LASKA OREGON WASHINGTON
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

·USDA FOREST SERVICE RESEARCH NOTE

PNW-181 June 1972

MAPLE SIRUP PRODUCTION FROM BIGLEAF MAPLE

by Robert H. Ruth, J. Clyde Underwood, Clark E. Smith, and Hoya Y. Yang[1]

ABSTRACT

Bigleaf maple sap flow during the 1970-71 season ranged from none to 16.9 gallons per taphole and sugar content of the sap from 1.0 to 2.6 percent. Sugar content also varied seasonally, with the sweetest sap flowing in late January. The sirup was very flavorful, although not as strong in typical maple flavor as that made from eastern sugar maple. Sirup production appears quite feasible as a hobby. The possibility of commercial production should not be ruled out as additional local experience is gained.

Keywords: Maple sugar, bigleaf maple, *Acer macrophyllum*, sap.

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INTRODUCTION

Maple sirup has been made from the sap of bigleaf maple (*Acer macrophyllum*) on numerous occasions (*1, 2, 9*), but we find no record of commercial sirup production. This contrasts with the large maple sirup industry developed around the sugar maple (*Acer saccharum*) of the northeastern United States. Recent work with sugar maple is resulting in increased sap flows, greater efficiency in handling and processing, and better control of flavor. The exploratory study reported here was undertaken to evaluate sap flow characteristics of bigleaf maple and the quality of bigleaf maple sirup. In addition, we hoped to gain an initial insight into the economic feasibility of maple sirup production in the Pacific Northwest.

Bigleaf maple is the largest and most valuable western maple. Its range extends from the mountains of southern California, northward through the western parts of Oregon, Washington, and British Columbia almost to the southern tip of Alaska. It grows on a variety of soils, but best growth is on deep alluvial soils near streams. Occasionally pure stands are found, but bigleaf maple generally occurs singly or in small groups. Mature trees average about 50 feet tall and 18 inches in diameter. Growth is rapid for the first 40 to 60 years, with maturity reached at 150 years or more. Bigleaf maple is a tolerant species, especially when young, and frequently is surrounded by taller conifers (*4*).

Past experience with bigleaf maple in the Pacific Northwest has shown an annual sap flow of 3 to 6 gallons per tree, with about 35 gallons of sap required to make 1 gallon of sirup. Using the "Rule of 86" formula

$$\frac{86}{\text{Sap sugar content, \%}} = \begin{array}{l}\text{Gallons of sap to}\\ \text{make 1 gallon sirup}\end{array}$$

the sugar content of the sap must have been about 2.5 percent. This approximates the general average for sugar maple (*10*).

Experience with eastern sugar maple has shown that sap flow is correlated with cool nights when temperatures drop to 34° F. or lower, followed by warming conditions up to 40° to 50° F. the next day. The eastern sugar bush has a continental climate with prolonged periods of freezing weather, and sap flow is delayed until warming trends occur in the spring. Our study area has a mild climate with frequent warm days. Sugar weather depends on occurrence of cold nights, which may occur almost anytime during the winter. Steele[2] found that trees producing well at the beginning of the sap-flow season continued for that season and tended to be good producers in subsequent seasons. Similar results have been reported for sugar maple (*6, 10*).

[2] Robert W. Steele. Final summary report of the maple sap study at Wind River. USDA Forest Serv. In service Rep., 6 p. (unpublished). 1948.

In contrast to an eastern sugar bush, our study area has little soil freezing. Annual precipitation is about 40 inches, mostly falling as winter rain. Soil moisture appears readily available for uptake by tree roots during the entire sap-flow season. Based on 12-year records near the study area, most bigleaf maple leaves have fallen by October 28, and buds begin to burst about March 23. The sap-flow season for bigleaf maple is tapering off about the time it begins in an eastern sugar bush.

METHODS

Tapping and Sap Collection

On November 17, 1970, about 2 weeks after leaf fall, we tapped 13 bigleaf maple trees ranging in size from 12 to 30 inches diameter breast high growing under a variety of conditions.[3] Five were in a mixed stand of maple, Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and red alder (*Alnus rubra*) (fig. 1). The others were in a cutting area where all the conifers had been removed. These essentially were free of competition in the overstory, but there was a vigorous brush understory. We selected the healthier, full-crowned trees, although some had sustained top damage in past years. Samples of six trees showed an age range from 78 to 183 years.

[3] The authors gratefully acknowledge permission to tap maple trees on property owned by Starker Forests, Philomath, Oregon, and School of Forestry, Oregon State University, Corvallis, Oregon.

Figure 1.—Bigleaf maple tree surrounded by taller conifers.

Initially, 11 trees were tapped with one taphole and two of the larger trees with two, for a total of 15. Taphole diameter was one-half inch and depth, 2-1/2 to 3 inches. Metal sap spouts were sterilized in an autoclave, and a germicidal pellet containing 250 milligrams paraformaldehyde was inserted in each taphole to retard microbial action. Rubber rain guards were placed around the spouts to prevent rainwater coming down the stem from running into the plastic sap collection bags (fig. 2). A supplemental test comparing flow from old and new tapholes was carried out on three trees January 25 to February 8. Consequently, on February 8, old tapholes were abandoned in the remaining trees and new tapholes tapped about 6 inches away.

Two trees were completely abandoned on January 18 as nonproducers. Six new trees were added at this time. Five were bored with one taphole and one tree with two tapholes. Sap collections were continued at about weekly intervals until bud bursting began in the spring.

U. S. Weather Bureau observations at Corvallis, Oregon, about 5 miles distant and at about the same elevation, were used to characterize conditions at the study area.

A portable refractometer was used in the field beginning December 16 to approximate the sugar content of the sap in degrees Brix[4/] from each taphole at each collection. The average Brix reading from each taphole was used to compare sweetness of the sap among the trees.

Laboratory Brix readings were taken on the pooled sap from each collection date and used to evaluate seasonal changes in sugar content of the sap.

Sap Processing to Sirup

The sap was concentrated to sirup in 2- to 20-gallon, steam-jacketed stainless steel kettles. The steam pressure was 55 pounds per square inch. Large batches of sap were concentrated in larger kettles first and then transferred to smaller kettles for final concentration. Most sap was processed immediately after collection from the field, but some was stored in a cold room at 33° F. for up to 24 hours.

The sap was brought to boiling quickly; then the heat was reduced to maintain a gentle, steady boiling. Scorching of sirup was at a minimum. The foam formed during the early part of the boiling was skimmed continuously. The finishing point of the sirup was determined with a laboratory refractometer. Although attempts were made to finish the sirup at 65° Brix, it was difficult to be precise because small quantities of sirup permitted rapid changes in Brix readings.

In contrast with the steam kettle method available here, commercial procedure with sugar maple sirup involves rapid boiling in large, shallow evaporators. This method brings out a better flavor than that attainable with small-scale laboratory procedures.

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[4] Same density as a solution containing a percentage of sugar numerically equal to the Brix value. The density of sap is due to a mixture of sugar and small amounts of other dissolved solids, and the refractometer does not distinguish between the density due to sugar and that due to other solids.

Figure 2.—Bigleaf maple trees tapped for sap collection. A, Metal sap spout. The rubber rain guard prevents rainwater from running into the sap bags. B, Method used to collect sap from sap bags.

Laboratory Analyses

Samples of sirup from each collection were sent to the Eastern Marketing and Nutrition Research Division of the Agricultural Research Service at Philadelphia for evaluation by their Maple Investigations Group. The sirups were filtered through a medium-porosity, fritted-glass filter to remove the "sugar sand." Samples too small for filtration were let stand in test tubes until they clarified by sedimentation. As the size of many of the samples, especially those from the December runs, was too small for a complete analysis, various constituents and physical constants were run on selected samples in such a manner that a general evaluation of the season's sirup could be made. Acidity values were determined with an in-line pH meter. Conductivity constants were measured with a Wheatstone bridge according to the official method of the Association of Official Analytical Chemists (AOAC) (*3*). Brix readings were made with a hand refractometer. Ash content was determined by the official method of the AOAC. The invert sugar value was by the Berlin method according to the AOAC. Flavor ratings were made by the members of the Maple Investigations Group.

