1/D^3)$
$- 36.3249\ (1/H) - .0204814\ (H/D) + 501.03\ (1/HD)$
$- 38884.7\ (1/HD^3) + 595741.0\ (1/HD^5)$
$- 1060.09\ (P/D^5) - 11.7193\ (T/D^3) - .00805095\ (RD/D)$
$+ 22461400.0\ (1/H^5)$.

Restrictions:

If $CV\hat{4}_{7.6} > CV\hat{4}_{5.6}$, $CV\hat{4}_{7.6} = CV\hat{4}_{5.6}$.

9. $CV6_{7.6}/CVTS = .984543 + 6.55643\ (H/D^5)$
$- 19687.8\ (1/HD^3) + 393312.0\ (1/HD^5)$
$- 28.83\ (P/D^3) - 13.588\ (T/D^3) - .00890657\ (RD/D)$
$+ 16376.3\ (1/H^3)$.

Restrictions:

If $CV\hat{6}_{7.6} > 0.96(CVTS)$, $CV\hat{6}_{7.6} = .96(CVTS)$.

10. $IV6_{7.6}/CVTS = 8.04286 - 1329.66\ (1/D^3)$
$- 192.389\ (1/H) + 20839.0\ (1/D^5) + 106.122\ (H/D^5)$
$- 139.485\ (P/D^3) - 66.0059\ (T/D^3) - .0556108\ (RD/D)$
$+ 98099100.0\ (1/H^5).$

Restrictions:

None.

11. $SV6_{7.6}/CVTS = 8.34551 - 15.541\ (1/D) - 232.834\ (1/H)$
$- 5.55669\ (H/D^3) + 166.021\ (H/D^5) - 103.673\ (P/D^3)$
$- 53.4672\ (T/D^3) - .0471846\ (RD/D)$
$+ 118540000.0\ (1/H^5).$

Restrictions:

None.

B. <u>Cut Component</u>:

1. $D_{5.6c}/D_c = .99778 - .150016\ (P/D_c)$
$+ 24.4189\ (H/D_c^5).$

Restrictions:

If $\hat{y} < 1.0$ or $D_c > 15.0$, $\hat{y} = 1.0$.

2. $G_{5.6c}/G_c = .996566 - 40594.1\ (1/D_c^6)$
$+ 961584.0\ (1/D_c^8) - 1286970.0\ (1/HD_c^6)$
$+ 38406.5\ (1/HD_c^4).$

Restrictions:

If $\hat{y} > 1.0$ or $D_c > 15.0$, $\hat{y} = 1.0$.

3. $CVTS_{5.6c}/CVTS_c = .99674 - 26160.8\ (1/D_c^6) + 7979.08\ (H/D_c^8) + 2020.83\ (1/HD_c^3) - 808.02\ (RD/D_c^7).$

[Note: RD is before cut value]

Restrictions:

If $\hat{y} > 1.0$ or $D_c > 15.0$, $\hat{y} = 1.0$.

4. $CV4_{5.6c}/CVTS_c = .967377 - 641.703\ (1/D_c^4) + 878.217\ (1/D_c^5) + .634701\ (H/D_c^4).$

Restrictions:

If $\hat{CV4}_{5.6c} > 0.97(CVTS_c)$, $\hat{CV4}_{5.6c} = .97(CVTS_c)$.

5. $D_{7.6c}/D_c = 1.03177 + 53.8217\ (1/D_c^2) - .246223\ (H/D_c^2) - 233.096\ (1/HD_c).$

Restrictions:

If $\hat{y} < 1.0$ or $D_c > 18.0$, $\hat{y} = 1.0$.

6. $G_{7.6c}/G_c = 1.00712 - 192.551\ (1/D_c^3) + 3888.64\ (1/D_c^5) + 70373.0\ (1/HD_c^3) + 2931700.0\ (1/HD_c^5) - 934558.0\ (1/HD_c^4).$

Restrictions:

If $\hat{y} > 1.0$ or $D_c > 18.0$, $\hat{y} = 1.0$.

7. $CVTS_{7.6c}/CVTS_c = .993026 - 89.5832\ (1/D_c^3) + 1306570.0\ (1/D_c^8) - 9631.5\ (H/D_c^8) + 2671.7\ (1/HD_c^2) - 24941.7\ (1/HD_c^3).$

Restrictions:

If $\hat{y} > 1.0$ or $D_c > 18.0$, $\hat{y} = 1.0$.

8. $CV4_{7.6c}/CVTS_c = .91505 - 83.8359\ (1/D_c^3)$
$+ 6240260.0\ (1/HD_c^6) - 1242810.0\ (1/HD_c^5)$
$+ 9.67241\ (1/H)$.

Restrictions:

If $\hat{CV4}_{7.6c} > \hat{CV4}_{5.6c}$, $\hat{CV4}_{7.6c} = CV4_{5.6c}$.

9. $CV6_{7.6c}/CVTS_c = .708274 + 10.1904\ (1/D_c)$
$- 92.0439\ (1/D_c^2) + 1215.26\ (1/D_c^4)$
$- .0943753\ (H/D_c^2) - 125129.0\ (1/HD_c^4)$
$+ 549227.0\ (1/HD_c^5)$.

Restrictions:

If $\hat{CV6}_{7.6c} > 0.99(\hat{CV4}_{7.6c})$, $CV6_{7.6c}$
$= 0.99(\hat{CV4}_{7.6c})$.

10. $IV6_{7.6c}/CVTS_c = 6.95049 + 62.942\ (1/D_c)$
$- 671.623\ (1/D_c^2) - .113959\ (H/D_c)$
$+ 8156.0\ (1/D_c^4) - 171.945\ (1/H)$.

Restrictions:

None.

11. $SV6_{7.6c}/CVTS_c = 9.75211 - 32.992\ (1/D_c)$
$- .115131\ (H/D_c) + 365922.0\ (1/HD_c^5)$
$- 187.155\ (1/H)$.

Restrictions:

None.

C. <u>Mortality:</u>[5]

1. $CVTS_{5.6m}.CVTS_m = 5.0650 - .10790\ (D_m)$
$- 9.5417\ (1/D_m^{1/2}) + 160.50\ (1/D_m^{4})$
$- 271.93\ (1/D_m^{5})$.

Restrictions:

If $\hat{y} < 0.0$, $\hat{y} = 0.0$;

If $\hat{y} > 1.0$ or $D_m > 14.0$, $\hat{y} = 1.0$.

2. $CVTS_{7.6m}/CVTS_m = 8.8335 - .11872\ (D_m)$
$+ 28.010\ (1/D_m) - 30.638\ (1/D_m^{1/2})$
$- 500.67\ (1/D_m^{8})$.

Restrictions:

If $\hat{y} < 0.0$, $\hat{y} = 0.0$;

If $\hat{y} > 1.0$ or $D_m > 18.0$, $\hat{y} = 1.0$.

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[5] We fit these equations by a "two-stage" procedure, using as predictor a regression estimate $\hat{D}_m$ = f(stand variables). This is consistent with intended use in a stand simulator, where the available D_m statistic is a stand mean, estimated from live stand characteristics.

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Appendix

List of Organizations Contributing Data

British Columbia Forest Service
Bureau of Land Management, U.S. Department of the Interior
Canadian Forestry Service
Crown Zellerbach Corp.
International Paper Co.
MacMillan Bloedel Ltd.
Oregon Department of Forestry
Oregon State University
Pacific Northwest Forest and Range Experiment Station, USDA Forest Service
Roseburg Lumber Co.
University of Washington
Washington Department of Natural Resources
Weyerhaeuser Co.

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A SYNTHETIC SEX PHEROMONE FOR THE LARGE ASPEN TORTRIX IN ALASKA

by

Richard A. Werner

and

J. Weatherston[1]

ABSTRACT

Cis-11-tetradecenal was found to be the specific attractant for adult male large aspen tortrix, *Choristoneura conflictana* (Walker), populations in quaking aspen, *Populus tremuloides* Michx., forests of interior Alaska. The attractant was dispersed from polyethylene caps in Pherocon® -2 traps placed 1.5 m above ground.

Keywords: Attractants (chemical) (-forest pest control, pheromones, large aspen tortrix, *Choristoneura conflictana*, quaking aspen, *Populus tremuloides*, Alaska (interior).

METRIC EQUIVALENTS

1 centimeter = 0.3937 inch
1 meter = 39.37 inches
1 kilometer = 0.62137 mile

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INTRODUCTION

The large aspen tortrix, Choristoneura conflictana (Walker), is a serious pest of quaking aspen, Populus tremuloides Michx., throughout northern regions of North America including Alaska. An extensive outbreak covering 26 000 km^2 of aspen type occurred in Alaska from 1966 to 1969 (Beckwith 1973). Since this time C. conflictana populations have been extremely low in Alaska. Repeated defoliation for a 2-yr period can cause reduced radial and terminal growth but 3-or-more-year defoliation usually results in tree mortality.

A synthetic sex pheromone was desired to monitor C. conflictana populations in order to predict population fluctuations. Field studies by Weatherston et al. (1976) indicated that various concentrations of cis-11-tetradecenal attracted male C. conflictana in Ontario. Field tests conducted in Fairbanks, Alaska, in 1976 and 1977 showed that certain synergistic effects were produced by various mixtures of cis-11-tretradecenal-1-ol and trans-11-tetradecenal (Weatherston et al. 1978). These same tests indicated that a 95/5 mixture of cis/trans-11-tetradecenal also appeared to be attractive to C. conflictana males. A more refined field test using concentrations and mixtures of those chemicals that were found most attractive in the 1978 tests was further evaluated.

MATERIALS AND METHODS

Field trapping was conducted in a 70-yr-old pure aspen stand 16 km west of Fairbanks. Pherocon®-2 (Zoecon Corp.)[2] traps (50 each) were baited with either 100% cis-11-tetradecenal or a 95/5 mixture of cis/trans-11-tetradecenal and were used to trap recently emerged moths. Pheromones were released from polyethylene caps (100 µg/cap) placed within the trap on the upper surface. Empty check traps were used in the test. Traps were attached 30 m apart to a wire stretched horizontally between two trees 1.5 m above the ground. Traps were inspected, changed, and rerandomized weekly from June 27 to August 8, 1978. The two treatments and control were treated as a completely random design. The two treatment means were contrasted at each time measurement with Duncan's new multiple range test. The controls were excluded from the analysis because all traps produced zero insects.

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[2]Mention of products, trade names, or companies does not imply endorsement by the U.S. Department of Agriculture.

The pheromones were either prepared on a polymer support (Fyles et al. 1977) or purchased from Chemical Samples Corporation. The two chemical materials were purified by chromatography on Adsorbosil CABN (50/100-mesh). Chemical purity and isomer composition were determined by gas-liquid chromatography (GLC) on a 5.1-m x 0.25-cm column of 10% Silar 10C on Gas Chrom Q (60/80-mesh) at 175°C with a carrier gas flow of 15 ml/min N_2.

RESULTS AND DISCUSSION

It is evident from the results of the 1978 field test (Table 1) that *cis*-11-tetradecenal is highly attractive to *C. conflictana* males. Pure *cis*-isomer-baited traps caught 95 percent more males than the 95/5 *cis/trans* mixture throughout the test period. In the 1977 field test conducted in the same area, the *cis*-isomer catch was 89 percent higher than the 95/5 *cis/trans* mixture. *C. conflictana* population levels appear to be increasing since captures of males in *cis*-11-tetradecenal-baited traps (100 µg/trap) increased from 2.3 males per trap in 1977 to 23.4 per trap in 1978. The use of this sex pheromone to monitor *C. conflictana* populations appears to be most effective, but further field tests are needed in which trapping data can be compared with larval sampling data from both endemic and epidemic levels.

Table 1--Numbers of male *C. conflictana* captured in traps baited with *cis*-11-tetradecenal and *cis/trans*-11-tetradecenal

Attractant (100 µg)	Mean catch per trap[1,2]				Total number per test
	July 4	July 11	July 18	July 25	
cis-11-tetradecenal	24.6_b	112.8_a	4.4_c	0.1_c	1174
cis/trans-11-tetradecenal	0.0_c	4.7_c	1.0_c	0.0_c	52
Unbaited trap	0.0_c	0.0_c	0.0_c	0.0_c	0

[1]Mean of 50 traps each per attractant.

[2]Values followed by the same letter are not significantly different at the 5-percent level as determined by Duncan's new multiple range test.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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SUBSTITUTION AND THE USDA FOREST SERVICE LOG EXPORT RESTRICTIONS

by

Gary R. Lindell[1]

Abstract

With some exceptions, the substitution of National Forest timber for exported private timber is forbidden by regulations. Certain firms may use a limited amount of National Forest timber as replacement for exported private timber, however, in accordance with their pattern of purchases and exports from 1971 through 1973. About 359 million board feet of National Forest timber could be used annually as replacement for exported private timber by this provision; in 1977 about 102 million board feet was used in this fashion. About 81 percent of the replacement volume was from National Forests in Washington.

KEYWORDS: Import/export (forest products), trade policy (international) National Forest administration.

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The pros and cons of permitting the export of unprocessed softwood logs from the west coast have been debated for a long time,[2] however, the conflict shows no signs of abating.

The controversy has led to the enactment of fairly extensive Federal regulations designed to prohibit the export of Federal timber and to prohibit the substitution of Federal timber for private timber to be exported. In addition, Oregon, California, and Alaska have implemented regulations to restrict the export of timber from State-managed lands. As a result of the combination of Federal and State restrictions, about 38 percent of the combined timber harvest of the three States of Washington, Oregon, and California is directly controlled by export regulations (table 1).

[2]For example, the October 3, 1936, issue of the Oregonian reported initiatives by the Portland Chamber of Commerce to check the flow of Port-Orford-cedar logs to Japan.

The purpose of export restrictions may be to insure domestic processing of logs from public lands or it may be to restrict the volume of exports. The volume of logs exported is on the increase. For example, in 1979, log exports from the west coast and Alaska reached a record 3.4 billion board feet.[3].

As a result of the large volume of exports, questions have been raised about the effectiveness of current regulations. Opponents of exports have expressed concern that the regulations may contain loopholes that permit timber purchasers to take actions against the intent of the regulations.

[3]Ruderman, Florence K. 1979. Production, prices, employment and trade in northwest forest industries. Published quarterly. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Table 1--Proportion of total timber harvest prohibited from export by Federal or State controls in Washington, Oregon, and California, 1977

State	Total timber harvest	Portion of total harvest prohibited from export by Federal controls		Portion of total harvest prohibited from export by State controls		Portion of total harvest prohibited from export by Federal and State controls	
	Million board feet	Million board feet	Percent	Million board feet	Percent	Million board feet	Percent
Washington	6,591	1,175	17.8	--	--	1,175	17.8
Oregon	7,525	3,952	52.5	228	3.0	4,180	55.5
California	4,787	1,757	36.7	28	0.6	1,785	37.3
Total (average)	18,903	6,884	(36.4)	256	(1.4)	7,140	(37.8)

Source: Ruderman, Florence K. 1979. Production, prices, employment, and trade in northwest forest industries. Published quarterly. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

One loophole that has come in for particular scrutiny is the grandfather clause of the USDA Forest Service substitution regulations. Although substitution is forbidden, this provision enables certain firms to use a limited amount of National Forest timber as replacement for private timber to be exported. This paper reports the result of a study to determine the nature and extent of this practice.

Substitution Regulations of the USDA Forest Service

The USDA Forest Service was specifically directed to control substitution according to the terms of a rider to the agency's 1974 appropriations bill (P.L. 93-120).[4] In October, 1973, proposed regulations were published and public comments were solicited. Considering these comments, the Forest Service implemented substitution regulations in March, 1974.