RESULTS

Sap Flow

Sap started flowing right after tapping on November 17, increased between December 4 and 7, continued to flow intermittently at a somewhat lower level through January 21, then tapered off rapidly in late January in spite of apparently favorable sugar weather (fig. 3). This reduced sap

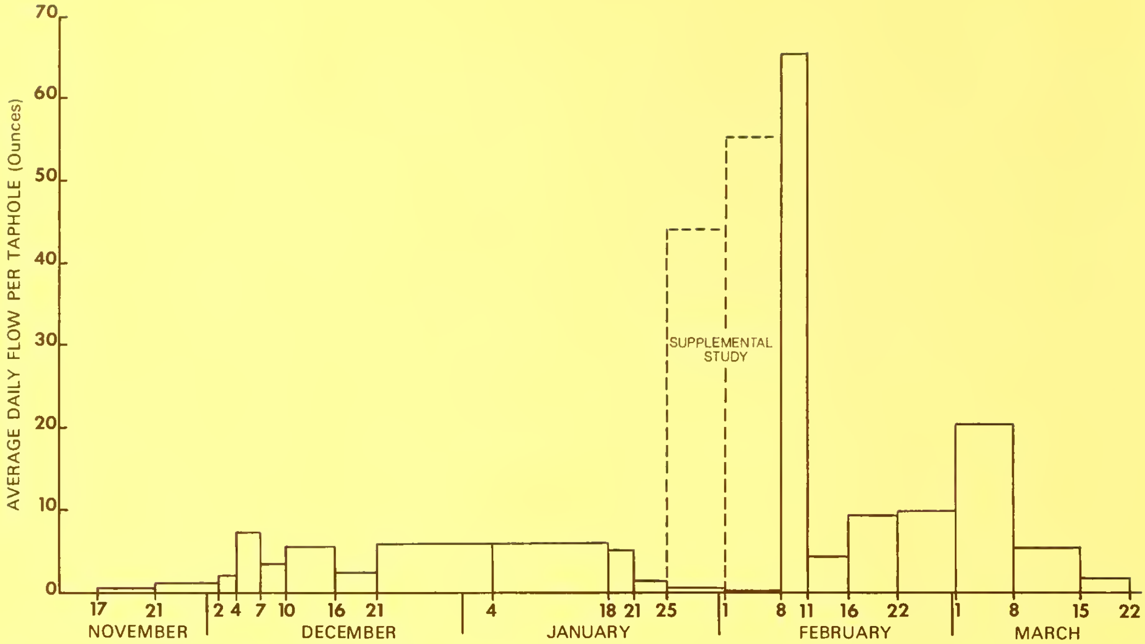

Figure 3.—Average daily bigleaf maple sap flow per taphole. Basis 15 tapholes tapped November 17, 1970; new taps February 8, 1971.

flow led us to suspect microbial activity or some other problem in the tapholes and prompted the supplemental test comparing flow from old and new tapholes in the same tree. Sap flow from the new tapholes in this supplemental test was excellent. New tapholes tapped February 8 began to flow immediately and the sap volumes measured for the February 8-11 period were the highest of the season. This was followed by several heavy flows through March 8.

The new trees tapped January 18 produced high sap flows January 18-21 and February 1-11 (fig. 4). Flows from all trees tapered off in mid-March and only a trace of sap flowed after March 22. Bud bursting was about March 29.

Total 1970-71 season sap flow per taphole for trees originally tapped November 17, 1970, ranged from zero to almost 17 gallons (table 1). Similar wide variation occurred among the seven tapholes in trees added to the study January 18. Sap flow from these trees ranged from 1.2 to 7.9 gallons per taphole. During the study, we collected 132 gallons of sap and made about 1.8 gallons of sirup.

During the sap-flow season, there were over 40 nightly minimums below 32° F. followed by daily maximums above freezing (fig. 5). Minimum soil temperature measured at 4-inch depth in the mineral soil was never below 33° F.

Sugar Content

Sweetness of bigleaf maple sap varied among individual tapholes from 1.0 to 2.6 degrees Brix (table 2). Average sap sweetness varied during the season with a peak of 1.4 degrees Brix reached about January 25 (fig. 6).

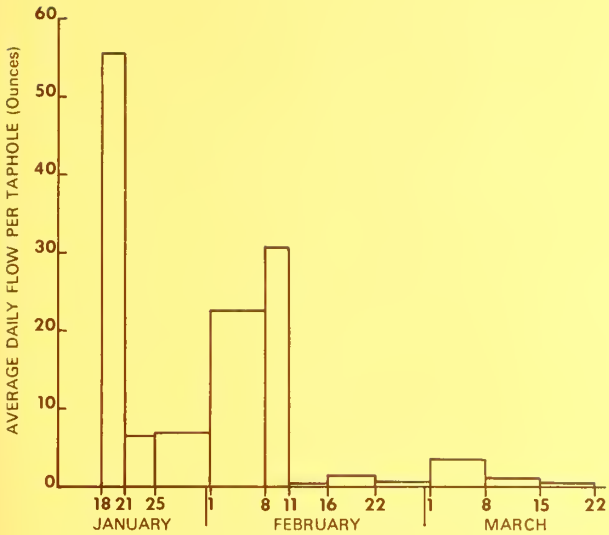

Figure 4.—Average daily bigleaf maple sap flow per taphole. Basis 7 tapholes tapped January 18, 1971.

Table 1.--*Total bigleaf maple sap flow per taphole, 1970-71 season, trees originally tapped November 17, 1970*

Taphole number[1/]	Original taps	New taps	Total
	- - - - - - - -	*Gallons* - - - - - - -	
1	[2/]6.28	[3/]9.93	16.21
2	[2/]4.08	[3/]12.82	16.90
3	1.30	[3/]8.29	9.59
4	1.78	1.04	2.82
5	[4/]6.09	.54	6.63
6	.74	[4/]7.53	8.27
7	1.65	2.93	4.58
8	1.36	6.30	7.66
[9	[4/]3.81	5.26	9.07
10]	2.32	3.43	5.75
[11	--	.31	.31
12]	.25	.66	.91
[5/]13	--	--	--
[5/]14	--	--	--
15	2.47	12.05	14.52
Total	32.13	71.09	103.22

1/ Brackets indicate tapholes in same tree.
2/ Sap bag vandalized and 1 collection lost.
3/ Sap volume from supplemental study included.
4/ Sap bag overflowed on 1 occasion.
5/ Abandoned January 18.

Sirup Quality

Results of laboratory tests on bigleaf sirup are shown in table 3. Analysis was same as that for commercial maple sirup. Typical values for a good commercial sugar maple sirup also are shown. These include a low invert sugar content and an average color toward the lighter end of the scale--reflecting recent quality improvements. The bigleaf maple sirup was concentrated in steam kettles, and this procedure is not equivalent to the commercial open-pan evaporator, where the intense heat brings out more flavor. The flavor comparison, therefore, is approximate.

Although the bigleaf maple sirup was very tasteful, all the samples were low in typical sugar maple flavor. This low level of the usual predominant flavor allowed other flavors to be identified. One was a detectable but not too objectionable varnishlike taste in some of the late-season samples. To determine the effect of additional heat, selected samples were autoclaved for 30 minutes at 15 pounds per square inch, but this did not improve the flavor. Rather, the "varnish taint" was increased in those late season samples that had it. The color of the Oregon sirup was dark for a product concentrated in steam kettles, and this does not correlate with the low value for invert sugar. Research has shown that color is proportional to the invert sugar in the sirup; the higher the invert, the darker the sirup (*5*).

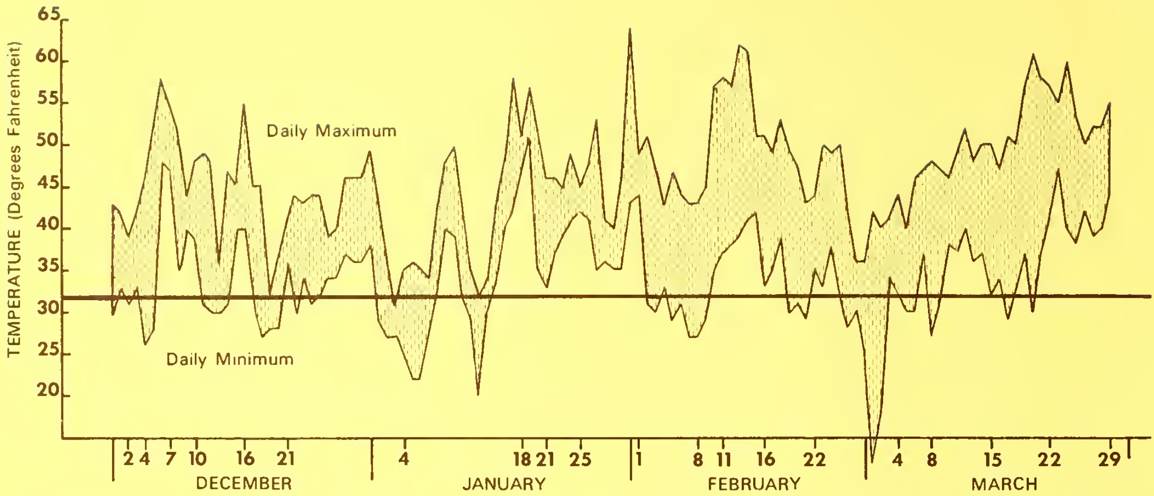

Figure 5.—Daily temperature variation during the sap flow season, Corvallis, Oregon, 1970-71.