Public comments appeared to favor using traditional marketing patterns as a base in control of substitution. Replacement by National Forest timber would be permitted in accordance with the traditional or historical pattern and substitution would be considered as occurring only when the exporter increases purchase of National Forest timber or increases export of private timber.

[4]For additional details see: Lindell, Gary R. 1978. Log export restrictions of the Western States and British Columbia. USDA Forest Service Gen. Tech. Rep. PNW-63, Pac. Northwest and Range Exp. Stn., Portland, Oreg.

Consequently, the regulations recognized a firm's historical base period as 110 percent of the firm's average annual volume of National Forest timber purchases and export of private timber for the calendar years 1971-73. A firm which had been exporting private timber and purchasing National Forest timber during this period could continue to do so subject to the export and purchase limitation or quota. Substitution was defined as, for any subsequent year, an increase in exports relative to the historical base while the firm continues to purchase National Forest timber or an increase in National Forest purchases while the firm continues to export. A firm violating either of these provisos is guilty of a contract violation and faces possible debarment from subsequent sales and cancellation of existing contracts.

Since timber is not readily transportable, the regulations are tied to a particular market area or tributary area. Thus a firm may establish different purchase and export quotas for different tributary areas. A tributary area is established for each mill where National Forest timber is to be processed. The boundary of the area is determined by establishing from the records the area from which each mill received its supply of timber for the base period (1971-1973). Once established, a tributary area is not normally subject to change.

Firms which want to purchase National Forest timber and export private timber are required to submit data to establish their historical purchase and export base. The data must also support the proposed tributary area.

Historical Base Levels

To obtain an estimate of the amount of National Forest timber that can be used as replacement through this provision of the regulations, all of the Western National Forests were canvassed to determine the historical bases which have been established. It was necessary to canvass each National Forest since the monitoring and enforcement of the substitution regulations are done at the Forest level.

As of mid-1979, 49 historical bases had been established in Washington and Oregon and an additional 7 had been established in California. No quotas have been established by firms in the Intermountain or Rocky Mountain areas. In most cases a firm has only one historical base, but some of the larger firms have established bases for several different tributary areas.

During the 1971-73 period, the firms with historical bases exported a total of 1.6 billion board feet of private timber and purchased 4.2 billion board feet of National Forest timber. The sum of the established historical bases is thus 0.6 billion board feet for exports (1.6 ÷ 3 x 110 percent) and 1.5 billion board feet for purchases (4.2 ÷ 3 x 110 percent).

This does not mean that an annual total of 0.6 billion board feet of National Forest timber may be used as replacement for exported private timber. For each firm the permissible volume is determined by the lesser of its export or purchase quotas. For example, a firm which has an export quota of 5 million board feet and a purchase quota of 25 million board feet can use no more than 5 million board feet of National Forest timber as replacement for exported private timber. To obtain a west-wide estimate of replacement, the lesser of these two figures are added for each firm.

Results indicate that 359 million board feet could be used annually as replacement in the West (table 2). Most of the quota has been established by firms operating in the State of Washington, particularly in the vicinity of the Gifford Pinchot National Forest. This does not mean that these volumes are necessarily tied to a particular National Forest; some firms have tributary areas which encompass more than one National Forest. Firms could switch their purchases to another National Forest as long as they fall within the same tributary area. The data in table 2 do indicate, however, the general area of activity of exporters which also were purchasers of National Forest timber.

Although 359 million board feet of National Forest timber could be used as replacement for exported private timber for any given year, the actual volume is less than the allowable. Some firms have stopped exporting. Some exporters have found their quotas too restricted and have stopped purchasing National Forest timber.

Table 2--Volume of National Forest timber that may be used as replacement for private timber to be exported within the substitution regulations

National Forest	Volume (thousand board feet)
Washington:	
Gifford Pinchot	98,120
Olympic	73,735
Mt. Baker-Snoqualmie	29,073
Wenatchee	1,000
Total	201,928
Oregon:	
Mt. Hood	62,586
Siuslaw	3,498
Willamette	5,897
Siskiyou	25,652
Total	97,633
California:	
Tahoe	28,600
Six Rivers	26,989
Shasta Trinity	196
Klamath	13
El Dorado	3,267
Total	59,065
All National Forests	358,626

To obtain an estimate of how much replacement occurs, each National Forest was queried to obtain followup data on purchases and exports by those firms with established historical bases. As before, the lesser of the volume of timber exported or purchased was used as a proxy for the volume of National Forest actually used as replacement.

Data were summarized for all of the firms involved in export and purchase in 1977. For that year, approximately 102 million board feet of National Forest timber was used as replacement for private timber to be exported (table 3). Most of the replacement occurred with timber from National Forests in Washington.

Table 3--Volume of National Forest timber used as replacement for privat timber to be exported, 1977

National Forest	Volume (thousand board feet)
Washington	82,919
Oregon	10,686
California	8,340
Total	101,945

Discussion

Results of this study indicate that about 100 million board feet of National Forest timber is annually used as replacement for private timber to be exported. This study measured only direct replacement; no effort was made to determine the amount which is indirectly substituted for private timber to be exported.

The Forest Service is not required to monitor export and purchase activity beyond the original purchaser. This means that a firm which is ineligible to purchase a National Forest sale because it has exceeded its export quota can purchase National Forest timber from another firm and thus indirectly engage in substitution. Indirect substitution cannot be precisely determined. In response to a congressional request, however, the Forest Service concluded that indirect substitution is not widespread and that modification of the regulations is unwarranted.[5]

Our purpose is not to argue for more or fewer export restrictions. Whether or not the permitted replacement, approximately 100 million board feet, constitutes a major loophole depends on one's point of view. Although this represents the annual log requirements for five to six medium-size sawmills, it is a small proportion of total exports, the bulk of which come from private lands or from lands managed by the State of Washington.

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[5]Letter dated September 28, 1979, from R. Max Petersen, Chief, USDA. Forest Service to the Honorable Norman D. Dicks. Copy on file at Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

There appears to be little basis for determining the net effect of closure of the replacement loophole on log supplies available to domestic processors. For examples, indirect substitution might increase in response to closure of the loophole, and firms affected by the closure who also buy and sell logs in the domestic market might reduce their domestic log sales in order to compensate for the loss of National Forest timber. Or firms might decrease export sales, decrease purchases of National Forest timber, and increase processing of private timber. Even in this situation, however, the net effect on supplies to domestic processors is uncertain: Firms not involved in purchasing National Forest timber might divert log sales from the domestic to the export market in response to any decline in export sales by competing firms.

In summmary, this study has documented the historical base level of 359 million board feet for firms eligible to substitute National Forest timber for private timber to be exported. Of this total, firms are substituting only about 100 million board feet. Over 80 percent of the substitution occurs in the State of Washington. Prohibition of substitution would not necessarily increase log supplies to domestic processors by 100 million board feet.

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Biology and behavior of a larch bud moth, *Zeiraphera* sp., in Alaska

Richard A. Werner [1]

Abstract

A possibly new species or subspecies of larch bud moth of the genus *Zeiraphera*, closely related to *Z. improbana* (Walker), was found associated with tamarack, *Larix laricina* (Du Roi) K. Koch, stands in interior Alaska. An outbreak occurred during 1975 and 1976 over an area of 240 000 ha (590,000 acres). Adult moths were mottled grayish in appearance. First instars emerged from the overwintering egg stage from mid-late May and began feeding as soon as the tamarack buds began to unfold. Pupation, adult emergence, and oviposition occurred from mid-June to mid-July and there was one generation per year. Defoliated tamarack stands turned reddish-brown color by mid-June as partially defoliated needles turned brown, but stands refoliated by mid-July. Parasites and disease killed 99.6 percent of the pupal stage in 1976.

KEYWORDS: Larch bud moth, *Zeiraphera* sp., tamarack, *Larix laricina*, defoliation, biology and behavior, Alaska (interior).

Introduction

An unidentified species or subspecies of bud moth, *Zeiraphera* sp., completely defoliated 142 000 to 240 000 ha of tamarack *Larix laricina* (Du Roi) K. Koch, during 1975 and 1976 in the Tanana River drainage near Fairbanks, Alaska (Rush et al. 1977). The area infested extended from Tok (near the Canadian border) west to Nenana and from Fairbanks south to the Alaska Range (fig. 1). An infestation by *Zeiraphera* apparently occurred throughout the same area in 1958[2] as extensive areas of tamarack were heavily defoliated. In Alaska, tamarack occurs throughout the river basins between the Brooks Range on the north and the Alaska Range on the south and is especially abundant along the Yukon, Kuskokwim, and Tanana Rivers (fig. 1)(Viereck and Little 1975). During the same time period 70 percent of the tamarack trees in southeastern Yukon Territory were defoliated by *Z. improbana* (Walker) (Canadian Forestry Service 1976).

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[2]Unpublished information on file at the Institute of Northern Forestry, Fairbanks, Alaska 99701.

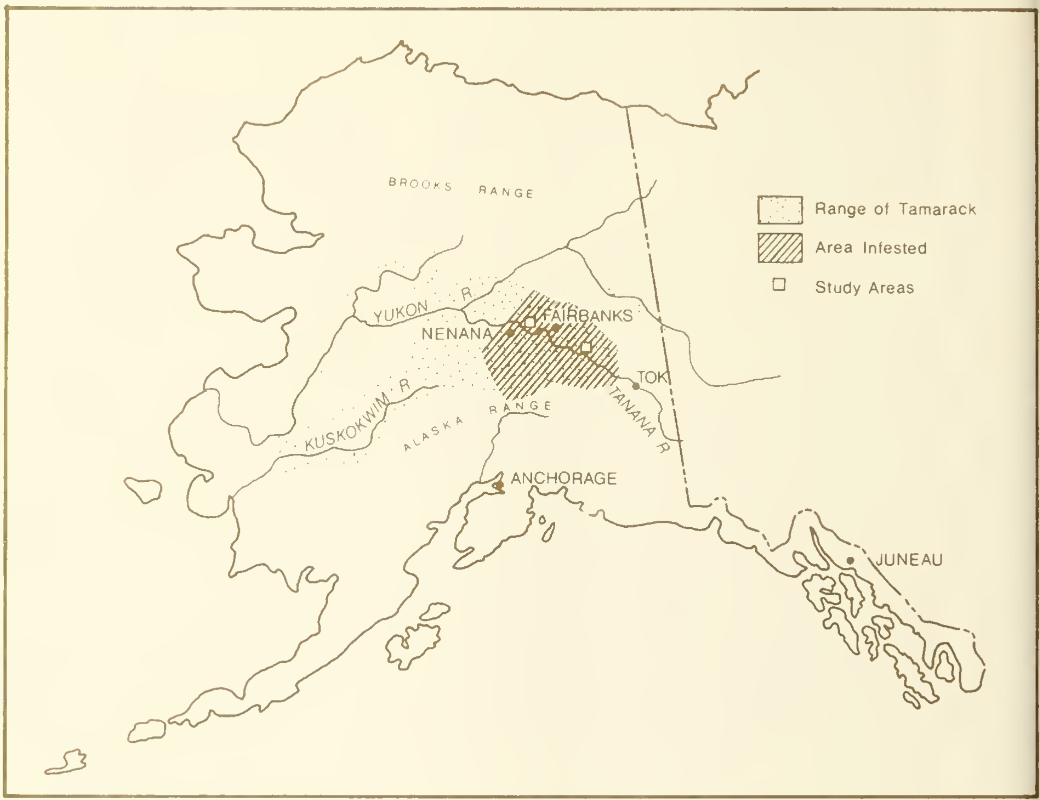

Figure 1.--Range of tamarack in Alaska and areas defoliated by larch bud moth, Zeiraphera *sp.*

Adult specimens reared during the 1975-1977 outbreak were identified by Dr. A. Mutuura, Biosystematics Research Institute, Ottawa, Ontario, as a possibly new species or subspecies of Zeiraphera closely related to Z. improbana (Walker). Mutuura and Freeman (1966) previously described seven North American species of Zeiraphera, and Z. improbana was the only species that fed on tamarack.

Baltensweiler et al. (1977) summarized the results of 26 years of research on the population dynamics of Z. diniana in Europe. The biology and behavior of the Alaskan species are quite similar to Z diniana except for host plants. The Alaska Zeiraphera feeds predominantly on L. laricina whereas Z. diniana feeds on several different coniferous hosts.

This paper describes the life cycle and behavior of an unidentified species of Zeiraphera in tamarack stands of interior Alaska

Methods

The study was conducted in two areas of heavy infestation located in the Tanana River drainage. Single sample plots were established in May 1975 in the Bonanza Creek Experimental Forest located 40 km west of Fairbanks and near Delta Junction located 134 km east of Fairbanks (fig. 1). The study sample plots contained open-grown, mixed species of tamarack and black spruce, Picea mariana (Mill.) B.S.P. The dominant and codominant trees ranged from ca. 6 to 9 m in height and ca. 6.5- to 15.2-cm d.b.h. Each of the two sample plots contained 100 trees which were marked and numbered with plastic tags. Branch samples were collected weekly from 10 randomly selected trees in each plot in order to estimate larval development and density from egg eclosion to pupation. All larvae were collected and counted on a 63-cm-long branch which was collected from the south side of the midcrown level. Preliminary sampling indicated no significant difference in egg or larval density in relation to crown level or direction. Larval density was expressed in terms of number per 0.64 m^2 (1,000 in^2) of branch area.

Branches were clipped with a pole pruner equipped with a muslin basket lined with a plastic bag which in turn held the clipped branch. The plastic bag with branch was sealed and transported to the laboratory for processing. In addition, 200 larvae were collected each week and measurements made by ocular micrometer of body length and width and head capsule width. Other external characteristics such as color were examined.

Pupal development was measured by trapping last instars as they dropped from the trees. Wire screen traps (50- x 50- x 7.5-cm) were partially filled with peat moss covered with a 2.35-cm-thick layer of sphagnum moss and placed on the ground beneath infested larch. Escape of larvae from the traps was prevented by coating the upper surface of the wooden trap frame with Tanglefoot®.[3] Pupal density was expressed as number per square meter. A wire screen cover was placed over the pupal trap following pupation in order to live trap emerging adult moths and parasites. Moth density and sex ratio were thus obtained. Pairs of adults were caged separately in plastic screen sleeve cages placed over the terminal 38 cm of uninfested tamarack branches. Mating and ovipositional behavior were observed and oviposition data recorded. Half of the sleeve cages were removed following oviposition in order to measure egg predation and parasitism.

All samples of larvae and pupae from the weekly collections were reared in the laboratory in order to collect emerging parasites. Diseased specimens were sent to specialists for identification.

[3]Mention of products, trade names, or companies does not imply endorsement by the U.S. Department of Agriculture.

Description of Stages

Adults: Moths of both sexes have a grayish-black head, thorax, and abdomen with scattered patches of brown. Forewings are mottled grayish with patches of white, brown, and black scales. Hindwings are light gray with a fuscous fringe on the posterior edge. Adults are 7.3$\pm$0.31 mm in length (range 6.2-10.8 mm) with a wingspread of 14.2$\pm$0.6 mm (range 12.3-17.2 mm).

Egg: Eggs are oblong, ca. 0.35-0.60 mm in length and 0.15-0.25 mm in width. Color varied from whitish-orange immediately after oviposition, changing with age to a dullish reddish brown.

Larvae: Body and head capsule measurements and color variations are described for each instar in table 1. The thoracic legs of each instar are brown, but the head and body color varies. Newly emerged larvae are pale green with black heads and transform through successive instars to a fifth instar characterized by a brown head and yellowish green body with light brown dorsal and lateral spots.

Pupae: Pupae are dull brown and are found in cocoons constructed from forest floor materials such as peat, moss, bark scales, and bits of other plant material. Pupae are 11.1$\pm$0.5 mm in length (range 9.5-12.6 mm) and 2.1$\pm$0.1 mm in width (range 1.9-2.3 mm). Sexes can be separated according to location of the genital opening. Females have the opening ventrally on the eighth abdominal segment, whereas for males it occurs ventrally on the ninth segment.

Table 1--External measurements (mm) and color phases of larch bud moth, *Zeiraphera* sp., larvae collected from tamarack, Fairbanks, Alaska

Instar	I	II	III	IV	V
No. measured	200	250	350	325	340
Length:					
Mean	3.5	7.4	9.4	9.9	10.3
Range	2.8-4.2	5.3-9.2	8.2-10.7	7.0-11.5	8.7-12.8
Body width:					
Mean	0.51	0.72	1.12	1.18	1.75
Range	.47-.55	.66-.77	.82-1.23	.90-1.32	1.48-2.04
Head width:					
Mean	.50	.83	1.11	1.22	1.32
Range	.46-.54	.76-.96	1.06-1.16	1.18-1.26	1.28-1.40
Color:					
Head	black	black	brownish-black	dark brown	brown
Body	pale green	pale green	green	yellowish-green	yellowish-green

Life History and Behavior

The seasonal development of the larch bud moth in Alaska is shown in fig. 2. The bud moth is univoltine with an egg diapause. The factors responsible for the induction of diapause are unknown; however, diapause was terminated when temperatures reached 10°C. Overwintering eggs successfully survived temperatures as low as -52°C, which often occur in interior Alaska.

Adults emerged from late June until late July with peak flight occurring when cumulative degree days reached ca. 500° above a 5°C threshold usually in early July. Moth emergence occurred in the early morning between 0300 h and 0500 h when light intensity was ca. 700 lux and when daily temperatures were at a minimum (mean of 10°C in June and July). Flight and mating occurred at twilight (2250-0150 h). Twilight is that period when the sun is not more than 6° below the horizon (Johnson and Hartman 1969). At latitudes north of 60-1/2°N, evening twilight overlaps morning twilight during the summer. In the study areas there was ca. 3 h of twilight from late June to late July. The light intensity during this twilight period ranged from 13.5 lux at 2250 h and 0150 h to 8.6 lux at 2400 h.

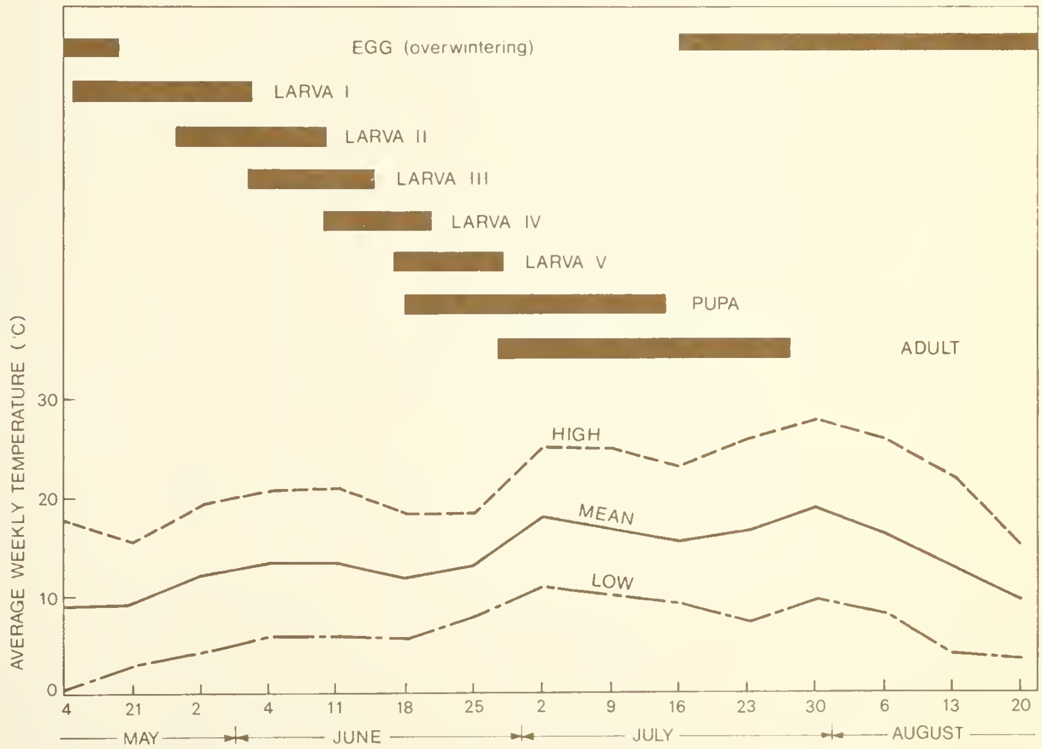

Figure 2.--Seasonal development of the larch bud moth, Zeiraphera sp., with daily temperatures in interior Alaska.

Mating occurred in previously defoliated trees which usually began to refoliate by mid-July. Adult females were capable of oviposition immediately after mating without a pre-oviposition period as was found with the spear-marked black moth, Rheumaptera hastata (L.), in Alaska (Werner 1977). Eggs were laid singly beneath bark scales, on cones, and in the axes of tree branchlets. An average of 160 eggs was laid per female over a period of 4 days.

First instars emerged in mid-May when the cumulative degree day temperature reached ca. 100° above the 5°C threshold. Larval emergence coincided with tamarack bud break, and thereafter larval development was closely related to host phenology. First instars fed within the newly developed needle clusters. Second, third, and fourth instars fed within a tubelike structure constructed from the needle clusters. Larval development began in mid-May and extended to mid-July. Fifth instars and occasionally fourth instars lived within finely webbed tunnels constructed along the branch axis. Fifth instars were often found outside of the webbed tunnels feeding on needles. Feeding by all instars except the first occurred during the twilight hours (2250-0150 h). First instar feeding occurred throughout all hours of the day.

When the fifth instars had completed feeding, they dropped to the ground on silken threads and constructed cocoons from pieces of moss, dead larch needles, or any other organic matter on the forest floor. The larvae did not burrow but followed natural channels in the peat soil which normally occurs beneath tamarack trees. Larvae preferred moist soil for pupation, and 80 percent of the cocoons were found within the upper 3 cm of the soil surface. Pupation began in late June and was completed by mid-July.

Natural Enemies

The impact of abiotic and biotic mortality agents on the density of the various stages of Zeiraphera sp. is shown in table 2. Rapid decreases in temperature during April 1976, i.e., from 0° to 30°C in 24 h, killed ca. 32 percent of the overwintering egg stage. Predation by lacewing larvae, Chrysopa sp., accounted for 2.4-percent reduction of the egg population following oviposition in July 1975 and the onset of winter in early October 1975. Predation by Chrysopa sp. and ants, Formica sp., reduced first-, second-, and third-instar populations by ca. 8 percent in 1975 and 9 percent in 1976. Bird predation removed 3 percent of the fourth instars and 10 percent of the fifth instars during the summers of 1975 and 1976. Slate-colored juncos, Junco hyemalis, redpolls, Acanthis sp., and chickadees, Parus sp., were observed feeding on larvae and adults.

Table 2--Seasonal density and mortality of *Zeiraphera* populations on heavy defoliation sites

Insect stage	Mean density[1]		Percent mortality	
	1975	1976	1975	1976
Egg (Sept.)	209±12.6	--	--	2.4
Egg (May)	--	123±10.2	31.6	--
Larvae I	112±8.5	94±9.6	1.3	2.1
Larva II	102±8.9	88±10.2	3.2	2.6
Larva III	75±6.3	68±8.4	3.8	3.2
Larva IV	72±4.5	63±5.6	4.9	12.2
Larva V	60±3.6	51±2.4	45.2	76.3
Pupa	89±1.3	43±1.7	62.3	99.6

[1]Egg and larval density per 0.64 m^2 branch area. Pupal density per square meter of litter.

Parasitism accounted for 16-percent reduction of fifth instars in 1975 and 30 percent in 1976. The greatest impact of parasitoids was on the pupal stage with a 55-percent reduction in 1975 and a 90-percent reduction in 1976. Three species of braconids, *Meteorus niveitarsis* (Cress.), *Apanteles* sp., and *Agathis* sp. were reared from fifth instars. The following ichneumonids were reared from fifth-instar larvae: *Glypta* sp. and *Elachertus* sp.

Ichneumonid pupal parasitoids were *Coccygomimus pedalis* (Cress.), *Mesochorus* sp., *Itoplectis quadricingulatus* (Prov.), *Gelis* sp., and *Mastrus annulicornis* (Thom.). One tachnid *Actia* sp. was reared from late-instar larvae.

A granulosis virus contributed to a 24- to 31-percent decline of fifth instars in 1975 and 1976 and ca. 8-percent decline of pupae in both years. Dead and dying larvae were found in the webbed shelters along tamarack branches and hanging from foliage where they died while spinning to the ground to pupate.

Acknowledgment

Parasite identifications were made by taxonomists at the Biosystematics Research Institute, Ottawa, Ontario. Insect pathogens were determined by K. M. Hughes, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon. I am indebted to the biological technicians, especially Tom Egan and Tom Ward. Thanks are also due to reviewers of the manuscript: Dr. Akira Mutuura, Biosystematics Research Institute, Ottawa, Canada; Dr. Robert E. Stevens, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado; and Dr. Edward Holsten, USDA Forest Service, Anchorage, Alaska.

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Forest and Range
Experiment Station

Research Note
PNW-357
April 1980

Ectomycorrhizal Inoculation of Containerized Western Conifer Seedlings

Randy Molina[1]

Abstract

Of 15 ectomycorrhizal fungi inoculated onto five container-grown conifer species (Larix occidentalis, Pinus contorta, P. ponderosa, Pseudotsuga menziesii, and Tsuga heterophylla), only Laccaria laccata and Cenococcum geophilum consistently formed ectomycorrhizae on all conifer hosts. Percents of mycorrhizal feeder roots were generally high, ranging from 86 on L. occidentalis to 94.5 percent on T. heterophylla for L. laccata and from 48.1 to 81.8 percent on these respective hosts for C. geophilum. L. laccata significantly colonized more feeder roots than C. geophilum for most conifer species. Only P. menziesii seedlings inoculated with C. geophilum were significantly larger than controls. There is a need for further studies with a wider range of fungi.

Keywords: Mycorrhizal inoculation, container nursery stock.

Introduction

Increasing needs to reforest cutover public and private forest lands have generated increasing demand for containerized seedlings. Given these needs as well as the sizable economic investments in container nurseries, use of container seedlings will continue for the immediate future.

Although the tops of seedlings grown in containers often grow luxuriantly, most root systems we have examined lack normal ectomycorrhizal development. This most likely results from the use of artificial (non-soil) potting substrates, restriction of natural fungus inoculation through greenhouse rearing, and, most importantly, the high dosages of regularly applied soluble fertilizers. High levels of fertility have been shown to retard mycorrhizal development of containerized seedlings (Marx and Barnett 1975). A more natural mycorrhizal root system may greatly improve planting success of containerized seedlings especially on hard-to-regenerate sites (Marx and Barnett 1975, Trappe 1977).

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Marx and Bryan (1975) have recently developed techniques to artificially inoculate bareroot seedlings with the ectomycorrhizal fungus Pisolithus tinctorius. Inoculations of containerized loblolly pine (Pinus taeda L.) (Marx and Barnett 1975, Ruehle and Marx 1977), lodgepole pine (Pinus contorta Dougl. ex Loud.) and Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) (Molina 1979) by similar techniques have also been successful. Little data is available, however, on artificial inoculation with other ectomycorrhizal fungi. Trappe (1977) suggests that ectomycorrhizal fungi in the genera Rhizopogon and Suillus, with their ease of isolation and rapid growth in pure culture, offer high potential for artificial inoculation of conifer seedlings. Also, fungi in these genera often fruit only with a particular host genus or species; the more specialized, host-specific fungus may benefit its particular host more than would a non-host-specific fungus (Mikola 1970).

The purpose of this study was to assess the success of inoculating containerized Douglas-fir, western hemlock (Tsuga heterophylla (Raf.) Sarg.), western larch (Larix occidentalis Nutt.), lodgepole pine, and ponderosa pine (Pinus ponderosa Dougl. ex Laws.) seedlings with a variety of host specific and non-host-specific fungi and their effects on seedling growth.

Methods

Fungus Isolates

Table 1 lists the fungus isolates tested for each tree species and their dates of isolation. Except for Cenococcum geophilum, all had originally been isolated from sporocarp tissue; C. geophilum was isolated from a surface-sterilized sclerotium (Trappe 1969). All isolates were previously tested in pure culture synthesis to confirm their mycorrhiza-forming ability.

Inoculations with Laccaria laccata, Cenococcum geophilum, Pisolithus tinctorius, Paxillus involutus, and a control of no fungus addition served as common inoculation treatments for all tested host tree species. These fungi are well known for their broad host ranges (Trappe 1962). The remaining three to four fungi tested per host tree species (see table 1) were selected for their known or inferred specificity to that particular host.

Inoculum Preparation

Inoculum was prepared according to Marx and Bryan (1975) as modified by Molina (1979). Vegetative mycelium of each isolate was grown aseptically in glass-capped 2-liter flasks containing 1 450 ml of vermiculite plus 50 ml of sphagnum peat moss moistened with 750 ml of modified Melin-Norkrans nutrient solution (Marx 1969); dextrose was substituted for sucrose in this solution. Control flasks contained no fungus. After 3 months at room temperature, inoculum was removed from the flasks and leached with cold running tap water to remove unused nutrients. Excess free water was removed by gently squeezing the inoculum wrapped in cheesecloth. Inoculum was placed in plastic bags and stored overnight at 5°C.

Table 1--Ectomycorrhizal fungus isolates used to inoculate containerized western conifers and their dates of isolation

Tree species inoculated	Fungus isolate		Date of isolation
	No.	Species	
Douglas-fir and western hemlock	A-153	Rhizopogon vinicolor Smith	August 1975
	S-311	Rhizopogon parksii Smith	November 1976
	S-242	Suillus ponderosus Smith & Thiers	October 1976
	S-243	Suillus lakei (Murr.) Smith & Thiers	October 1976
Lodgepole and ponderosa pine	S-297	Rhizopogon occidentalis Zeller & Dodge	November 1976
	S-218	Rhizopogon vulgaris (Vitt.) M. Lange	September 1976
	S-223	Suillus brevipes (Pk.) Kuntze	September 1976
	S-222	Suillus tomentosus (Lanf.) Snell, Singer & Dick	September 1976
Western larch	S-255	Suillus grevillei (Kl.) Singer	October 1976
	S-281	Fuscoboletinus aeruginascens (Secr.) Pom. & Smith	October 1976
	S-298	Suillus cavipes (Opat.) Smith & Thiers	October 1976
All of the above	A-145	Cenococcum geophilum Fr.	December 1974
	S-238	Laccaria laccata (Scop. ex Fr.) Bk. and Br.	September 1976
	S-403	Paxillus involutus (Batsch.) Fr.	September 1977
	S-216	Pisolithus tinctorius (Pers.) Coker & Couch.	September 1976

Inoculation and Sowing

A potting substrate, containing equal volumes of vermiculite and sphagnum peat moss, was pasteurized in steam at 80°C for 30 min to kill resident mycorrhizal fungi. For each species of fungus, one part inoculum was added to six parts potting substrate in large plastic bags and was then vigorously shaken to evenly distribute the inoculum particles. Sixty individual "Leach super cell" containers, 165-ml capacity, were then filled with the inoculated potting substrate per tree-fungus combination; of these, groups of 20 cells each were then randomly placed into three replicate blocks per host tree. A randomized block design containing three replicate blocks, each with 20 seedlings per fungus treatment, was used for each tree species. The large number of treatment combinations necessitated keeping each tree species as a separate test. Cells were then sown with three prestratified seeds and misted twice daily until germination was complete. Seedlings were then thinned to one per cell.