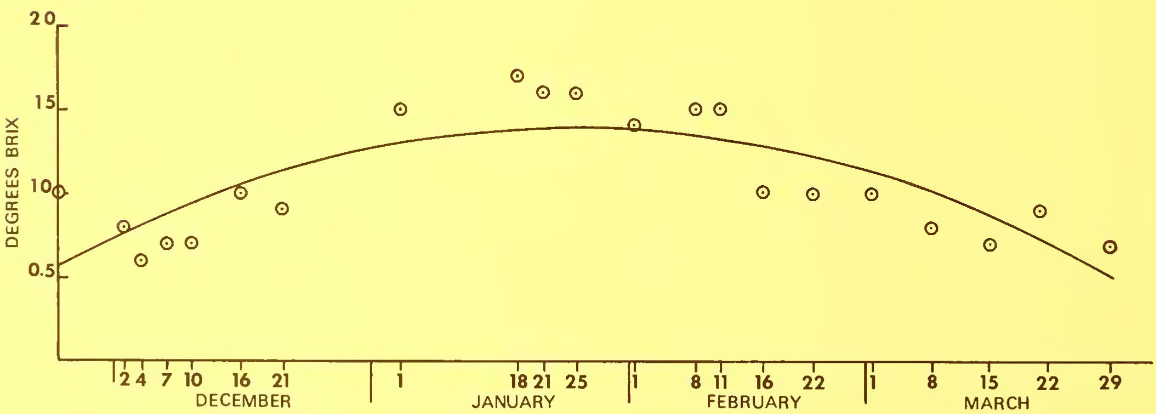

Figure 6.—Seasonal variation in sweetness of sap collected from bigleaf maple trees, 1970-71 season.

Table 2.--*Sweetness of bigleaf maple sap from individual tapholes*

Taphole number[1]	Sap sweetness
	°*Brix*[2]
1	1.3
2	1.1
3	1.0
4	1.2
5	1.0
6	1.2
7	1.2
8	1.3
[9	1.5
10]	1.3
[11	1.2
12]	1.3
15	1.0
16	1.2
17	1.0
18	1.0
[19	1.2
20]	1.3
21	1.5
22	2.6

1/ Brackets indicate 2 tapholes in 1 tree.

2/ Approximately equal to percent sugar content.

The pH of eastern maple sirup is normally just above 7. The Oregon sirups were significantly more acidic, ranging from 4.9 in December to 6.9 for later season sirup. This may explain the lack of a typical maple flavor. Sap from sugar maple is slightly acid (pH 6.5 to 6.9), but as soon as it begins boiling it becomes alkaline, often reaching a pH of 9 (*5*). This alkaline condition is necessary for development of good maple flavor.

The ash content and conductivity values of the bigleaf maple sirup were both much higher than for normal sugar maple sirup. As the conductivity of the sirups is due to their salt content, these two values should and did parallel one another. The high values for the western sirup may reflect the relatively low sugar content of the bigleaf maple sap. It has been noted with all types of maple trees that sap with low sugar content produces high ash sirup due to the greater concentration needed to produce standard density sirup.

Table 3.--*Quality comparison between bigleaf maple sirup and a fancy number 1 sugar maple sirup*

Determination[1]	Bigleaf maple			Sugar maple range
	Number of samples	Average	Range	
Ash percent	6	3.3	2.0-5.5	0.5-1.1
pH	10	6.3	4.9-6.9	6.9-7.2
Conductivity	9	630	476-885	105-158
Invert sugar percent	2	0.32	0.31-0.32	0.25-2.30
Color grade[2]	18	B	A-C	AA-A
Eastern sugar maple flavor	18	Poor	Fair-poor	Excellent-good

1/ On sirup with 66 percent solids.

2/ USDA standards.

DISCUSSION AND CONCLUSIONS

Sap production of bigleaf maple may vary widely from year to year, as it does with eastern sugar maple, and the 1970-71 season studied here may prove to be above or below average. Assuming 1970-71 to be an average season, we conclude that sirup production from bigleaf maple appears fully feasible as a hobby.

Several approaches have the potential for greatly increasing production. The slowdown in late January could have been avoided by boring new tapholes sooner. A still more efficient approach might be to delay boring any tapholes until early December, thus avoiding the early season period of low sap flows. The same would apply to late flows in the spring. Collections could have been terminated in early March. This decision should be based on local freezing-thawing cycles, which will vary considerably within the range of bigleaf maple.

Production can be increased by finding new trees to replace low producers. Three of our original tapholes produced over 14 gallons of sap, even though the original tapholes were used too long, some sap bags overflowed, and some bags were vandalized. One hundred tapholes like these three should provide about 1,500 gallons of sap. Assuming an average Brix value of 1.5, this would make about 26 gallons of sirup. Two of these three high producers were intermixed with conifers, indicating that such trees indeed should be considered in searching for the best trees. However, experience with sugar maple is that open-growth trees produce more and sweeter sap than trees growing under crowded conditions.

Additional production should come from selection of trees with high sugar content. There was considerable variation among the study trees, with sap from one taphole containing 2.6 percent sugar, more than twice the average of the other trees. The tree with this taphole was growing in the logged-over area. Many sugar producers in the East believe it does not pay to process sap which tests less than 1.5 percent. Availability of inexpensive fuel in the West may reduce this somewhat, but possibilities of commercial production will be greatly enhanced if sweeter trees can be found. The low sugar content of early and late season sap flows is further argument for limiting sap collections to the main part of the sap-flow season.

Besides placing of germicidal pellets in the tapholes, two additional techniques developed with sugar maple offer possibilities for increased efficiency and further increases in sap production. One is the use of flexible plastic tubing for collecting sap. The tubing is connected directly to sap spouts so the sap will run by gravity directly into large collection tanks. This system eliminates the need for a large labor force to collect sap and permits one- to two-man operations to handle 1,000 or more taps. The second is the use of vacuum pumping on an unvented tubing system to increase sap yields. Fourfold increases in sap flow have been reported in some studies (*7*). To our knowledge, neither technique has been tried with bigleaf maple.

If the above approaches do indeed lead to production increases, commercial production may be possible. The scattered distribution of bigleaf maple trees will always be an obstacle to efficient production. The best opportunities will be in occasional pure stands or where numerous trees are accessible along all-weather roads. The composition of bigleaf maple in a stand can be improved by thinning the other species, and, of course, pure stands can be developed by planting.

Standard practice in the East is that sap must not remain in the buckets or sap bags more than a few hours before it is collected; otherwise it will ferment and spoil (*10*). We were not able to visit the study area frequently enough to follow this practice, and some sap remained in bags a week or more. No sign of fermentation was noted. Perhaps microorganisms in the sap were killed by solar radiation transmitted through the sap bags (*8*). On the other hand, this delay may have adversely affected the flavor of the sirup.

In any event, the quality of the sirup made from the bigleaf maple trees in this study was lower than sirup from the sugar maple, being generally comparable to sirup made from eastern soft maples, such as red and silver maple. The sap from the soft maples, like the bigleaf maple sap, often is low in sugar content. Some of the bigleaf samples did have a trace of an unfamiliar "varnish" taste, but this was not too objectionable. It occurred only in late-season sap collections which may not warrant collection anyway because of low sap flow. With experience in collecting and processing bigleaf maple sap, procedures surely will be found to make a good, marketable sirup, even if its flavor may be different from that of sugar maple.

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ALASKA OREGON WASHINGTON
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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SOIL SURFACE CONDITIONS FOLLOWING BALLOON LOGGING

by

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ABSTRACT

Balloon logging caused substantially less soil disturbance than previous studies had shown for tractor, high-lead, and skyline logging methods. Deeply disturbed and compacted soil areas occupied 4.3 percent of the total area, and 15.8 percent of the area was classed as slightly disturbed.

Keywords: Logging forest cutting systems, soil conservation.

In recent years, added emphasis has been placed on development of improved logging systems which minimize soil disturbance, especially by road construction.[1] One of the newer systems uses a helium filled balloon. In addition to reduction of road mileage, the main advantage is that the lift provided by the balloon keeps logs clear of the ground the entire yarding distance, thus minimizing soil disturbance. This paper reports the results of some preliminary measurements taken to test this assumption. Similar studies,

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[1] Virgil W. Binkley. Economics and design of a radio-controlled skyline yarding system. Portland, Oreg., Pac. Northwest Forest & Range Exp. Stn. USDA Forest Serv. Res. Pap. PNW-25, 30 p., illus., 1965.

using the same measurement techniques, have already been reported for areas logged by the three yarding methods most commonly used in the Pacific Northwest--tractor,[2] high-lead,[2] and skyline.[3] This report provides a good opportunity to compare the effects of balloon logging on surface soil with the effects of three other logging methods.