Growing Conditions

All seedlings were grown in the greenhouse from late May through November 1978. Supplemental light of approximately 11 000 lx over a 15-h photoperiod was provided by overhead sodium-vapor lamps. Photoperiod was lengthened to 20 h from mid-August through September to offset premature budset. Because high fertility is known to retard mycorrhiza formation of container seedlings (Marx and Barnett 1975), a completely soluble 20-19-18 NPK fertilizer (Peat-lite special)[2] plus Sequestrene Fe 330 iron chelate were applied at approximately one-quarter strength, the dosage suggested by Owston (1975) for growing western conifers. The soluble fertilizer was dissolved in tap water and evenly distributed by hand over all seedlings at the rate of 6 g/m^2 of bench space; Sequestrene was applied at the rate of 3 g/m^2 of bench space. Each seedling thus received approximately 3.1 mg of Peat-lite special fertilizer plus 1.6 mg of Sequestrene in each fertilization. Fertilizations were performed twice monthly from July through October. Seedlings were mist irrigated with tap water as needed.

Data Collection and Analysis

At the end of the experiment, all seedlings were harvested and their roots gently washed free of potting substrate. Each seedling root system was examined by stereomicroscopy for success of inoculation. For those fungus treatments showing successful inoculation, 10 seedlings were randomly selected per treatment replication; and their height, stem diameter, percent of mycorrhizal feeder roots, and ovendry weights of tops and

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[2]Trade names used do not imply endorsement by the U.S. Department of Agriculture over similar products.

roots were recorded. Degree of mycorrhiza formation was assessed by randomly removing three to six major lateral roots per seedling from their points of attachment to the tap roots and then counting the total number of mycorrhizal and non-mycorrhizal feeder roots. At least 100 total feeder roots were counted per seedling. Mycorrhiza formation was expressed as percent of total feeder roots examined which had formed mycorrhizae. Control or inoculated seedlings with other, contaminant mycorrhiza types were discarded initially and not included in analyses. All results were subjected to analysis of variance and differences among treatment means were compared with Scheffé tests. All significant differences are reported at $P \leq 0.05$.

Results

Only 2 of the 15 fungi tested, L. laccata and C. geophilum, formed abundant mycorrhizae on all the conifer species. P. involutus produced mycorrhizae with only a few seedlings from each tree species. No mycorrhizae were produced by any Suillus species, Rhizopogon species, Fuscoboletinus aeruginascens, or P. tinctorius. Control seedlings were mostly free of any mycorrhiza formation . Thelephora terrestris (Ehrh.) Fr. was the most prevalent contaminant mycorrhizal fungus but only colonized about 4 percent of all seedlings.

Inoculation success with both L. laccata and C. geophilum was excellent. With very few exceptions, practically all L. laccata- and C. geophilum-inoculated seedlings formed abundant mycorrhizae. Percent of mycorrhizal feeder roots ranged from 86 on western larch to 94.5 percent on western hemlock for L. laccata inoculations and from 48.1 to 81.8 percent on these respective hosts for C. geophillum inoculations (table 2). Except for ponderosa pine, L. laccata significantly colonized more feeder roots than C. geophilum. Mycorrhizal development was always strongest at the top of seedling plugs for both fungi, but usually the entire plug was colonized.

L. laccata sporocarps fruited prolifically among the different hosts, and various stages of primordia were abundant in the containers. Sclerotia of C. geophilum were also frequently observed on the root systems. Both fungi were easily reisolated from these reproductive structures. The effects of these fungi on seedling growth will be briefly discussed for each tree species.

Douglas-Fir

L. laccata mycorrhizae were most often well developed, pinnately branched structures and averaged 89 percent of the total short roots. C. geophilum mycorrhizal development was also extensive, colonizing 76.7 percent of total short roots. Mycorrhizae were most often short and cylindric to simple pinnate and of typical jet black color.

Table 2--Mean growth and mycorrhiza formation of Douglas-fir, western hemlock, western larch, lodgepole pine, and ponderosa pine seedlings inoculated with *Laccaria laccata* and *Cenococcum geophilum*[1]

Tree species	Fungus treatment	Height	Stem diameter	Dry weight		Top: root	Percent mycorrhizal short roots
				Tops	Roots		
		Centimeters	Millimeters	Grams			
Douglas-fir	Control	9.27a	2.00	0.535	0.921	0.585	--
	Laccaria laccata	9.20a	2.00	.549	.853	.656	89.0a
	Cenococcum geophilum	10.51b	2.02	.561	.813	.694	76.7b
Western hemlock	Control	12.23	2.09	.574	.581a	.996	--
	Laccaria laccata	11.44	1.94	.520	.489b	1.090	94.5a
	Cenococcum geophilum	12.56	1.96	.533	.474b	1.168	81.8b
Western larch	Control	9.97	2.17	.576	.679	.868ab	--
	Laccaria laccata	9.61	2.27	.468	.650	.735a	86.2a
	Cenococcum geophilum	12.08	2.03	.573	.626	.923b	48.1b
Lodgepole pine	Control	4.24	1.78a	.243	.670a	.360a	--
	Laccaria laccata	4.30	1.56b	.204	.501b	.418a	93.0a
	Cenococcum geophilum	4.42	1.77a	.274	.524ab	.532b	69.7b
Ponderosa pine	Control	5.84a	2.81a	.564a	.994a	.585	--
	Laccaria laccata	5.27a	2.24b	.319b	.607b	.557	89.5
	Cenococcum geophilum	5.81a	2.45ab	.499ab	.740b	.684	77.8

[1]When no letters follow a group of means, no significant differences were seen in the analysis of variance. Means within individual tree species not sharing a common letter are significantly different ($P \leq 0.05$) by Scheffé tests.

No significant differences were found in stem diameter, dry weights of tops or roots, or in top:root ratio between any treatments (table 2). *C. geophilum*-inoculated seedlings, however, were significantly taller than all other seedlings.

Western Hemlock

Although *L. laccata* colonized 94.5 percent of total feeder roots, the mycorrhizae were most often very short, 2-5 mm long, occasionally becoming slightly longer and pinnate. Similarly, *C. geophilum* colonized 81.8 percent of total short roots, but these were also usually short and simple.

Control seedlings had significantly greater root dry weight than either fungus treatment, possibly as a result of the very short mycorrhizae observed (table 2). No significant differences were found in height, stem diameter and dry weight, or top:root ratio.

Western Larch

L. laccata mycorrhizal development on western larch resembled Douglas-fir inoculations in colonizing 86.2 percent of total short roots and in forming elongate, variously branched to pinnate mycorrhizae. *C. geophilum* development was less extensive, colonizing 48.1 percent of total feeder roots, these often concentrated in the upper third of the plug.

No significant differences between treatments occurred in seedling height, stem diameter, or dry weights of tops and roots (table 2). *C. geophilum*-inoculated seedlings had a significantly higher top:root ratio than *L. laccata*-inoculated seedlings; yet, *L. laccata* colonized significantly more short roots than *C. geophilum*.

Lodgepole Pine

L. laccata formed abundant mycorrhizae with lodgepole pine colonizing on the average 93 percent of total feeder roots. Mycorrhizae were well developed, often forming large coralloid clusters. *C. geophilum* mycorrhizae were also abundant and colonized 69.7 percent of total feeder roots. Mycorrhizae were most often simple cylindric to bifurcate, occasionally compoundly bifurcate.

No significant differences between treatments were seen in height or top dry weight. Significant differences were found, however, for stem diameter, root dry weight, and top:root ratio (table 2). *L. laccata*-inoculated seedlings had smaller stem diameters than either control or *C. geophilum*-inoculated seedlings. Control seedlings had greater root dry weight than *L. laccata*-inoculated seedlings and also a lower top:root ratio than *C. geophilum*-inoculated seedlings.

Ponderosa Pine

Both *L. laccata* and *C. geophilum* formed extensive mycorrhizae on ponderosa pine, colonizing 89.5 and 77.5 percent of total feeder roots, respectively. Mycorrhizae were very similar to those described for lodgepole pine.

Significant differences among fungus treatments were found for seedling height, stem diameter, and dry weight of tops and roots. Control seedlings had significantly greater stem diameters and top dry weight than L. laccata-inoculated seedlings and also greater root dry weight than both fungus treatments. Analysis of variance indicated significant differences among treatment means for seedling height, but comparison of means with Scheffé tests (a conservative mean comparison test) failed to isolate the differences.

Discussion

It remains unknown why only two of the many fungi consistently formed abundant mycorrhizae after inoculation. Clearly this inoculation technique may not work for many fungi. The failure with P. tinctorius-isolate S-216 is particularly puzzling; this isolate performed well in an inoculation the previous year (Molina 1979). Long-term culture maintenance with repeated transferring may have been a problem; Marx (personal communication 1979) found that this fungus quickly loses its ability to form mycorrhizae as the culture ages and is repeatedly transferred

Successful inoculation of containerized seedlings with species of Suillus or Rhizopogon have not been reported; only limited success has been reported for their inoculation onto bareroot nursery seedlings (Moser 1959, Theodorou and Bowen 1970, Vozzo and Hacskaylo 1971). Maybe these particular isolates cannot withstand the disturbance involved in inoculum preparation or survive within the vermiculite particle until young germinants produce feeder roots for mycorrhizal colonization. Also, their growth pattern in inoculum flask culture resembles that of many fungi growing in petri plate culture: young, actively growing mycelium progresses as a colony edge into the peat-vermiculite substrate leaving behind darkened, slower growing mycelium. Whether the older, darkened mycelium remains viable is unknown. Because fungi in these genera are easily isolated, grow quickly in culture, and are often host-specific, their use in mycorrhizal inoculation of seedlings is highly desirable (Trappe 1977).

The successful mycorrhizal inoculation with L. laccata and C. geophilum still emphasizes the practical use of this inoculation technique. Most seedlings inoculated with these two fungi formed abundant mycorrhizae, at times the entire feeder root system being colonized. The prolific sporocarp formation by L. laccata among the various hosts indicates the high activity of this fungus in the container system. Also, for both fungi, the seedling root plugs were usually strongly bound by the fungal mycelium; this may significantly reduce root disturbance during outplanting. Future research will concentrate on ecotypic variation among different isolates of these fungi as it influences the inoculation potential of nursery seedlings and outplanting performance onto various sites.

Mycorrhizal inoculation of containerized seedlings grown under routine nursery conditions utilizing completely soluble fertilizers, even at reduced rates, rarely increases growth (Molina 1979, Marx and Barnett 1975). In this study, only Douglas-fir growth was significantly increased; C. geophilum-inoculated Douglas-fir seedlings were significantly taller than both control and L. laccata-inoculated seedlings. L. laccata seedlings were generally smaller than controls, sometimes significantly so; both Pinus species inoculated with L. laccata had significantly smaller stem diameters and root dry weights than control seedlings. The prolific mycelial growth of L. laccata, including its abundance of mycorrhizal colonizations and sporocarp formation, may have been a considerable drain on host photosynthates.

To fully realize the practical significance of mycorrhizal inoculation of containerized seedlings, further research is needed on the effects of different nutrient levels and fertilizer schedules on inoculation success. Inoculation methods may have to be modified to include a more diverse array of fungi in future experiments. Finally, the performance of inoculated vs. uninoculated seedlings when planted at various sites must be evaluated.

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Guidelines for Developing or Supplementing Natural Photo Series

Wayne G. Maxwell and Franklin R. Ward[1]

Abstract

These guidelines provide the land manager with procedures for making local supplements to General Technical Report PNW-105, "Photo Series for Quantifying Natural Forest Residues in Common Vegetation Types of the Pacific Northwest"; the process used to photograph and measure residues and summarize the data is described.

KEYWORDS: Residue surveys, data recording methods, photography.

Introduction

Natural photo series have been developed for major forest types in the Pacific Northwest by the Pacific Northwest Forest and Range Experiment Station, the Pacific Northwest Region of the Forest Service, and cooperating land management agencies.[2] They are comprised of 86 photo examples, forming 25 series, in 12 vegetation types.

These photo series provide a suitable tool for managing residue in most of the forested area of the Pacific Northwest and much of the forested area in other regions of the West. It may be desirable, however, to develop local series for other vegetation types, or to supplement the published series for forests containing signficant amounts of residue not well represented by these series.

Locally produced series or supplements may be useful in other forest units or regions. Sharing photo series examples can save many man-hours and dollars by avoiding duplicate efforts. The acceptance of work done by neighboring units will depend in a large part on quality photography, use of established sample procedures, and display of complete data in a familiar format.

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[1]Wayne G. Maxwell is a forester and Franklin R. Ward a forestry technician with the Pacific Northwest Forest and Range Experiment Station.

[2]Maxwell, Wayne G., and Franklin R. Ward. 1979. Photo series for quantifying forest residues in common vegetation types of the Pacific Northwest. USDA For. Serv. Gen. Tech. Rep. PNW-105, 229 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

These guidelines are provided to assist other forest units and agencies in producing natural photo series or supplements to fill their needs. Following the procedures outlined in this guide, users can:

- Capitalize on previous experience in producing natural photo series.
- Collect information on total available fuel from the areas photographed.
- Display data from each photo area in a familiar and standardized format.
- Assemble natural photo series that not only will improve fuel management capabilities on the home unit but will be readily acceptable and beneficial to other units with like forest types.

Major Objectives for Preparing Natural Photo Series

The major objectives in forming natural photo series in timbered vegetation types are to provide an array of loadings of dead-down residue that will: (1) enable trained technicians to make logical comparative estimates of loading by size classes in similar stands and (2) enable multidiscipline groups to quantify desirable residue loadings.

Criteria for Loading Levels in a Series

There is no set number of loading levels needed to form a series. If tonnage of dead-down residue in a given vegetation type and size class ranges from 5 to 20, three levels may be adequate. If tonnage ranges from 20 to 300, 8 to 10 levels may be desirable.

Extensive series for brush, if they are made, should be based on vegetation type, age class, and density or stocking level, rather than the size classes used in timber stands.

Reconnaissance

Variations in loadings of dead-down residue in natural forest stands result from such events as windstorms, epidemics of insects and disease, ice breakage, and fire. Knowledge of where such events have occurred in the past several decades is helpful in locating variations in loadings of dead-down residue.

It is generally helpful to first find the very light and the very heavy loading examples in the proposed series, then determine the desired number of examples in between and search for such areas.

Select slightly concave topography so that residue in the 180 feet of possible sampling distance has the best chance of being visible in the picture.

In dense stands and brush fields, it is not possible to see the dead-down residue in 180 feet of possible sampling distance. In these situations, reconnoiter the entire sampling area to make sure the dead-down residue in the picture is representative of the sampling area.

Photographing

Some guidance on photographing is provided in the "National Fuel Classification and Inventory System" guidelines.[3] Most of the suggestions are included here, along with suggestions specific to natural stand and residue situations.

The following should be helpful:

1. Photograph on cloudy or overcast days. If this is not possible, photograph early in the morning or late in the afternoon on clear days. Bright sunlight streaming through canopies creates sharp contrasts. Photographing under these conditions produces pictures with patches either too light or too dark to distinguish details.
2. Use a quality 35-mm camera with a 50- or 55-mm lens, or other quality camera with a comparable field of view.
3. Take photos with the long dimension horizontal.
4. Use a reasonably fast color film, such as Kodachrome 64.[4] This permits a reduced aperture (F-8 to F-16) which will provide reasonable focus of both background and foreground.
5. Always use a tripod, or similar stable platform, for the camera. Low light under timber canopies may require shutter speeds down to one twenty-fifth of a second. Under such a setting, the slightest camera movement causes a blurred photo.
6. Use the standard National Fuel System marker and pole (see footnote 3) placed 30 feet from the camera, in the center of the scene.
7. Use a light meter to determine proper exposure.
8. Take several pictures (three to five minimum), using slight variations of exposure. Occasionally, the exposure indicated by the light meter for the total picture is not the best for showing the detail of dead-down residue. Remember, the cost of film is minor compared with costs for salary and travel. A few extra shots may make a return trip unnecessary.

There are no known filters or flash attachments that will materially improve photographs taken in timbered stands.

Sampling Dead-Down Woody Material

Viewing the area through the camera viewfinder, establish five base lines with five sample points on each base line as shown in figure 1.

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[3]U.S. Department of Agriculture, Forest Service. 1975. National fuel classification and inventory system, preliminary draft. 61 p., illus. Washington Office, Washington, D.C.

[4]Mention of products does not constitute an endorsement by the U.S. Department of Agriculture.

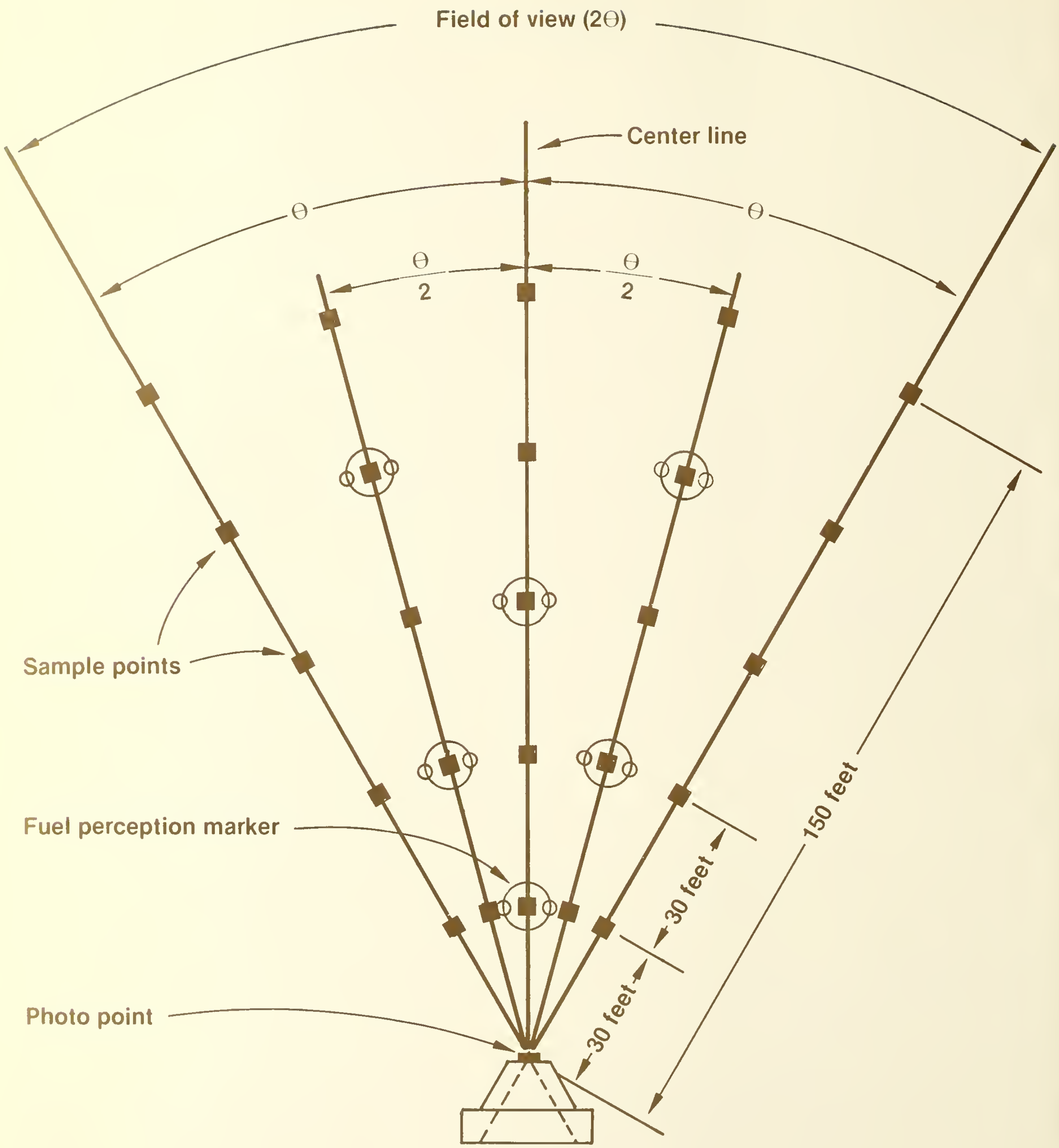

Figure 1.--The sampling pattern.

Angle of the sample plane from the base line will be determined by the toss of a die, as explained in the "Handbook for Inventorying Downed Woody Material," page 4.[5] All sample planes from the left base line will be alined with, or to the right of this base line. All sample planes from the right base line will be alined with, or to the left of this base line. Sample planes from the three interior base lines can be alined with, or to the right or left of the base line.

At each sample point on the three interior lines, flip a coin to determine whether the sample plane will go to the left or the right of the base line if the random angle is other than 0°.

Then conduct sampling from each of the 25 sample points, following instructions in the "Handbook for Inventorying of Downed Woody Material" (see footnote 5), starting with step 3 on page 3. Lengths of sample lines, however, are established at 3 feet for 0- to 1/4-inch material, 6 feet for 1/4- to 1-inch; 10 feet for 1- to 3-inch; and 30 feet for 3-inch and larger.

Use a separate Field Tally form for recording data from each sample plane (see fig. 2); a blank form is included at the end of this publication.

Complete sampling of dead-down material at each point before sampling live and dead standing material, to avoid disturbing the natural character of the dead fuel before measuring it.

Sampling Live and Dead Standing Material

Sampling of both live and dead standing material will be conducted at 6 sample points in the 25-point pattern, as indicated by the circled sample points (fig. 1). Measurements for both variable and fixed plots are made from these points. Dimensions and arrangement of fixed plots are detailed in figure 3.

Measurements of variable and fixed plots are recorded on the back of the "Field Tally" form for the appropriate sample point.

Following are detailed instructions for this sampling:

I. Variable Plot Information.
   Use a Relaskop, prism, or wedge (record factor for instrument on data sheet--fig. 2 (back)). Locate all trees and snags over 8 inches in d.b.h. in the plot.

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[5]Brown, James K. 1974. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16, 24 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Figure 2.--"Filled in" "Field Tally" form.

FIELD TALLY FORM (front of form)

GENERAL INFORMATION

Photo point designation Bright

Sample point number 12 Date 8-12-79

Observers Smith & Jones

Sample plane angle Left 60° Slope along sample plane 10%

SLASH PARTICLE TALLY

Diameter class	Line length	Tally of intersections
0-¼ inch	3 feet	36
¼-1 inch	6 feet	3
1-3 inches	10 feet	1
Over 3 inches	30 feet	

COMMENTS

	Species					
	DF					
	Diam.	Diam.²	Diam.	Diam.²	Diam.	Diam.²
Sound	10	100				
	4	16				
Sum of squared diameters						
	All species					
Rotten						
	12	144				
Sum of squared diameters						

DEPTH MEASUREMENTS AND SPECIES COMPOSITION

Slash depths (nearest 0.1 foot)		Duff depths (nearest 0.2 inch)		Species composition (nearest 10 percent).		
					Species	Percent
First foot	0.1	10 feet	3.0	1.		
Second foot	0	20 feet	3.2	2.		
Third foot	0.2	30 feet	2.6	3.		

LIVE AND DEAD STANDING VEGETATION (back of form)

VARIABLE PLOT
TREES AND SNAGS

Basal area factor 40

SPECIES	D.B.H.	HEIGHT	CROWN HEIGHT	AGE
Abbrev.	Nearest inch	Nearest 5 feet	Nearest 5 feet	Nearest 5 years
LIVE TREES OVER 20-INCH D.B.H.				
DF	42	190	95	265
DF	29	170	60	240
DF	29	170	65	
DF	40	190	85	
DF	32	175	70	
Estimated available crown space occupied 40%				
LIVE TREES 8- TO 20-INCH D.B.H.				
H	9	35	15	
H	10	35	15	
Estimated available crown space occupied 10%				
SNAGS 8 INCHES AND OVER				
DF	25	25		
DF	26	35		
DF	18	90		

COMMENTS

FIXED PLOT
TREES—LIVE AND DEAD<8-INCH D.B.H., 1/300 ACRE

SPECIES	D.B.H.	HEIGHT	CROWN HEIGHT
Abbrev.	Nearest inch	Nearest foot	Nearest foot
H	3	16	12
Estimated available crown space occupied 20 %			

BRUSH, ¼ MIL-ACRE (2)

SPECIES	STEM DIAMETER at 6 inches	HEIGHT	CROWN HEIGHT	AVERAGE CROWN DIAMETER
Abbrev.	Nearest 1/10 inch	Nearest inch	Nearest inch	Nearest inch
LEFT PLOT				
None				
Ground space occupied 0 %				
RIGHT PLOT				
OR.GR.	.2	7	2	12
Ground space occupied 30 %				

GRASS AND FORBS, ¼ MIL-ACRE (2)

	Ground space occupied	Predominant species	Average height
	Percent	Abbrev.	Inches
L	None		
R	20	Violet	1

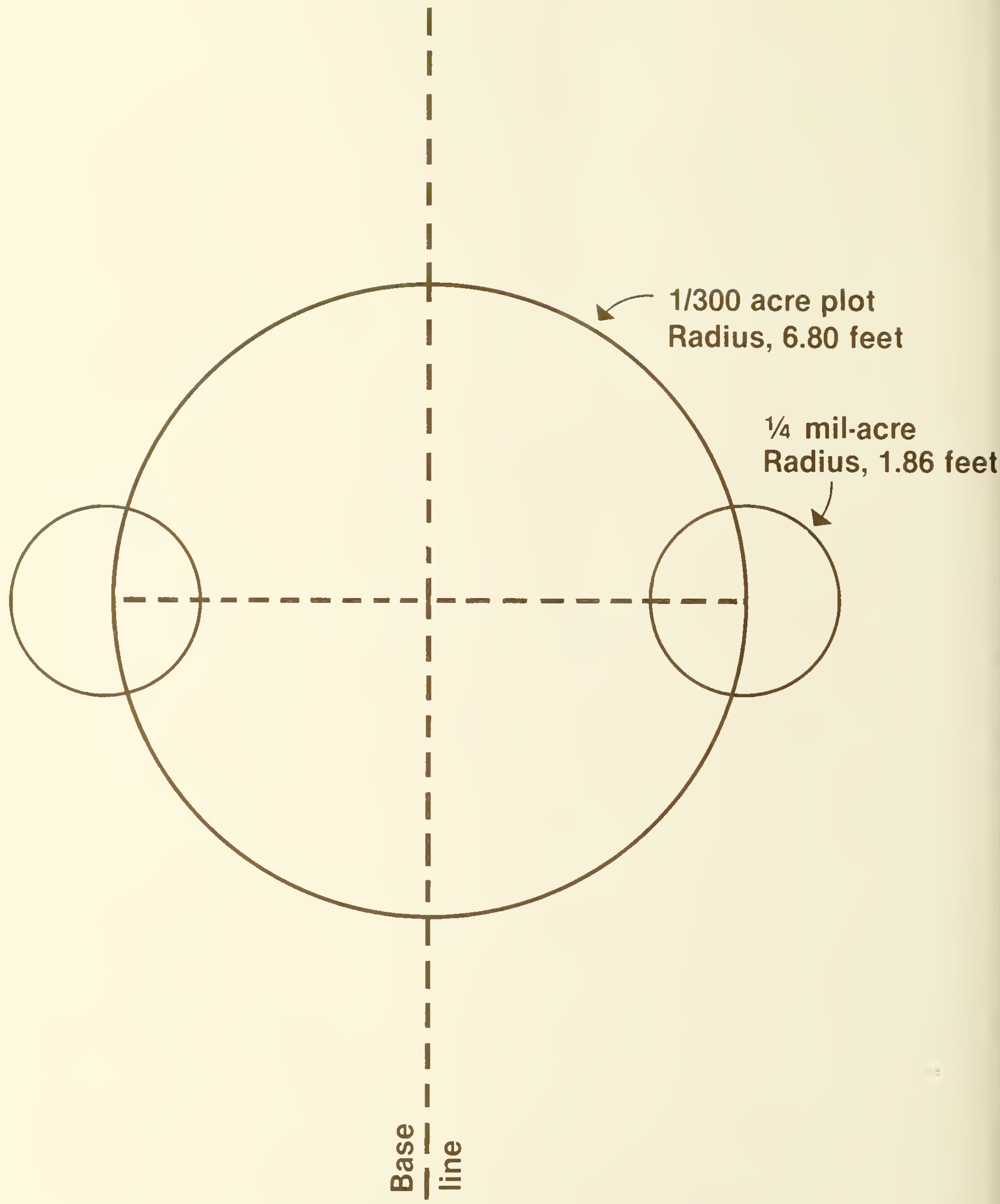

Figure 3.--Dimensions of fixed plots.

A. For each tree in the plot, record in the 8- to 20-inch d.b.h. block or the ≥20-inch d.b.h. block the following information:
   1. Species (identify).
   2. D.b.h. (measure).
   3. Height (measure).
   4. Crown height (measure).
   5. Age (bore and count). When at least four dominant trees have been bored in the photo sample area, if the observer is confident that these samples represent the stand age, no additional trees need be bored.

B. When all information on live trees on variable plots has been recorded, estimate to the nearest 10 percent the available space occupied by the crowns of trees in each of the two diameter classes. Visualize being high above the sample area looking straight down; judge how much of the ground would be blocked from view by crowns of trees in each of the two diameter classes.

C. For each snag over 8 inches, record in the snag block:
   1. Species (identify).
   2. D.b.h. (measure).
   3. Height (measure).

II. Fixed Plot Information.

A. For trees under 8 inches in d.b.h. on the 1/300-acre plot, record:
   1. Species (identify).
   2. D.b.h. (measure).
   3. Height (measure).
   4. Crown height (measure).
   5. Crown space occupied (estimate to nearest 10 percent); use the method recommended for larger trees.

B. For brush, on each of the two one-fourth mil-acre plots, record:
   1. Species (identify).
   2. Stem diameter at 6 inches from ground (measure).
   3. Height (measure).
   4. Crown height (measure).
   5. Average crown diameter (measure). For crowns, measure the widest and narrowest dimensions and average these for diameter. Measure the crowns on stems that originated in the plot even though the crown extends beyond the plot boundary. Do not measure crowns extending into the plot from stems outside the plot.
   6. Ground space occupied (estimate). Estimate the percentage of plot area covered by crowns. Visualize being above the plot looking straight down and judge how much of the ground would be blocked from view by the crowns.

C. For grass and forbs on the two one-fourth mil-acre plots, record:
   1. Ground space occupied (estimate). Use method recommended for brush.
   2. Dominant species (identify).
   3. Average height (estimate).