THE STUDY

This study was conducted at the Deception Creek balloon logging test site in the Lowell Ranger District, Willamette National Forest. This was a cooperative venture to test the feasibility of balloon logging undertaken from 1966 to 1970 by the Pacific Northwest Forest and Range Experiment Station, the Willamette National Forest, and Bohemia Lumber Company. During this time, a total of five clearcuts, ranging from about 44 to 99 acres in size, were logged by balloon. Initially a V-shaped balloon was used, but in 1968 this was replaced by a more stable, natural-shaped balloon (fig. 1).[4] By use of this method, direct lift to the logs is provided by the balloon which is tethered about 500 feet above the butt rigging.

Figure 1.--Balloon logging area at Deception Creek, Lowell District, Willamette National Forest. The sampled clearcut units (units 2 and 5) are to the left of the balloon.

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[2] C. T. Dyrness. Soil surface condition following tractor and high-lead logging in the Oregon Cascades. J. For. 63: 272-275, illus., 1965.

[3] C. T. Dyrness. Soil surface conditions following skyline logging. Portland, Oreg., Pac. Northwest Forest & Range Exp. Stn. USDA Forest Serv. Res. Note PNW-55, 8 p., 1967.

[4] Virgil W. Binkley and Ward W. Carson. An operational test of a natural-shaped logging balloon. Portland, Oreg., Pac. Northwest Forest & Range Exp. Stn. USDA Forest Serv. Res. Note PNW-87, 8 p., illus., 1968.

Soil surface observations were made on two of the five balloon-logged units--units 2 and 5. The units are contiguous, with 45 acres in unit 2 and 38 acres in unit 5. Both units occupy a steep (about 60- to 70-percent) south-facing slope and extend from a ridgetop to just north of Deception Creek (fig. 1). The most common soil in the area is a Regosol derived from breccia parent material. The soil possesses a granular silt loam surface horizon and an average stone volume of approximately 35 percent. Before logging, the area supported a stand of old-growth Douglas-fir mixed with western hemlock and western redcedar. Average tree d.b.h. (diameter at breast height) was about 36 inches.

Trees in unit 2 were felled in 1966, and logs were yarded during 1966 to 1969. Falling was carried out in unit 5 during the summer of 1969, and yarding occurred during the fall of 1969 and spring of 1970. Our observations of surface soil condition were made in late March 1970. In both units, logs were yarded downhill to a landing on the opposite (south) side of Deception Creek. All of unit 5 and most of unit 2 were yarded with the natural-shaped balloon. That small portion of unit 2 yarded with the V-shaped balloon was included in the sample, as no obvious differences could be discerned.

Four soil surface disturbance classes were used to determine the extent of disturbance after logging:

1. Undisturbed--litter still in place and no evidence of compaction.
2. Slightly disturbed--three conditions fit this class:
   a. Litter removed and mineral soil exposed.
   b. Mineral soil and litter intimately mixed, with about 50 percent of each.
   c. Pure mineral soil deposited on top of litter and slash.
3. Deeply disturbed--surface soil removed and the subsoil exposed.
4. Compacted--obvious compaction due to dragging of a log. The soil surface directly under large cull logs was assumed to be in this condition.

The percentage of the total logged area in each of the four disturbance classes was determined from observations made at 10-foot intervals along six randomly located transects. These transects crossed both units 2 and 5 and were run on the contour.

Slash density observations were made within 1 square foot centered at each observation point. The four slash density classes are as follows:

1. Heavy--entire square foot covered with slash at least 1 foot deep.
2. Light--10 percent or more of the square foot covered with slash less than 1 foot deep.

3. Absent--total slash cover is less than 10 percent of the square foot.
4. Cull log--log 12 inches or more in diameter present on the square foot.

RESULTS AND DISCUSSION

Soil surface disturbance and slash density were observed at 1,125 points within the two balloon-logged units. Estimates of proportion of the total area in the disturbance and slash density classes are shown below:

Class	Percent of total clearcut area
Soil surface disturbance:	
Undisturbed	78.1
Slightly disturbed	15.8
Deeply disturbed	2.6
Compacted	1.7
Nonsoil areas[5]	1.8
Total	100.0
Slash density:	
Heavy	20.2
Light	52.6
Absent	21.3
Cull log	5.9
Total	100.0

Results of disturbance estimates for balloon logging are compared graphically in figure 2 with results for three more common logging methods. Although the tractor, high-lead, and skyline logging studies were conducted in the H. J. Andrews Experimental Forest about 30 miles to the northeast, timber, soil, and topographic conditions are sufficiently similar to allow comparison.[6]

The proportion of the area in the deeply disturbed and compacted classes was very low (see tabulation), much lower than with other logging methods (fig. 2), totaling only 4.3 percent of the total clearcut unit. Only 15.8 percent of the area had been slightly disturbed, also considerably lower than for any of the other logging methods (fig. 2).

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[5] Stumps, rock outcrops, and streambeds.

[6] All units supported old-growth Douglas-fir, principal soils were somewhat stony Regosols derived from breccia, and all units (with the exception of the tractor area) had average slopes of 55 to 65 percent.

Figure 2.--Soil surface condition following tractor, high-lead, skyline, and balloon logging in the western Cascades of Oregon.

Figure 2 shows appreciably less soil disturbance from balloon logging than from the other three methods. For example, an average of about 57 percent of high-lead logged areas was undisturbed compared with 78 percent for the two balloon-logged units. Likewise, slight disturbance, which averaged about 21 to 26 percent for tractor, high-lead, and skyline logging, was less than 16 percent for balloon logging.

The proportion of bare soil exposed after logging was 14.1 percent for high-lead, 12.1 percent for skyline, and 6.0 percent for balloon yarding. Thus, balloon logging resulted in less than half as much bare soil; since surface erosion occurs almost exclusively in bare soil areas, this method reduces the likelihood of large-scale erosion. It should, of course, be borne in mind that amounts of bare soil may be greatly increased if logging slash is broadcast burned.

For example, broadcast burning of slash on the skyline-logged clearcut increased percent of bare mineral soil from 12 to 55.[7]

Slash accumulation data for each of the four logging methods are shown in figure 3. With the possible exception of a lesser amount of heavy slash following skyline logging, slash distribution patterns are roughly comparable for the four methods. These results are somewhat surprising since one would expect the yarding method to have considerable effect on the distribution of logging residues. For example, we expected a higher proportion of the tractor-logged area to be in heavy slash due to piling. Sampling procedures and the broad class designations for slash may account at least partially for the relative lack of measured differences among logging methods. Thus, although this study failed to show them, real differences may exist which we were simply unable to measure.

Amounts of disturbance caused by balloon logging as reported here are undoubtedly among the lowest reported for clearcut logging operations in the Pacific Northwest. During the course of making our observations, it became

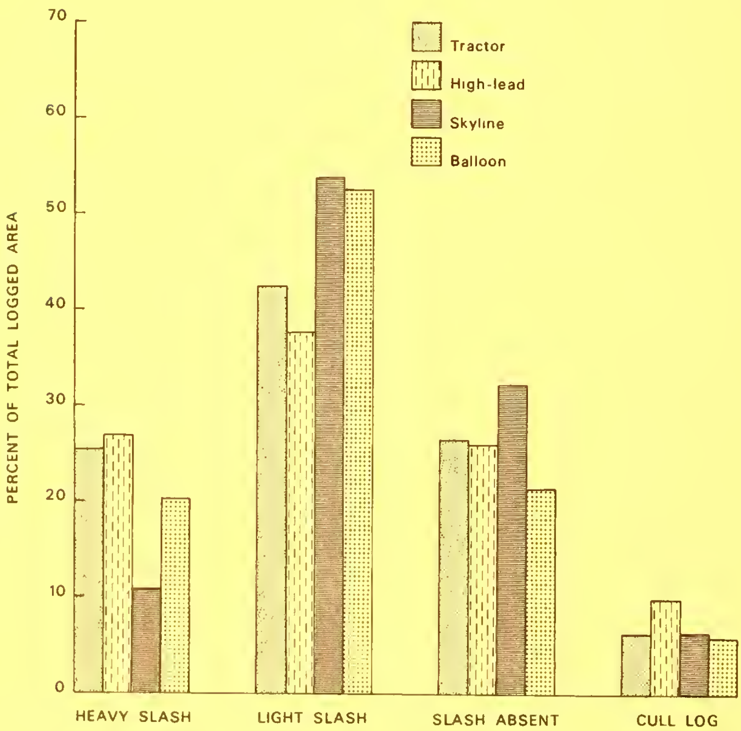

Figure 3.--Distribution of logging slash following tractor, high-lead, skyline, and balloon logging in the western Cascades of Oregon.

[7] R. C. Mersereau and C. T. Dyrness. Accelerated mass wasting after logging and slash burning in western Oregon. J. Soil & Water Conserv. 27: 112-114, 1972.

apparent that most of the slightly disturbed areas were not caused by yarding but rather by disturbance from tree falling and bucking. Thus, any reduction in disturbance might require additional precautions during tree falling. Yarding with the natural-shaped balloon virtually eliminates gouging, dragging, and other types of contact between log and soil which damage the site. Because the balloon provides sufficient lift, the logs are held free of the ground and surface vegetation from the time they are picked up until they reach the landing. In addition to preserving unaltered surface soil conditions, this capability also makes it possible to leave protective ground vegetation and streamside strips in an essentially undisturbed state, and to protect advance tree regeneration.

Perhaps the main advantage of yarding methods, such as skyline and balloon, capable of yarding over long distances is the reduction in necessary road mileage. In the western Cascades of Oregon, conventional high-lead yarding generally requires a midslope road. In steep terrain, these midslope roads are difficult to maintain and are important reoccurring sources of stream sediment. Since balloon yarding can be carried out over distances up to 1 mile, midslope roads are eliminated with obvious cost and water quality benefits. However, downhill balloon yarding, as was done in the present study, still requires roads, landings, and a bedding ground for the balloon in valley bottoms. Unless special precautions are taken, such locations may have a negative effect on water quality. A more ideal arrangement, from the standpoint of maintaining the water resource, would be uphill balloon yarding to suitable landings on or near ridgetops. In this way, disturbance by road construction or landing activities would be well removed from live streams.

GPO 986-300

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-183 August 1972

MEASUREMENT OF LOGGING RESIDUE—

Alternative Applications of the Line Intersect Method

by

James O. Howard, *Resource Analyst*

Franklin R. Ward, *Research Technician*

ABSTRACT

This study was initiated to test the application of the line intersect method for measuring logging residue using a systematic grid-point approach.

Results indicate that a random orientation of sample line is best for cutover areas where topography and logging create residue orientation patterns. For areas where the terrain is more gentle, a unidirectional configuration can be used. In general, estimates of residue volume within ± 15 to 20 percent of the true value can be expected in an 8-hour day. Sampling intensity required to meet various levels of precision is also given.

KEYWORDS: Logging residue, measurement, sampling.

INTRODUCTION

Increasing interest of forest managers in the utilization and abatement of logging residues has generated the need for detailed information on the quantity and characteristics of such residue. Residue management programs require specific data for each cutover area. Conventional cruising methods such as strip or plot cruising are extremely costly for the degree of precision needed.

Adaptation of the principles of line transect sampling to the estimation of logging residues by Warren and Olsen (1964) with modifications by Van Wagner (1968) and Bailey (1970) offers a quicker and less costly method for obtaining the needed information. Bailey reported time savings of 55 percent for the line intersect method compared with conventional cruising methods. In addition to the gross volume information used in this study, other data on residue, such as percent chippable, length, and diameter, may be readily collected and compiled.

The line intersect, or line transect, method uses the length of sample line and accumulated diameters of the residue pieces intersected to develop estimates of the volume of logging residue.[1/] The line intersect method has been used in the Pacific Northwest by Howard (1971) to estimate the characteristics and average volume of logging residue for a large number of cutover tracts within ownership

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[1] The basic equation, as derived by Van Wagner, is:

$$V = \frac{\pi^2 \ \Sigma d^2}{8L}$$

where

V = cross-sectional area of residue per unit of sample line
d = diameter of residue at point of intersection, in inches
L = length of sample line, in feet.

Estimates of cubic-foot volume or weight can be readily obtained by application of appropriate conversion factors to the basic equation.

For cubic-foot volume per acre, the formula is:

$$V = \frac{\pi^2 \ \Sigma d^2}{8L} \cdot \frac{43{,}560}{144}$$

For tons per acre, the formula is:

$$W = \frac{11.65 \ S \ \Sigma d^2}{L}$$

where

S = specific gravity of wood being sampled.

classes. However, no attempt was made to obtain precise estimates for any specific tract.

The line intersect method as traditionally used for estimating residue for a cutover area (see fig. 1) has certain disadvantages. First, since each line crossing the cutover area must properly be considered as only one sampling unit, many lines are required in order to obtain an estimate with a low sampling error. As the size of the cutover area increases, the effort required to meet the specified level of precision increases rapidly. Second, statistical analysis is complicated whenever sampling lines of unequal length are encountered. This problem occurs frequently with the irregularly shaped clearcuts common in the Pacific Northwest. Finally, as is evident in figure 1, the use of a small number of sample lines leaves substantial areas of the cutover tract unsampled. This is particularly critical as the size of the cutover area increases. The wide variation in residue concentration in a cutover area indicates that a good distribution of sample units is highly desirable.

Figure 1.—Traditional application of the line intersect using two sets of continuous lines at right angles to each other. Note: each line represents one sample unit.

The search for possible solutions to these problems generated the study reported here. The purpose of the study is: to test an alternative design for applying the line intersect method to obtain estimates of residue volume for specific tracts; to develop broad guidelines for estimating the sampling intensity needed to attain various levels of precision in the estimate of residue volume; and to provide some information as to the relative precision which might be expected in a two-man, 8-hour day.

STUDY PROCEDURE

Specifically, this study was designed to test the application of the line intersect method using a systematic grid-point sampling design, with three configurations of 200-foot line segments located at each grid point.[2] The three patterns of sample line tested are shown in figure 2. All three patterns were repeated once on each of two clearcuts, located on the Mount Hood and Willamette National Forests in western Oregon. The clearcuts selected were approximately 40 acres, with a moderate volume of residue and gently sloping, unbroken terrain. This last requirement was included to reduce the effect of topography on the concentration and orientation of the residue. On each clearcut the sample units (200-foot line segment) were located at points on a systematic grid having a 4-chain by 4-chain spacing. This grid interval was selected in order to produce about 25 sample units, a number deemed adequate for sound statistical analysis.

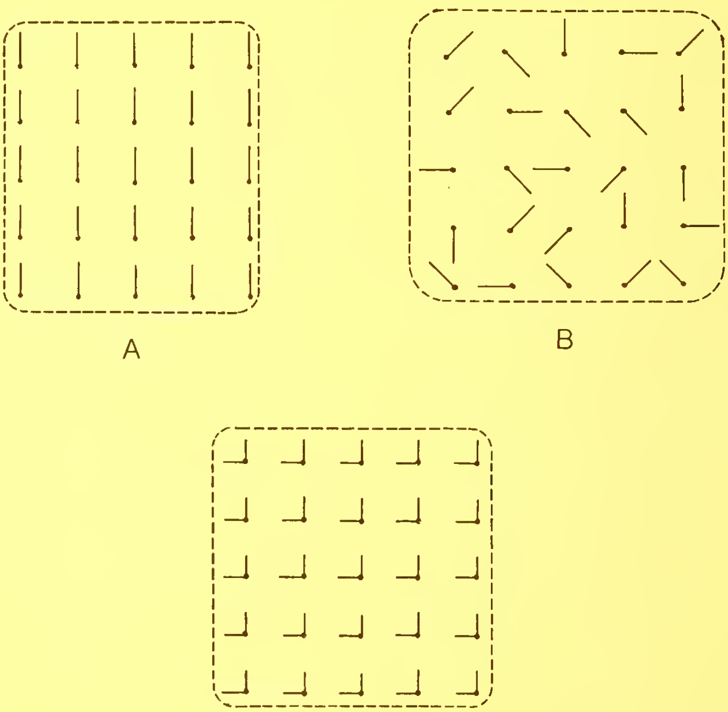

Figure 2.—Patterns of 200-foot segments tested: *A*, unidirectional pattern; *B*, randomly oriented pattern; *C*, L-shaped pattern. (Sample units located at points on a 4-chain by 4-chain grid system.)

[2] Although the use of a systematic sampling design does not lead to absolute independence of sample units, the sample observations of the three patterns of line tested are assumed to be random events and sufficiently independent for statistical analyses.

For the purposes of this study, logging residue was defined as all roundwood, except stumps and standing trees, at least 4 inches in diameter and 4 feet in length. The diameter at the point of intersection was recorded, by 1-inch class, for all residue material intersected by a sample line. These data were recorded separately for each sample unit for each of the six samples.