Computation of Loadings of Dead-Down Material and Other Measurements

Computations of weights, volumes, and depth of dead wood and depth of duff and litter are conducted in accordance with the "Handbook for Inventorying Downed Woody Material" (see footnote 5).

Percentages of ground area covered by residue and ground area covered by duff and litter are determined by dividing total points sampled into points that had measurable material. For example, if depth of woody residue was measured on 50 of the 75 sample segments, the ground area covered by residue would be 67 percent. Similarly, if depth of duff and litter was measured on 60 of the 75 sample points, the ground area covered by duff-litter would be 80 percent.

Computation of Data on Standing Fuel

Calculate the average heights of trees, crown heights of trees and brush, height of grass and forbs, and average diameter of trees by summing the units in each category and dividing the total by the number of units. The average in this case is the mean or:

$$\bar{X} = \frac{\Sigma X}{n};$$

where:

$\bar{X}$ = average (mean);
X = observed values in each category;
n = number of trees sampled.

Ground space occupied is also an average of the number of samples taken. So the above formula also applies here.

Calculate the number of trees or snags per acre from the formula for a single tree:

$$T = \frac{43,560}{\pi(DR)^2};$$

where:

T = trees per acre;
D = d.b.h.
R = plot radius factor based on basal area factor (BAF) used (the plot radius factor for BAF's of 5, 10, 20, and 40 are 3.889, 2.750, 1.944, and 1.375, respectively).

Add the trees per acre for each diameter at breast height by plot; then compute the average by dividing by the number of plots.

Weight of grass and forbs can be estimated by an ocular method or by clipping and weighing. The ocular method can best be done by asking an experienced range specialist to estimate the amount on the basis of pounds per acre. If clipping and weighing is the desired method, plants from each one-fourth mil-acre plot are clipped and allowed to air dry until an equilibrium for an average summer day is reached. Average the weights from the plots. Then multiply the average weight by 4,000 to obtain the average weight per acre.

Trees less than 8 inches in d.b.h. in each 1/300-acre plot are counted and then computed on a per-acre basis. The formula is:

$$y = 300x;$$

where:

y = trees per acre for each plot;
x = count by plot.

$$\text{Average trees per acre for all plots} = \frac{\Sigma y}{n};$$

where:

n = number of plots.

Remember, for all size classes of trees per acre, include all plots to calculate the average even though some may be zero.

Record completed computations for the various categories of material in the appropriate blocks on the data sheet (fig. 4) which accompanies the photo.

Recommended Descriptive Codes of Local Natural Photo Series and Supplements

1. Descriptive codes for supplements:
   When supplementing published series, precede the code with the unit name. Then use decimal numbers for order of rank in the total series. For example, if the Bend District is supplementing the three level mixed conifer, size class 3 series (General Technical Report PNW-105) with two levels of loading lighter than number 1, one level between number 2 and number 3 and two levels heavier than number 3, photos in the supplements would be coded as follows:

   Bend-0.1-MC-3
   Bend-0.2-MC-3
   Bend-2.1-MC-3
   Bend-3.1-MC-3
   Bend-3.2-MC-3

DATA SHEET

Residue descriptive code ____________

LOADING			OTHER MEASUREMENTS
Size class (inches)	Weight (tons/acre)	Volume (ft^3/acre)	Average residue depth (feet) ______
0.0 - 0.25			Ground area covered by residue (percent) ______
0.26- 1.0			Average duff and litter depth (inches) ______
1.1 - 3.0			Ground area covered by duff and litter (percent) ______
3.1 - 9.0			Sound residue 3.1-inch diameter and larger (percent) ______
9.1 -20.0			Rotten residue 3.1-inch diameter and larger (percent) ______
20.1+			
Total			

STAND INFORMATION

Trees over 20-inch d.b.h.

Dominant species ______
Trees per acre ______
Average d.b.h. (inches) ______
Average tree height (feet) ______
Average crown height (feet) ______
Estimated crown space occupied (percent) ______

Trees and dead stems under 8-inch d.b.h.

Dominant species ______
Trees per acre ______
Average d.b.h. (inches) ______
Average tree height (feet) ______
Average crown height (feet) ______
Estimated crown space occupied (percent) ______

Trees 8- to 20-inch d.b.h.

Dominant species ______
Trees per acre ______
Average d.b.h. (inches) ______
Average tree height (feet) ______
Average crown height (feet) ______
Estimated crown space ______

Snags 8-inch d.b.h. and over

Number per acre ______
Average d.b.h. ______
Average height ______

BRUSH INFORMATION

Dominant species ______
______
Average height (inches) ______
Average crown height (inches) ______
Ground space occupied (percent) ______

GRASS AND FORBS INFORMATION

Dominant species ______
______
Average height (inches) ______
Ground space (percent) ______
Estimated weight (pounds per acre) ______

ASSESSMENT OF FIRE BEHAVIOR AND SUPPRESSION DIFFICULTY

Spread rate (chains/hour) ______
Flame length (feet) ______
Resistance to suppression (chains/man-hour) ______

Ecoclass coding ______

REMARKS

Figure 4.--Data sheet.

2. Descriptive codes for new series:
   When assembling a series for a vegetation type, start coding with the name of the unit; continue as with published series, using the appropriate abbreviation for the vegetation type.

Assessment of Fire Behavior and Difficulty of Suppression

Anticipated rate of spread of wildfire and length of flame are estimated for each photo example; selected moisture content of fine fuels and wind conditions are used. Conditions selected for the assessment should approximate the average of conditions expected during the critical portion of the fire season. Results should provide a benchmark for judging fire behavior when conditions are more or less critical.

The assessments of fire behavior and difficulty of suppression for photo series examples in General Technical Report PNW-105 (see footnote 2) were determined from fuel model scaling tables developed by Dr. David V. Sandberg, and a resistance to suppression matrix developed by Wayne G. Maxwell.[6]

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[6]These unpublished procedures are on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Metric Equivalents

1 acre	=	0.404 7 hectare
2.471 acres	=	1 hectare
1 foot	=	0.304 8 meter
3.281 feet	=	1 meter
1 inch	=	2.54 centimeters
0.3937 inch	=	1 centimeter
1 pound	=	0.453 6 kilogram
2.205 pounds	=	1 kilogram
1 ton (short)	=	0.907 2 ton (metric)
1.1023 tons (short)	=	1 ton (metric)

FIELD TALLY FORM

GENERAL INFORMATION

Photo point designation ______________________________

Sample point number ______________________________ Date ______________________________

Observers ______________________________

Sample plane angle ______________________________ Slope along sample plane ______________________________

SLASH PARTICLE TALLY

Diameter class	Line length	Tally of intersections
0-¼ inch	3 feet	
¼-1 inch	6 feet	
1-3 inches	10 feet	
Over 3 inches	30 feet	

COMMENTS

	Species					
	Diam.	Diam.^{2}	Diam.	Diam.^{2}	Diam.	Diam.^{2}
Sound						
Sum of squared diameters						
	All species					
Rotten						
Sum of squared diameters						

DEPTH MEASUREMENTS AND SPECIES COMPOSITION

Slash depths (nearest 0.1 foot)		Duff depths (nearest 0.2 inch)		Species composition (nearest 10 percent).		
					Species	Percent
First foot		10 feet		1.		
Second foot		20 feet		2.		
Third foot		30 feet		3.		

LIVE AND DEAD STANDING VEGETATION

VARIABLE PLOT
TREES AND SNAGS

Basal area factor ________

SPECIES	D.B.H.	HEIGHT	CROWN HEIGHT	AGE
Abbrev.	Nearest inch	Nearest 5 feet	Nearest 5 feet	Nearest 5 years
LIVE TREES OVER 20-INCH D.B.H.				
Estimated available crown space occupied %				
LIVE TREES 8- TO 20-INCH D.B.H.				
Estimated available crown space occupied %				
SNAGS 8 INCHES AND OVER				

COMMENTS

FIXED PLOT
TREES—LIVE AND DEAD<8-INCH D.B.H., 1/300 ACRE

SPECIES	D.B.H.	HEIGHT	CROWN HEIGHT
Abbrev.	Nearest inch	Nearest foot	Nearest foot
Estimated available crown space occupied %			

BRUSH, ¼ MIL-ACRE (2)

SPECIES	STEM DIAMETER at 6 inches	HEIGHT	CROWN HEIGHT	AVERAGE CROWN DIAMETER
Abbrev.	Nearest 1/10 inch	Nearest inch	Nearest inch	Nearest inch
LEFT PLOT				
Ground space occupied %				
RIGHT PLOT				
Ground space occupied %				

GRASS AND FORBS, ¼ MIL-ACRE (2)

	Ground space occupied	Predominant species	Average height
	Percent	Abbrev.	Inches
L			
R			

GPO 990-795

United States
Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

Research Note
PNW-359
June 1980

Laminated Root Rot Damage in a Young Douglas-Fir Stand

E. E. Nelson[1]

Abstract

Damage occurring from the disease laminated root rot (*Phellinus weirii* (Murr.) Gilbertson) on two 10-acre plots in a young (40-year-old) stand of Douglas-fir was studied for 25 years. After 25 years, nearly 5 percent of the basal area was killed by the disease. Stand damage caused by vegetative spread of the fungus was significantly related to previous mortality from the disease and to slower net growth during that period. Nonproductive stand openings caused by the disease occupied over 11 percent of one plot and over 7 percent of the other. Although additional losses can be anticipated before harvest, severe losses are not expected in this stand before commercial maturity.

Keywords: Root rot, *Phellinus weirii*.

Introduction

Phellinus weirii (Murr.) Gilbertson was first described by Murrill (1914) as *Poria weirii*, the cause of butt rot in western redcedar *Thuja plicata* Donn ex D. Don). The fungus was not found on other species until 1929, when it appeared in young Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) on Vancouver Island (Bier and Buckland 1947). Since then, *P. weirii* has been found in the Pacific Northwest on all conifers of commercial importance (Buckland and Wallis 1956).

In 1951, the Pacific Northwest Forest and Range Experiment Station, Division of Forest Pathology (then a part of the Bureau of Plant Industry), began a series of studies to determine the importance of *P. weirii* in the Pacific Northwest. About 200 acres of permanent plots were established to determine the rate of damage in Douglas-fir stands infested with *P. weirii*. Unfortunately, many of the stands available for study at that time were beyond what today would be considered rotation age. Nevertheless, a few plots were established in young stands. This paper describes

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stand development over a quarter century on two 10-acre plots established in an infested 40-year-old Douglas-fir stand in southwestern Washington. Guidelines formulated from observations on these plots and plots in other stands will provide a basis for better management of infested stands.

The Study Area

The study area is located in the Wind River Ranger District of the Gifford Pinchot National Forest, about 8.5[2] miles northwest of Carson, Washington (long. 121°57', lat. 45°48'N). Plots were established in 1951 (Martha Flat) and 1952 (Martha Creek) when the trees in the stand were about 40 years old. The preceding stand had been clearcut and burned before 1910, but a few widely scattered old-growth Douglas-fir could still be found. Site index was judged to be 105 in 1949, based on 25 trees dissected in the area. Average age of dominants and codominants was 39 years and height 60 feet. Height measurements in 1976 indicate a higher site index; 12 trees selected on the two plots averaged 64 years and 110 feet, indicating a site index near 130 (McArdle et al. 1949). Stand characteristics are summarized in table 1.

Table 1--Basal area, number of stems, and average diameter of conifers at plot establishment (age 40) and last measurement (age 65) based on trees greater than 3-inch diameter at breast height (d.b.h.)

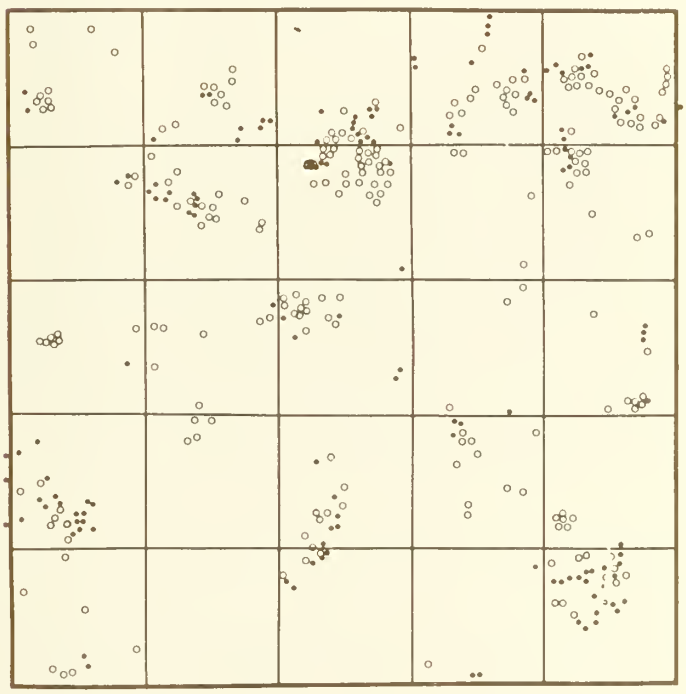
Plot	Age	Basal area per acre	Stems per acre	Average d.b.h.
	Years	Square feet	Number	Inches
Martha Flat	40	144	508	7.2
	65	207	299	11.3
Martha Creek	40	156	548	7.2
	65	199	265	11.7

Douglas-fir is the predominant tree species, but some western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western white pine (*Pinus monticola* Dougl. ex D. Don), and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) are present. Hardwoods, principally red alder (*Alnus rubra* Bong.), bitter cherry (*Prunus emarginata* Dougl. ex Eaton), and bigleaf maple (*Acer macrophyllum* Pursh), occur sporadically throughout the stand.

[2]Metric equivalents are on page 15.

Establishment of Plots

Plots were located in areas known to have laminated root rot (*P. weirii*) and were readily accessible for study. The Martha Flat plot (fig. 1) is on nearly level ground at about 1,100-foot elevation. The Martha Creek plot (fig. 2) has a gentle to moderate slope with variable but generally northern aspect and an average elevation of 1,150 feet. The Martha Flat plot is 10 by 10 chains, gridded at 2-chain intervals, thus breaking the plot into 25 blocks of 0.4 acre. The Martha Creek plot is similarly composed of 25 blocks of 0.4 acre but is irregular in shape to avoid a road and topographic features that change the character of the stand. Grid intersections are marked with 4-foot cedar stakes and location of gridlines by bark blazes and paint on the "line" side of nearby trees.