Working time was recorded for each of the three patterns on both clearcuts.

All lines were measured horizontally using slope corrections where necessary.

RESULTS

Table 1 shows the significant data for each of the six samples in the study. With the exception of the randomly oriented pattern on clearcut 2, each sample was completed in less than 3-1/2 hours. In both study areas, the unidirectional pattern required the least time.

Table 1.--*Sample information from line intersect technique study*

Sample design	Number of sampling units	Estimated average residue volume	Coefficient of variation	Working time[1]	Estimated results of 8-hour day: Number of sampling units	Estimated results of 8-hour day: Degree of precision attained[2]
		Cu. ft. per acre	*Percent*	*Hours*		*Percent*
Clearcut 1						
Unidirectional pattern	23	3,393	78.1	2.43	76	±18
Randomly oriented pattern	23	3,611	79.1	3.08	60	±20
L-shaped pattern	23	4,298	102.0	3.18	58	±27
Clearcut 2						
Unidirectional pattern	25	4,173	88.7	2.62	76	±21
Randomly oriented pattern	25	4,322	57.3	3.65	55	±16
L-shaped pattern	25	3,802	71.4	3.32	60	±19

1/ Two-man crew basis.

2/ Computed sampling error at the 95-percent confidence level.

It might be noted that the high coefficient of variation associated with the L-shaped pattern on clearcut 1 was the result of a few sample units being located in a heavy concentration of residue. This is a frequent problem, where landings and broken and steep terrain tend to concentrate the residue.

The data in table 2 indicate the number of sample units required to meet various degrees of precision at the 95-percent confidence level for each of the six samples. These estimates were arrived at by use of a standard formula.[3/]

Table 2.--*Number of sample units*[1/] *needed to meet specified degree of precision*

Sample design	Degree of precision (percent)								
	±10	±15	±20	±25	±30	±35	±40	±45	±50
	- - - - - - - - - - *Number of sampling units* - - - - - - - - -								
Clearcut 1									
Unidirectional pattern	235	104	59	38	26	19	15	12	9
Randomly oriented pattern	241	107	60	38	27	20	15	12	10
L-shaped pattern	400	178	100	64	44	33	25	20	16
Clearcut 2									
Unidirectional pattern	302	134	76	48	34	25	19	15	12
Randomly oriented pattern	126	56	32	20	14	10	8	6	5
L-shaped pattern	196	87	49	31	22	16	12	10	8

[1/] A sampling unit is defined as a 200-foot segment of line intersect, located at each point on a systematic grid.

[3] The formula used to compute the number of sample units is:

$$N = \frac{(C.V.)^2 \ (t)^2}{(Z)^2}$$

where

N = required number of sample units
C.V. = coefficient of variation related to each sample
t = "Student's" *t* value at the 95-percent confidence level
Z = desired degree of precision.

The variation in residue volume on a cutover area determines the sample size required for a desired level of precision. For example, in the case of the L-shaped pattern on clearcut 1 where the coefficient of variation exceeds 100 percent, 400 sample units are required to reach the 10-percent precision level. Thus it may well be that the wide variability of residue volume, coupled with the costs of measurement and the uses to which the estimates will be put, may dictate acceptance of lower standards of precision.

DISCUSSION AND CONCLUSIONS

Generally, the sampling schemes analyzed in this study obtain estimates of logging residue volume within ±15 to 20 percent of the actual volume in an 8-hour day. The results also indicate that attempts to reach precision levels of less than ±15 percent will require substantial effort.

Based on the findings of this study and previous work with the line intersect method, the randomly oriented pattern is recommended for use where cable logging is practiced, or where other variables create residue orientation bias. This bias, documented in earlier works (Warren and Olsen 1964, Van Wagner 1968, Bailey 1970), is simply the angular orientation of residue in one direction, resulting from cable yarding, slope, or downhill skidding. The straight line pattern should not be used in areas with these characteristics.

Any of the three patterns tested may be used where residue orientation bias is nonexistent, such as on flat terrain where tractor logging is practiced. The general randomness of residue dispersion for these areas was substantiated by Warren and Olsen (1964). On these types of cutover areas, the unidirectional pattern is recommended primarily because of its distinct time advantage.

In this study the sensitivity of the sampling error to changes in the length of line intersect per sample unit was not tested. It is possible that length of sample line greater than 200 feet might yield lower sampling errors.

The systematic grid-point system of locating sample units of line intersect offers a simple and efficient method for obtaining reliable estimates of logging residue volume for a specific cutover tract. A random orientation pattern of sample lines appears to be the best approach, particularly in the Douglas-fir region where cable-logged clearcuts are common.

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GPO 986-315

ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-184 August 1972

LITTERBAGS: AN EVALUATION OF THEIR USE

by

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Randel F. Washburne, *Research Assistant*, University of Washington

ABSTRACT

A study conducted in Mount Rainier National Park indicates that only a very small proportion of the litterbags handed out end up in park trash cans. Furthermore, most of the remaining litterbags are carried away unused from the Park. Of the two types of litterbags tested, plastic bags were used more often than paper bags.

Portions of this study were conducted under cooperative agreement between the Forest Service and the College of Forest Resources, University of Washington.

Keywords: Litter (public places).

Litterbags are commonly provided in recreation areas with the assumptions that they will be used for litter disposal and that, through their use, the amount of litter on the ground will decrease.

A test of the first assumption, that people use litterbags when they are provided, was conducted over a 3-day period during July 1971 in Mount Rainier National Park.[1] The objectives were to determine: (1) if the litterbags routinely handed out at park entrances are used by visitors; and (2) if the type of litterbag, plastic or paper, influences their use.

METHOD

During the study period, two types of litterbags were handed out at the National Park entrances. Their use was traced by checking a sample of garbage cans in the Park and by briefly questioning visitors at exits when they left.

For three July weekdays, a paper or a plastic litterbag was alternately handed out to a total of 2,821 cars at the Nisqually entrance, on the west side of Mount Rainier National Park, and the Stevens Canyon entrance, on the east. The Sunrise entrance on the opposite side of the Park was not included, and visitors entering through that gate were not given a litterbag unless they specifically requested one. Litterbags used were the Johnny Horizon plastic litterbags, which have a hole for hanging from car windows or dash, and the paper lunchbag type commonly used in National Parks.

To help identify the litterbags included in the study, they were all marked inconspicuously. In addition, no litterbags were given out the days preceding and following the study.

To determine the number of litterbags disposed of in the National Park, a 30-percent random sample of the 260 public trash cans along roads and in parking areas was selected. The cans in the sample were so marked that regular garbage collection crews would not empty them. Garbage accumulating in these cans was collected on each of 3 days, beginning on the second day of the study and ending on the day following the last day that litterbags were given out. When marked litterbags were found, the type of bag, plastic or paper, was recorded. Observers also indicated whether the bag had been used.

To account for bags not disposed of in the Park, all visitors were stopped at the exits to determine: (1) which day they had entered the Park, (2) which gate they had entered, (3) which type of litterbag

[1] The generous cooperation of Mr. John Townsley, Superintendent of Mount Rainier National Park, and several of his staff is gratefully acknowledged. Several members from the nearby Youth Conservation Corps camp also played a major role in making this experiment successful.

they had received, (4) if they still had the bag, and (5) if the litterbag was being used. The gates were manned from 8 a.m. to 5 p.m. by boys and girls from the nearby Youth Conservation Corps camp. Prior to the beginning of the study, the procedures for asking questions designed to measure the above were explained in detail to the interviewers.

An essentially "closed system" was established with the above procedures, so that it was possible to account for almost all the litterbags handed out with relatively little error. However, three potential sources of error should be noted. First, the projected total number of bags to be found in trash cans was estimated from a sample and therefore subject to the small sampling error associated with a 30-percent random sample of a finite population. Second, some visitors left the Park after the entrance stations were closed, but this was not viewed as serious since officials estimated that over 90 percent of the visitors generally leave before closing time. Third, people who entered the Park during the study period, but left after the study was over, were not interviewed. Again, this was not a serious source of error, since officials report that few visitors usually remain in the Park for more than a single day and night.

RESULTS

The results from this study are shown in table 1. During the study 2,821 litterbags were handed out--1,410 paper and 1,411 plastic.

A total of only 29 litterbags were found in the sample of trash cans, representing a projected total for all trash cans of 94 bags of the 2,821 handed out (3.3 percent).[2] Of the 29 litterbags found, only one was plastic. Of the 28 paper bags found, 25 (89.3 percent) had been used.

A total of 2,382 cars were stopped as they left the Park, and 2,290 (96.1 percent) still had their litterbags with them. Of these, 48.6 percent were paper and 51.4 percent were plastic. When it could be determined, it was found that, of the bags in the cars, 35.5 percent of the paper bags and 48.0 percent of the plastic bags had been used.

The disposition of approximately 437[3] (15.5 percent) of all litterbags handed out could not be ascertained. It is likely, however, that they were in the 439 cars which passed through the gates when the interviewers were not on duty.

DISCUSSION

The results of this study suggest, first, that the majority of the litterbags provided at park entrances

[2] Confidence limits for the projection at the 95-percent level of probability were 68 and 120.

[3] The figure 437 is based on the total number of bags handed out, minus the total found in cars, plus the projected number to be found in all trash cans, i.e., 2,821 – (2,290 + 94) = 437.

Table 1.--*Disposition of litterbags by type*

Litterbags	Paper		Plastic	
	Number	*Percent*	*Number*	*Percent*
Number handed out	1,410	50.0	1,411	50.0
Found in trash cans:1/ (sample)				
Used	25 (81)	86.2	1 (3)	3.2
Empty	3 (10)	10.6	0 (0)	--
Total	28 (91)	96.8	1 (3)	3.2
Found in cars:2/				
Used	380	35.5	552	48.0
Empty	691	64.5	599	52.0
Total3/	1,071	100.0	1,151	100.0

1/ Projected numbers are shown in parentheses following actual numbers.

2/ 2,382 cars were stopped as they left the Park.

3/ The total excludes 41 paper and 27 plastic bags for which it could not be determined whether used.

are not likely to be used, at least up until the time the visitors leave the Park. Whether those bags which leave the Park empty are ever used is not known.

Second, of the few bags discarded in the Park, 96.8 percent were paper. At first glance, it may appear that paper litterbags are the type most likely to be used. But additional evidence suggests otherwise. Of the paper litterbags found in trash cans, 10.6 percent were thrown away empty. In addition, of the litterbags remaining in cars leaving the Park, a greater percentage of the plastic bags (48.0 percent) were being used than of the paper bags (35.5 percent).

Thus, plastic bags were kept longer and were more often used than paper bags, even though they were less likely to be found in park trash cans. It appears, therefore, that plastic litterbags stimulate use more effectively than paper bags. This is an important finding but should not overshadow the fact that well over half the litterbags handed out were unused when taken from the Park.

Results from this study are highlighted by findings from two other studies of anti-litter behavior. Evidence from these studies also suggests that not only are litterbags unlikely to be used when provided, but they may in fact have little or no effect on the level of litter already on the ground.

The provision of litterbags in a theater reduced the amount of litter normally found on the floor from about 80 to 70 percent of the total litter in the theater.[4/] It is interesting to note, however, that less than half the children who were given litterbags actually used them. In fact, many of the litterbags ended up on the floor as additional litter.

In a study of four widely dispersed car camping locations, litterbags were given to campers for their use, with the bags to be left for the Ranger to pick up.[5/] It was found that in the absence of any incentive to use the litterbags litter levels remained about the same. Only "fresh" garbage was deposited in the litterbags. No *old* cans, bottles, or paper were found, although such "litter" was scattered around each area. It seems, therefore, that although litterbags may be used to dispose of waste material which otherwise might end up on the ground (garbage), they do not by themselves encourage other anti-litter behavior, i.e., litter pickup.

SUMMARY AND CONCLUSIONS

The results of this and related studies suggest several things about the use of litterbags. It appears that most litterbags provided at Parks such as Mount Rainier are not likely to be used. Only 3 percent of all bags distributed were found in park garbage cans, and over half the bags handed out were taken from the Park, unused. Plastic litterbags were more likely to be retained and used than the paper bags. Furthermore, when litterbags were used in a dispersed car camping environment, they seemed to have only a small impact on litter levels as they were used primarily for "garbage disposal" and not litter pickup.

Provision of litterbags is an important ingredient in a successful litter control program and provides a means of disposing of refuse as it is created. However, litterbags alone do not solve the problem, since they do not stimulate the picking up of existing litter.

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[4] Robert L. Burgess, Roger N. Clark, and John C. Hendee. 1971. An experimental analysis of anti-litter procedures. J. Appl. Behav. Anal. 4: 71-75, illus.

[5] Roger N. Clark, John C. Hendee, and Robert L. Burgess. The experimental control of littering Accepted for publication in the Winter 1972 issue of The Journal of Environmental Education.

GPO 986-217

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ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-185 *September 1972*

A 31-DAY BATTERY-OPERATED RECORDING WEATHER STATION

by

Richard J. Barney, *Principal Fire Control Scientist*

ABSTRACT

The battery-powered recording weather station measures and records wet bulb temperature, dry bulb temperature, wind travel, and rainfall for 31 days. Assembly procedures and cost of supplies and components are discussed.

Keywords: Weather, measuring equipment.

INTRODUCTION

It is often desirable to monitor meteorological information in accessible as well as remote sites. Desired observation intervals are usually frequent enough to warrant some type of recording system. Many of the currently available commercial recording weather stations are quite expensive.

This article discusses a recording weather station system which will operate 31 days using battery power. The system measures wind travel, temperature, and rainfall continuously. Hourly observations are recorded for an aspirated wet bulb temperature providing relative humidity or dewpoint measurements. Figure 1 shows the recording system with all the transducers. Most of the items are "off the shelf" components. The only fabrications necessary are the "battery saver" and a psychrometer or thermistor and fan assembly. The most attractive feature of the entire system is its basic simplicity.

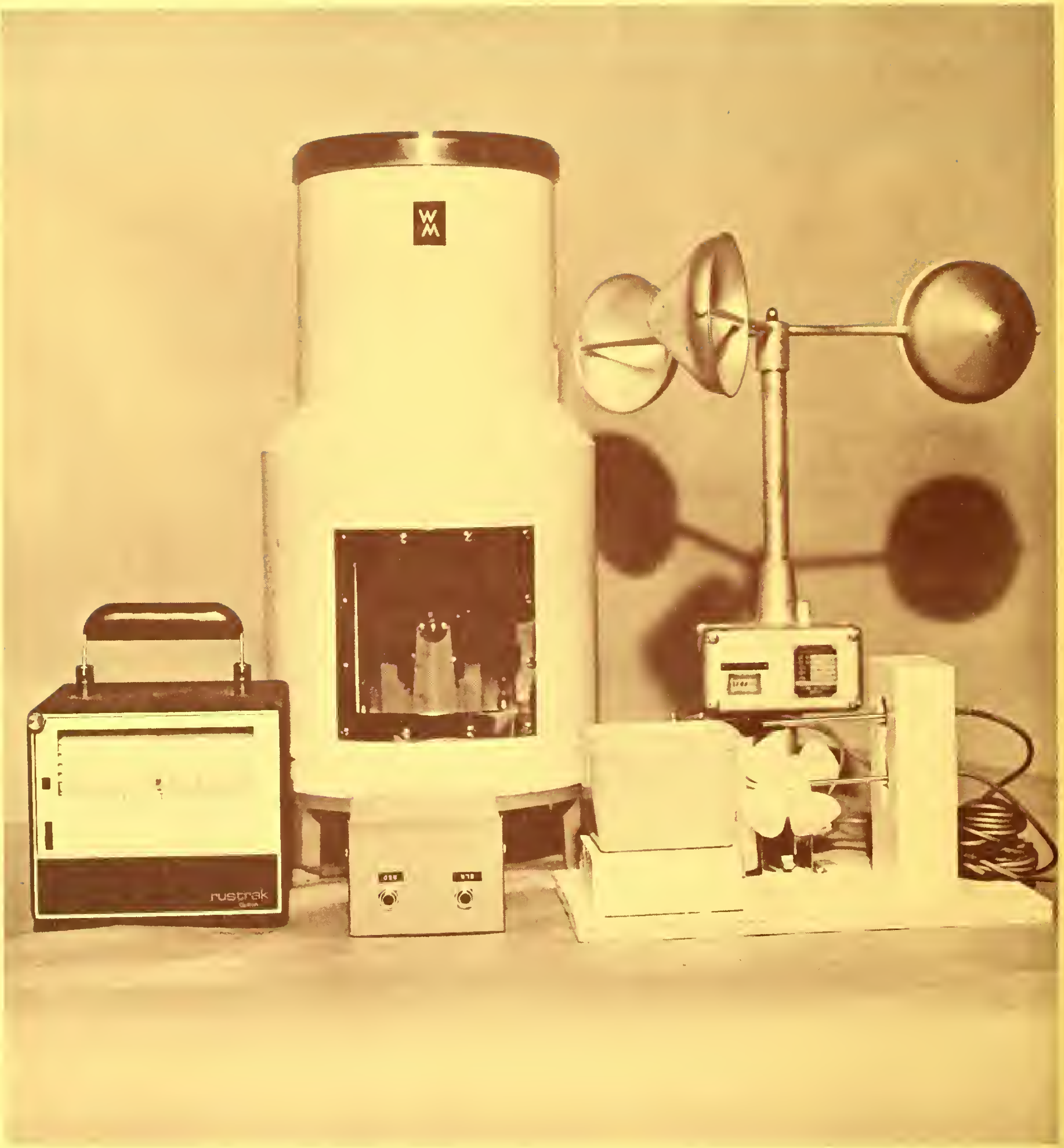

Figure 1.--Components of the recording weather station. Front row, left to right: recorder, "battery saver," psychrometer. Back row: tipping bucket rain gage, anemometer.