• Trees killed before 1951
○ Trees killed from 1951 to 1975
1 chain = 66 feet

Figure 1.--Mortality from Phellinus weirii *on the 10-acre plot on Martha Flat.*

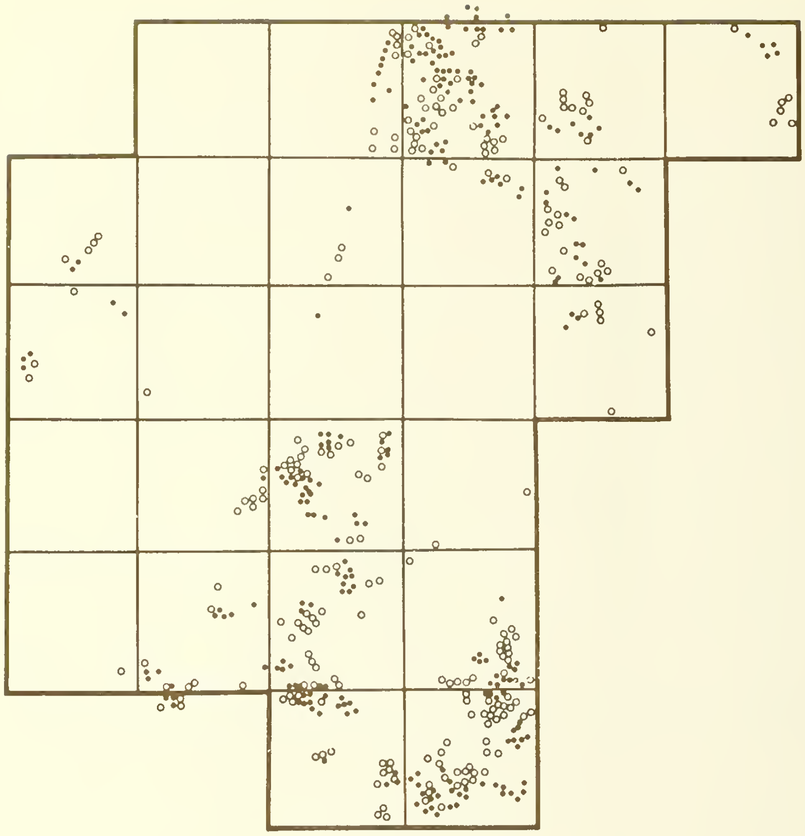


Figure 2.--Mortality from Phellinus weirii *on the 10-acre plot on Martha Creek.*

Collected Data

The following data were recorded by 0.4-acre blocks on each 10-acre plot:

1. At time of establishment and after 25 years.
   (a) Diameter at breast height (d.b.h.) by 2-inch classes and species category (Douglas-fir, other conifer, or hardwood) of each living tree greater than 3 inches.

   (b) D.b.h. and estimated year of death of mortality caused by *P. weirii* since previous plot examination.

   (c) Location of *P. weirii* mortality (figs. 1 and 2).

2. At periodic intervals.
   (a) D.b.h. of *P. weirii*-caused mortality since last examination and estimated year of death.

   (b) Location of *P. weirii*-caused mortality (figs. 1 and 2).

After blocks having more than 10 percent of basal area in hardwoods were eliminated, analysis of covariance ($P \leq 0.05$) of data by block was used to relate: (1) number and basal area of trees killed before plot establishment to number and basal area of those killed in the following 25 years, (2) increase in living basal area in 25 years to number of stems or basal area lost to *P. weirii* for the same period, (3) increase in living basal area in 25 years to number of stems or basal area killed before plot establishment and (4) percent increase in number of stems or basal area over 25 years to number of stems or basal area lost to *P. weirii* for the same period. The regressions from the two plots were compared to determine whether a common regression could represent both plots.

Openings in the crown canopy associated with activity of *P. weirii* were visually projected to the ground, measured with a steel tape, and mapped at 1:396 scale.[3] The area within mapped openings was measured with a digitizer coupled with a computer.

When surviving trees occurred in openings, their diameters at breast height were measured. Within openings, the area occupied by these survivors was assumed to be the same as that occupied by trees of the same basal area in uninfested blocks. (Area÷basal area = average ground area occupied per unit basal area.) The area occupied by survivors was subtracted from that of measured openings to arrive at a corrected "area out of conifer production."

In 1961 and 1962, samples of *P. weirii*-infested wood were collected for isolation of the fungus. These isolates were cross plated on malt agar to determine clonal relationships among infection centers (Childs 1970). As new mortality occurred, additional samples were collected to further define clonal boundaries of the infestation.

Results

For the 25 years after plot establishment, numbers of conifer stems decreased from 5,078 to 2,978 on the Martha Flat plot (table 2), whereas basal area increased from 1,437 to 2,068 square feet; on the Martha Creek plot, stems decreased from 5,475 to 2,647 (table 3), but basal area increased from 1,558 to 1,988 square feet. Average diameter increased from 7.2 to 11.3 inches at Martha Flat and from 7.2 to 11.7 inches at Martha Creek (table 1). Average number of trees and average basal area per acre on the two plots approximate what is normal for site III Douglas-fir stands (McArdle et al. 1949).

Basal area of conifers and numbers of stems varied considerably among 0.4-acre blocks on each plot. Typically, greater basal area is associated with greater numbers of stems, not larger trees. Lowest stocking of conifers when plots were established

[3]Blocks 1 through 5 on the Martha Flat plot were destroyed before openings could be measured.

Table 2--Stand inventory on the Martha Flat plot at establishment and 25 years later

Block number	Basal area at plot establishment			Basal area 25 years later			Stems at plot establishment			Stems 25 years later		
	Douglas-fir	Other conifers	Hardwoods	Douglas-fir	Other conifers	Hardwoods	Douglas-fir	Other conifers	Hardwoods	Douglas-fir	Other conifers	Hardwoods
	-Square feet-						-Number-					
1	79.46	0.37	9.29	92.38	2.70	11.93	262	3	12	132	20	12
2	71.30	.96	2.97	113.25	3.09	5.23	314	8	6	186	23	11
3	73.17	.09	3.80	107.28	1.09	7.90	274	1	4	158	7	7
4	64.34	0	0	97.87	.09	0	277	0	0	179	1	0
5	48.56	0	0	73.42	.28	0	200	0	0	150	2	0
6	51.40	0	.35	77.49	.48	1.46	136	0	1	85	3	6
7	57.58	.09	.70	73.82	.63	2.14	230	1	2	107	6	5
8	66.15	.57	1.96	79.05	1.29	3.80	301	4	3	128	4	4
9	54.83	1.27	0	79.22	3.00	.96	238	7	0	130	4	6
10	54.76	.09	0	66.39	.09	.37	290	1	0	135	1	3
11	49.66	.44	2.77	77.95	.28	6.21	131	2	5	90	2	20
12	57.18	.09	0	86.27	.48	1.72	187	1	0	129	3	5
13	57.58	.09	0	78.88	.37	.09	235	1	0	124	3	1
14	68.83	.48	2.33	96.48	1.33	6.21	274	3	5	131	4	13
15	66.37	0	.70	81.04	.63	.57	267	0	2	123	6	4
16	37.02	.83	0	62.26	.39	.72	91	3	0	83	2	4
17	45.86	.28	0	67.52	.74	.09	116	2	0	81	2	1
18	48.50	.20	.35	74.89	.55	.35	142	1	1	97	1	4
19	66.78	5.02	2.18	93.65	4.12	1.96	212	15	4	112	9	4
20	73.87	.09	.55	85.21	.20	2.27	254	1	1	117	1	6
21	34.41	1.18	0	54.92	2.84	0	83	4	0	62	2	0
22	46.86	0	.55	85.01	.17	.96	113	0	1	85	2	3
23	24.48	.17	0	45.93	.63	3.99	58	2	0	49	3	10
24	70.95	.92	6.63	108.25	3.66	7.81	183	5	13	100	9	15
25	53.12	.92	17.72	75.14	5.65	26.00	141	4	23	71	14	23
Total	1,422.96	14.15	52.85	2,033.57	34.78	92.74	5,009	69	83	2,844	134	167

Table 3--Stand inventory on the Martha Creek plot at establishment and 25 years later

Block number	Basal area at plot establishment			Basal area 25 years later			Stems at plot establishment			Stems 25 years later		
	Douglas-fir	Other conifers	Hardwoods	Douglas-fir	Other conifers	Hardwoods	Douglas-fir	Other conifers	Hardwoods	Douglas-fir	Other conifers	Hardwoods
	Square feet						Number					
1	23.58	2.62	29.06	40.00	6.37	40.94	57	9	47	27	12	59
2	30.61	2.40	12.46	53.17	3.03	24.56	70	9	16	38	9	36
3	53.08	0	1.59	65.37	.78	6.30	155	0	4	76	6	19
4	88.84	0	0	99.45	.26	.28	303	0	0	128	3	2
5	84.78	0	0	90.51	.17	.20	308	0	0	124	2	1
6	56.33	1.37	7.03	91.71	3.60	12.67	159	5	14	82	15	27
7	57.82	.17	5.45	91.67	.37	6.54	131	2	9	75	3	14
8	77.91	1.68	.87	105.65	2.92	3.86	192	7	2	107	5	10
9	71.17	0	8.77	90.82	0	13.00	212	0	9	95	0	15
10	67.70	0	0	86.39	0	.37	218	0	0	104	0	3
11	55.85	.35	0	82.02	1.59	1.44	221	4	0	117	9	4
12	57.99	.17	1.57	79.76	.39	3.86	192	2	2	92	2	3
13	78.17	1.75	.55	90.72	3.60	.63	323	9	1	128	13	2
14	70.95	1.92	.70	79.14	3.44	3.36	302	11	2	119	14	9
15	71.91	0	.70	90.10	0	1.70	280	0	2	154	0	4
16	68.18	0	1.88	86.32	.17	3.38	245	0	3	105	2	5
17	57.23	.09	0	71.84	.57	.92	179	1	0	82	4	4
18	64.60	.17	0	80.13	2.29	.26	209	2	0	110	7	3
19	59.06	3.49	0	60.75	6.23	2.03	277	17	0	113	20	5
20	56.96	0	0	71.95	.09	0	233	0	0	105	1	0
21	63.38	0	0	69.81	.09	0	277	0	0	102	1	0
22	71.12	.63	0	75.87	2.22	.20	282	6	0	125	12	1
23	53.21	0	.35	67.23	.48	5.06	185	0	1	104	3	14
24	57.99	0	0	79.40	1.04	.57	230	0	0	111	12	4
25	42.08	.28	.55	46.56	1.92	5.63	149	2	1	63	6	8
Total	1,540.50	17.09	71.55	1,946.34	41.62	137.76	5,389	86	113	2,486	161	252

was 150 trees per acre (block 13, Martha Flat) and after 25 years, 98 trees per acre (block 1, Martha Creek). Low stocking of conifers was due in part to competition from hardwoods.

Although hardwoods sometimes invade openings caused by root rot, hardwoods were usually found in areas where root rot was not evident. Stocking was as high as 830 trees per acre (block 13, Martha Creek) at time of plot establishment and 522 trees per acre after 25 years (block 2, Martha Flat).

Mortality from *P. weirii* over 25 years (tables 4 and 5) represents only 4.57 percent of stems and 6.33 percent of basal area of conifers at age 40 at Martha Flat and only 4.04 percent of stems and 6.16 percent of basal area at Martha Creek. If stand age 65 is the base, losses to *P. weirii* are 7.79 percent of stems and 4.40 percent of basal area at Martha Flat and 8.35 percent of stems and 4.83 percent of basal area at Martha Creek. Average diameter of trees killed by *P. weirii* was near the average diameter of living Douglas-fir when the mortality occurred. Mortality from suppression and other causes, although not measured directly, was considerably greater than the one tree per acre per year from *P. weirii*.

Regressions from the two plots did not differ significantly. When data on growth and mortality from root rot were combined and compared by block, using analysis of covariance, significant relationships emerged:

1. Number of trees killed by *P. weirii* over 25 years was related ($r = 0.764$) to number killed by *P. weirii* before plot establishment.

2. Basal area of trees killed by *P. weirii* over 25 years was related ($r = 0.776$) to basal area killed by *P. weirii* before plot establishment.

3. Number of trees killed by *P. weirii* over 25 years was negatively related ($r = 0.317$) to increase in basal area over the same period.

4. Basal area of trees killed by *P. weirii* over 25 years was negatively related ($r = 0.344$) to the increase in basal area for the same period.

Number of trees or basal area killed before plot establishment did not have a significant negative relationship with increase in basal area over 25 years nor did number of trees or basal area killed over 25 years have a significant negative relationship with percent increase in basal area for the same period.

Cross-plating of cultures from dead trees indicated new mortality was caused by the same clone of the pathogen as was previous mortality in the contemporary and preceding stands.

Table 4--Periodic mortality from *Phellinus weirii*, Martha Flat plot

Block number	Before 1951[1]		1951-55		1956-60		1961-65		1966-70		1971-75		1951-75 (total)	
	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area
	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet
1	2	1.61	1	0.09	2	0.89	2	0.70	4	2.11	1	0.44	10	4.23
2	6	.89	1	.20	1	.55	0	0	7	1.16	0	0	9	1.91
3	7	1.35	3	.74	0	0	3	.89	3	.74	0	0	9	2.37
4	9	1.75	3	.72	1	.09	5	1.81	5	.62	0	0	14	3.24
5	10	1.20	6	1.16	1	.35	9	2.33	6	2.37	4	4.86	26	11.07
6	2	.09	1	.20	0	0	1	.20	0	0	0	0	2	.40
7	9	1.59	2	.55	2	.89	0	0	6	4.58	4	2.94	14	8.96
8	6	1.37	6	1.11	5	1.96	2	1.09	8	2.55	11	4.62	32	11.33
9	0	0	0	0	0	0	2	.39	1	.20	1	.20	4	.79
10	3	.59	1	.20	4	.63	5	.81	1	.35	2	.44	13	2.43
11	1	.20	2	.63	0	0	2	.74	1	.09	2	1.85	7	3.31
12	2	.89	0	0	0	0	0	0	3	.48	4	1.90	7	2.38
13	5	.76	4	1.02	0	0	3	.98	2	.55	4	1.40	13	3.95
14	1	.09	0	0	0	0	1	.20	1	.09	1	.09	3	.38
15	3	.37	4	.72	0	0	0	0	0	0	4	1.72	8	2.44
16	17	5.54	0	0	1	.09	3	.37	1	1.07	2	.98	7	2.51
17	0	0	1	.35	0	0	0	0	2	.87	1	.09	4	1.31
18	5	1.35	1	.20	2	.55	4	1.88	1	.35	4	2.44	12	5.42
19	3	.63	0	0	0	0	4	1.48	3	1.61	3	.74	10	3.83
20	1	.09	2	.55	0	0	3	1.68	0	0	1	1.77	6	4.00
21	1	.20	2	2.14	0	0	1	2.18	1	.20	3	2.97	7	7.49
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	5	1.03	1	.09	0	0	1	.20	0	0	1	.55	3	.84
24	3	.48	0	0	0	0	0	0	1	.20	0	0	1	.20
25	21	3.75	2	1.33	1	.09	3	.48	4	2.99	1	1.40	11	6.29
Total	122	25.82	43	12.00	20	6.09	54	18.41	61	23.18	54	31.40	232	91.08

[1] Year plot was established.

Table 5--Periodic mortality from *Phellinus weirii*, Martha Creek plot

Block number	Before 1952[1]		1952-56		1957-61		1962-66		1967-71		1972-76		1952-76 (total)	
	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area	Stems	Basal area
	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet	Number	Square feet
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	10	4.70	2	0.17	2	1.48	1	.35	0	0	3	3.19	8	5.19
3	64	18.24	8	2.77	5	2.79	8	6.39	5	3.29	3	1.94	29	17.18
4	8	2.95	3	.59	0	0	2	.39	3	.83	2	1.27	10	3.08
5	5	1.04	0	0	1	.35	2	.28	1	.09	2	1.09	6	1.81
6	2	.28	0	0	0	0	1	.20	0	0	3	.59	4	.79
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	3	.89	0	0	0	0	3	.89
9	7	1.75	0	0	2	.55	1	.55	0	0	0	0	3	1.10
10	13	2.90	0	0	5	1.72	5	.87	2	.70	3	1.61	15	4.90
11	5	.54	0	0	1	.35	1	.09	1	.79	0	0	3	1.23
12	0	0	0	0	0	0	0	0	0	0	1	.35	1	.35
13	1	.09	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	3	.37	0	0	1	.55	2	.63	2	.39	1	.55	6	2.12
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	1	.09	2	.55	1	1.40	1	.20	2	1.61	1	.35	7	4.11
18	31	7.77	6	2.42	2	1.94	8	2.42	3	2.14	1	.35	20	9.27
19	0	0	0	0	0	0	1	.79	0	0	1	.35	2	1.14
20	0	0	0	0	0	0	0	0	1	.09	1	.35	2	.44
21	10	1.35	1	.09	2	.44	0	0	2	.39	2	1.94	7	2.86
22	21	4.32	3	1.48	7	1.44	8	3.34	1	.79	3	2.92	22	9.97
23	14	2.77	2	.28	8	3.07	2	1.27	2	.74	5	3.60	19	8.96
24	19	3.20	8	1.55	4	2.27	3	1.53	2	.55	0	0	17	5.90
25	40	9.72	7	2.59	8	2.46	10	4.10	4	1.18	8	4.38	37	14.71
Total	254	62.08	42	12.49	49	20.81	59	24.29	31	13.58	40	24.83	221	96.00

[1]Year plot was established.

Area out of production at stand age 65 totalled 11.24 percent of the Martha Creek plot (table 6) and 7.34 percent of the 20 blocks measured at Martha Flat (table 7).

Table 6--Area lost for production of conifers because of *Phellinus weirii*, Martha Creek plot

Block number	Gross area lost	Conifer survivors[1]	Hardwood survivors[1]	Net area lost	
	- - - - - - - - -	- Acres -	- - - - - - - - - -		Percent
1	0	0	0	0	--
2	.0140	0	0	0.0140	3.50
3	.0723	0	0	.0723	18.08
4	.0413	0	0	.0413	10.33
5	.0312	0	0	.0312	7.80
6	0	0	0	0	--
7	0	0	0	0	--
8	.0125	0	0	.0125	3.13
9	.0094	0	0	.0094	2.35
10	.0265	0	0	.0265	6.63
11	.0203	0	0	.0203	5.08
12	0	0	0	0	--
13	.0016	0	0	.0016	.40
14	0	0	0	0	--
15	0	0	0	0	--
16	.0218	0	0	.0218	5.45
17	.0796	0	0	.0796	19.90
18	.0764	0.0049	0	.0715	17.88
19	.0439	0	0	.0439	10.98
20	.0125	0	0	.0125	3.13
21	.1264	.0049	0	.1215	30.38
22	.1534	.0064	0	.1471	36.78
23	.0811	.0061	.0157	.0750	18.75
24	.1046	0	0	.1046	26.15
25	.2621	.0449	.0011	.2172	54.30
Total	1.1909	.0672	.0168	1.1237	11.24

[1]Based on area occupied by conifers of equal basal area on uninfested blocks.

Table 7--Area lost for production of conifers because of *Phellinus weirii*, Martha Flat plot

Block number[1]	Gross area lost	Conifer survivors[2]	Hardwood survivors[2]	Net area lost	
	- - - - - - - - - - -Acres-	- - - - - - - - - -			Percent
6	0.0265	0	0	0.0265	6.63
7	.0484	.0290	0	.0194	4.85
8	.0422	0	0	.0422	10.55
9	0	0	0	0	--
10	.0318	0	0	.0318	7.95
11	.0410	0	0	.0410	10.25
12	.0361	.0008	0	.0353	8.83
13	.0372	0	0	.0372	9.30
14	0	0	0	0	--
15	.0409	0	0	.0409	10.23
16	.0551	.0306	0	.0245	6.13
17	.0331	0	0	.0331	8.28
18	.0655	.0069	0	.0586	14.65
19	.0175	0	0	.0175	4.38
20	.0109	0	0	.0109	2.73
21	.0687	.0130	0	.0557	13.93
22	0	0	0	0	--
23	.0210	0	.0066	.0210	5.25
24	0	0	0	0	--
25	.0946	.0030	.0333	.0916	22.90
Total	.6705	.0833	.0399	.5872	7.34

[1]Blocks 1-5 were destroyed before data were taken.

[2]Based on area occupied by conifers of equal basal area on uninfested blocks.

Discussion

The Martha Flat and Martha Creek sites were selected because damage to the stand by *P. weirri* was apparent. The stand has not been subjected to thinning, fertilization, control of competing vegetation, or other management practices. Because presence of root rot was a criterion for selection, one might expect more damage at this site than would be typical of young, unmanaged Douglas-fir stands.

Losses to *P. weirii* over 25 years (about 4.6 percent of basal area at stand age 65) cannot be considered catastrophic, but at this age with average stand diameter less than 12 inches, continued damage must be expected before commercial maturity.

Although mortality from other causes (primarily suppression) was far greater than from *P. weirii*, most of these trees would not have become crop trees. Many of the trees killed by *P. weirii* would otherwise have become crop trees. Their basal area, had they not been lost, could have increased considerably by age 65. Thus, the estimates for loss of basal area are conservative.

In addition, the nature of the disease (causing persistent openings in stands) increases its relative importance among all causes of mortality. Forested areas opened by the disease (over 11 percent of Martha Creek and over 7 percent of Martha Flat plots) cannot be expected to yield timber in the present forest generation. Not only will these openings increase in size in coming years, but they will carry over into future forest generations unless specific control measures are applied (Hadfield and Johnson 1977). Further indirect losses can be expected because the stand, which is overstocked in most areas, cannot be thinned without increasing losses from windthrow of root-rotted residual trees (Hadfield and Johnson 1977).

Incidence of the disease for the 25 years after plots were established was related to its incidence before establishment; that is, in areas where substantial mortality was recorded when plots were established, mortality (measured either as number of trees or as basal area) was likely to continue to be substantial in the next 25 years. This supports the contention that spread of the disease depends primarily on distribution and amount of vegetative inoculum (Childs 1970). Clonal analysis of fungus cultures from trees killed by *P. weirii* also supports this, since all new infections appeared to result from contact with vegetative inoculum associated with root systems of current or past generations.

The diameter of trees killed by *P. weirii* was not unlike the average diameter of Douglas-fir alive at the time mortality occurred. Even though losses from root rot are a relatively small part of total mortality (numbers or basal area), the disease itself did significantly affect stand productivity, since both number and basal area of trees lost over 25 years were negatively related to increase in basal area over the same period. Although loss was not related to percent increase in basal area on the two plots combined, the relationship was significant on the Martha Flat plot alone. By one rule of thumb, damage doubles about every 15 years (Childs 1960). This appears to be the case for Martha Flat. Martha Creek, however, has a near constant rate of damage.

Perhaps the most inclusive measure of damage in unmanaged stands is area out of production. Estimates of area out of production can be converted to estimates of timber loss by comparing them with cruises of similar, uninfested stands or with yields from appropriate volume tables; but losses from reduced growth of live, infected trees is not accounted for, and unsalvaged mortality within delineated openings is ignored. In some cases, scattered mortality from root rot not associated with definite stand openings can be added to the volume not realized from areas out of production to further refine estimates of damage.

At the time these two plots were established, *P. weirii* was a relatively unknown consideration in forest management. Twenty-five years of data have indicated that the disease can be destructive in unmanaged stands but that under the conditions of infection encountered in this stand at age 40, severe damage is not likely to occur in one rotation. Unless control measures are implemented after this stand is harvested or unless future stands on the site are established and managed to reduce *P. weirii* losses greater damage is likely to occur in future rotations of Douglas-fir.

This is a case study of two plots in one root-rot-infested stand. The disease might affect other stands on other sites similarly, or perhaps differently enough to change these conclusions.

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Metric Equivalents

1 acre = 0.404 7 hectare
1 foot = 0.304 8 meter
1 chain = 20.116 8 meters
1 mile = 1.609 34 kilometers

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A Guide for Comparing Height Growth of Advance Reproduction and Planted Seedlings

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Abstract

This guide can be used in evaluating the height growth potential of planted seedlings and advance reproduction. An equation and tables are presented, with an example of their use.

Keywords: Increment (height), advance growth, seedling growth.

Many conifer forests are two layered, consisting of a mature or overmature overstory and a well-stocked understory of saplings and/or poles. In such stands, one silvicultural alternative is to clearcut the entire stand and plant seedlings. If the understory consists of vigorous advance reproduction, another alternative is to carefully remove the overstory, leaving sufficient saplings or poles to form the new stand.

One factor that must be considered when evaluating clearcutting and planting versus saving the advance reproduction is the height that will be attained by each type of regeneration at some time in the future. A height advantage for planted trees would be an indication that the clearcutting and planting alternative might be desirable, whereas greater height of the advance reproduction would suggest this alternative.

To make such an evaluation, managers must know the average height of the planted seedlings and the advance reproduction and the average height growth rates of both classes of regeneration. From this information, the annual growth rate required of planted seedlings to equal the height of the advance reproduction at the end of a given period can be estimated as follows:

$$A = \frac{B - E}{D} + C;$$

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where,

A = annual height growth of planted seedlings needed to equal height of advance reproduction at the end of a given period,

B = average height of advance reproduction after the overstory is removed,

C = average annual height growth of advance reproduction after release,

D = number of years in growth period, and

E = average height of planted seedlings.

With this equation, the required height growth of planted seedlings can be estimated for any combination of the variables B, C, D, and E. Tables 1 through 6 give solutions for selected values of the variables within the range commonly found in the field. The tables show annual height growth for planted seedlings needed to equal height of advance reproduction 5, 10, and 15 years after overstory removal. The reader can interpolate within the tables for values not given or use the equation to estimate required seedling height growth for other combinations of variables.

An example of use of the tables follows: Assume the average height of the advance reproduction to be 9 feet,[2] with the potential of growing 0.5 foot per year after release. Planted seedlings averaging 0.5 foot tall would then have to grow in height at the rate of 2.2 feet per year to equal the height of the advance reproduction after 5 years (table 1).

The average height of advance reproduction and planted seedlings can easily be obtained from measurements before logging and from nearby plantations. An estimate of height growth of the advance reproduction after release may be more difficult to obtain. Since growth response varies--depending on site, species, and spacing--local observations and measurements in stands where the understory has been released should be used if possible. If no local information is available, published results can be used to estimate growth response, but such data are strictly applicable only to conditions under which the study was conducted. Some estimates of growth response of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) and true fir (*Abies* spp.) advance reproduction after release are available (Barrett 1973, 1979; Seidel 1977, 1980; Ferguson and Adams 1979).

Decisions on the appropriate silvicultural prescription for a given stand are based on many factors, and the height growth relationships of planted seedlings and advance reproduction must be balanced against the other constraints. For example, it may be desirable to save the advance reproduction in areas where seedling establishment is difficult because of animal damage

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2/ 1 foot = 0.03048 meter.

Table 1--Average annual height growth of planted seedlings averaging 0.5 foot tall needed to equal height of advance reproduction after 5 years

Height growth of advance reproduction	Height of advance reproduction after overstory removal (feet)						
	3	5	7	9	11	13	15
Feet per year	Feet per year						
0.25	0.75	1.15	1.55	1.95	2.35	2.75	3.15
.5	1.00	1.40	1.80	2.20	2.60	3.00	3.40
1.0	1.50	1.90	2.30	2.70	3.10	3.50	3.90
1.5	2.00	2.40	2.80	3.20	3.60	4.00	4.40
2.0	2.50	2.90	3.30	3.70	4.10	4.50	4.90
2.5	3.00	3.40	3.80	4.20	4.60	5.00	5.40
3.0	3.50	3.90	4.30	4.70	5.10	5.50	5.90

Table 2--Average annual height growth of planted seedlings averaging 0.5 foot tall needed to equal height of advance reproduction after 10 years

Height growth of advance reproduction	Height of advance reproduction after overstory removal (feet)						
	3	5	7	9	11	13	15
Feet per year	Feet per year						
0.25	0.50	0.70	0.9	1.10	1.30	1.50	1.70
.5	.75	.95	1.15	1.35	1.55	1.75	1.95
1.0	1.25	1.45	1.65	1.85	2.05	2.25	2.45
1.5	1.75	1.95	2.15	2.35	2.55	2.75	2.95
2.0	2.25	2.45	2.65	2.85	3.05	3.25	3.45
2.5	2.75	2.95	3.15	3.35	3.55	3.75	3.95
3.0	3.25	3.45	3.65	3.85	4.05	4.25	4.45

Table 3--Average annual height growth of planted seedlings averaging 0.5 foot tall needed to equal height of advance reproduction after 15 years

Height growth of advance reproduction	Height of advance reproduction after overstory removal (feet)						
	3	5	7	9	11	13	15
Feet per year	Feet per year						
0.25	0.42	0.55	0.68	0.81	0.94	1.07	1.20
.5	.67	.80	.93	1.06	1.19	1.32	1.45
1.0	1.17	1.30	1.43	1.56	1.69	1.82	1.95
1.5	1.67	1.80	1.93	2.06	2.19	2.32	2.45
2.0	2.17	2.30	2.43	2.56	2.69	2.82	2.95
2.5	2.67	2.80	2.93	3.06	3.19	3.32	3.45
3.0	3.17	3.30	3.43	3.56	3.69	3.82	3.95

Table 4--Average annual height growth of planted seedlings averaging 1.0 foot tall needed to equal height of advance reproduction after 5 years

Height growth of advance reproduction	Height of advance reproduction after overstory removal (feet)						
	3	5	7	9	11	13	15
Feet per year	Feet per year						
0.25	0.65	1.05	1.45	1.85	2.25	2.65	3.05
.5	.90	1.30	1.70	2.10	2.50	2.90	3.30
1.0	1.40	1.80	2.20	2.60	3.00	3.40	3.80
1.5	1.90	2.30	2.70	3.10	3.50	3.90	4.30
2.0	2.40	2.80	3.20	3.60	4.00	4.40	4.80
2.5	2.90	3.30	3.70	4.10	4.50	4.90	5.30
3.0	3.40	3.80	4.20	4.60	5.00	5.40	5.80

y

r

g
d

i

Table 5--Average annual height growth of planted seedlings averaging 1.0 foot tall needed to equal height of advance reproduction after 10 years

Height growth of advance reproduction	Height of advance reproduction after overstory removal (feet)						
	3	5	7	9	11	13	15
Feet per year	Feet per year						
0.25	0.45	0.65	0.85	1.05	1.25	1.45	1.65
.5	.70	.90	1.10	1.30	1.50	1.70	1.90
1.0	1.20	1.40	1.60	1.80	2.00	2.20	2.40
1.5	1.70	1.90	2.10	2.30	2.50	2.70	2.90
2.0	2.20	2.40	2.60	2.80	3.00	3.20	3.40
2.5	2.70	2.90	3.10	3.30	3.50	3.70	3.90
3.0	3.20	3.40	3.60	3.80	4.00	4.20	4.40

Table 6--Average annual height growth of planted seedlings averaging 1.0 foot tall needed to equal height of advance reproduction after 15 years

Height growth of advance reproduction	Height of advance reproduction after overstory removal (feet)						
	3	5	7	9	11	13	15
Feet per year	Feet per year						
0.25	0.38	0.52	0.65	0.78	0.92	1.05	1.18
.5	.63	.77	.90	1.03	1.17	1.30	1.43
1.0	1.13	1.27	1.40	1.53	1.67	1.80	1.93
1.5	1.63	1.77	1.90	2.03	2.17	2.30	2.43
2.0	2.13	2.27	2.40	2.53	2.67	2.80	2.93
2.5	2.63	2.77	2.90	3.03	3.17	3.30	3.43
3.0	3.13	3.27	3.40	3.53	3.67	3.80	3.93

problems even though a height growth comparison favors the planted seedlings. On the other hand, planting may be favored because of potential disease problems such as dwarf mistletoe or heart rots in the advance reproduction, although the advance reproduction may have a height advantage. Regardless of the other factors involved in selecting silvicultural prescriptions, the height growth relationships among planted seedlings and advance reproduction are important and should always be considered when such decisions are made.

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