CONSTRUCTION

The following is a list[1] of primary parts, estimated cost, and a source of possible suppliers:

Anemometer, Belfort model	
Belfort Instrument Company 1600 South Clinton Street Baltimore, Maryland 21224	$170.00
Tipping bucket rain gage, model P501	
Weather Measure Corporation P.O. Box 41257 Sacramento, California 95841	180.00
Thermistor, Yellow Springs model 403 (2 each)	
Van Waters and Rogers P.O. Box 3200, Rincon Annex San Francisco, California 94119	44.00
Psychrometer fan	
Western Fire Equipment 440 Valley Drive Brisbane, California 94005	26.00
Recorder, Rustrak model 3133/3146 with a 1-hour interval timing switch (2-4 minutes on time) and two each 12-volt d.c. event channels	
Rustrak Instrument Division Gulton Industries, Inc. Municipal Airport Manchester, New Hampshire 03103	650.00
Miscellaneous supplies-- "battery saver" parts, hookup wire, dry batteries, etc.	30.00
Total estimated cost (January 1972)	$1,100.00

[1] Names and products listed are for the convenience of the reader and do not indicate endorsement by the USDA Forest Service. Parts of a similar type can be obtained from other suppliers.

The thermistor psychrometer shown in figure 2 is easy to construct. A stand must be built to hold the two thermistors. Cotton wicking is placed over the bottom thermistor and is then run into the water reservoir. The water reservoir is a plastic food container obtainable at a variety store. Standard one-hole rubber laboratory stoppers are used to hold the thermistors firmly in the stand. The layout should allow free air movement from the fan across the thermistors. Note that the dry bulb thermistor is above the wet bulb, avoiding possible dripping. The distance from the reservoir to the thermistor must also be limited (1 to 2 inches) to avoid excessive evaporation before the water reaches the sensing tip of the thermistor. The only additional item needed in construction is the "battery saver." Details for the "battery saver" construction can

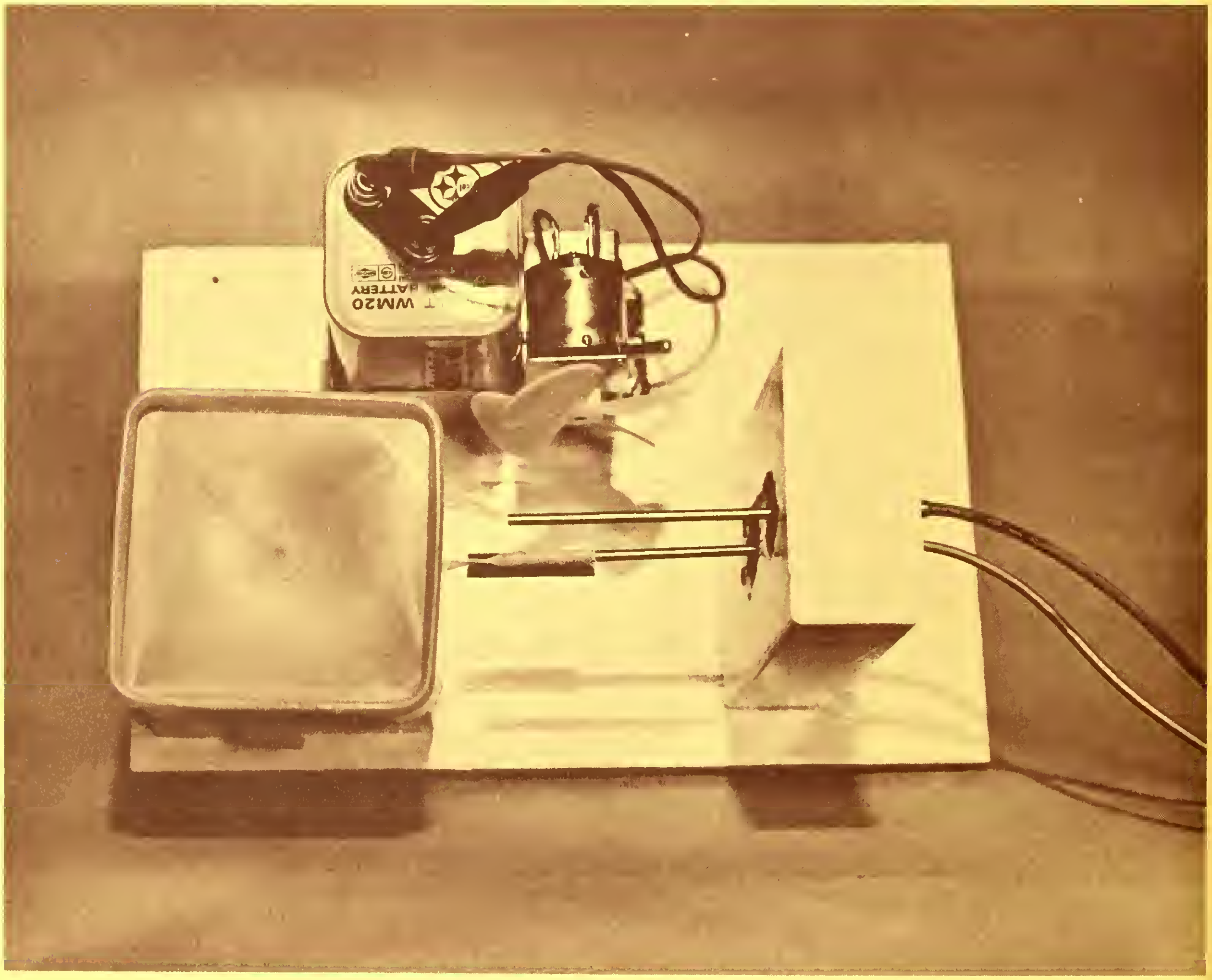

Figure 2.--Thermistor psychrometer used in the recording weather station.

be found in an earlier publication.[2] This battery saver is designed to eliminate excessive battery drain when the contacting transducers remain in the "on" or closed position for prolonged periods. The recording weather station can be assembled with or without this device; however, experience indicates that it is good insurance against losing data.

STATION OPERATION

Operation of the station is simple. Once the transducers have been placed in a "Cotton Region" instrument shelter and connected to the recorder, the wick reservoir is filled with mineral-free water. Mineral-free clean water prevents scaling and keeps water moving from the reservoir through the wicking to the thermistor. A 6-volt battery is connected to the psychrometer fan and 12-volt batteries are connected to the "battery saver" and the recorder. Once the recorder is operating, the appropriate temperature channels can be adjusted, using an accurate psychrometer, for both the dry bulb and wet bulb temperatures.

The psychrometer fan, when connected to the timing switch, will run 2 to 4 minutes once every hour. With a 1-inch-per-hour chart speed, the recorder chart paper will last slightly over 31 days. Chart paper is sensitive to pressure; therefore, no cleaning or inking of the pens is required. At each servicing, mineral-free clean water should be added and the old wick cut off and fresh wick pulled out of the reservoir and placed on the wet bulb thermistor. The 12-volt recorder and 6-volt fan batteries should be changed at the end of each month. The "battery saver" battery should be checked at this time and replaced when necessary. Figure 3 is a schematic of the weather station hookup.

An example of the recorder chart is shown in figure 4. This chart is an actual example of data obtained using the system. Point A in the figure shows that the 11:00 wet bulb temperature was 56° F., and the dry bulb temperature at point C was 66° F. Precipitation in the amount of 0.04 inch (point B) was recorded between 11:00 and 12:00. For the same 1-hour time period, point D on the chart showed 6 miles of wind or a 6 m.p.h. average.

We have had several months of satisfactory service from this system. Psychrometric readings have been found to be as accurate as those made with a portable fan-aspirated psychrometer. Its relatively inexpensive cost makes this station within the reach of many budgets.

[2] Richard J. Barney and Thomas C. Van Wickle. A "battery saver" for event recorders. Portland, Oreg., Pac. Northwest Forest & Range Exp. Stn., USDA Forest Serv. Res. Note PNW-168, 6 p., illus., 1971.

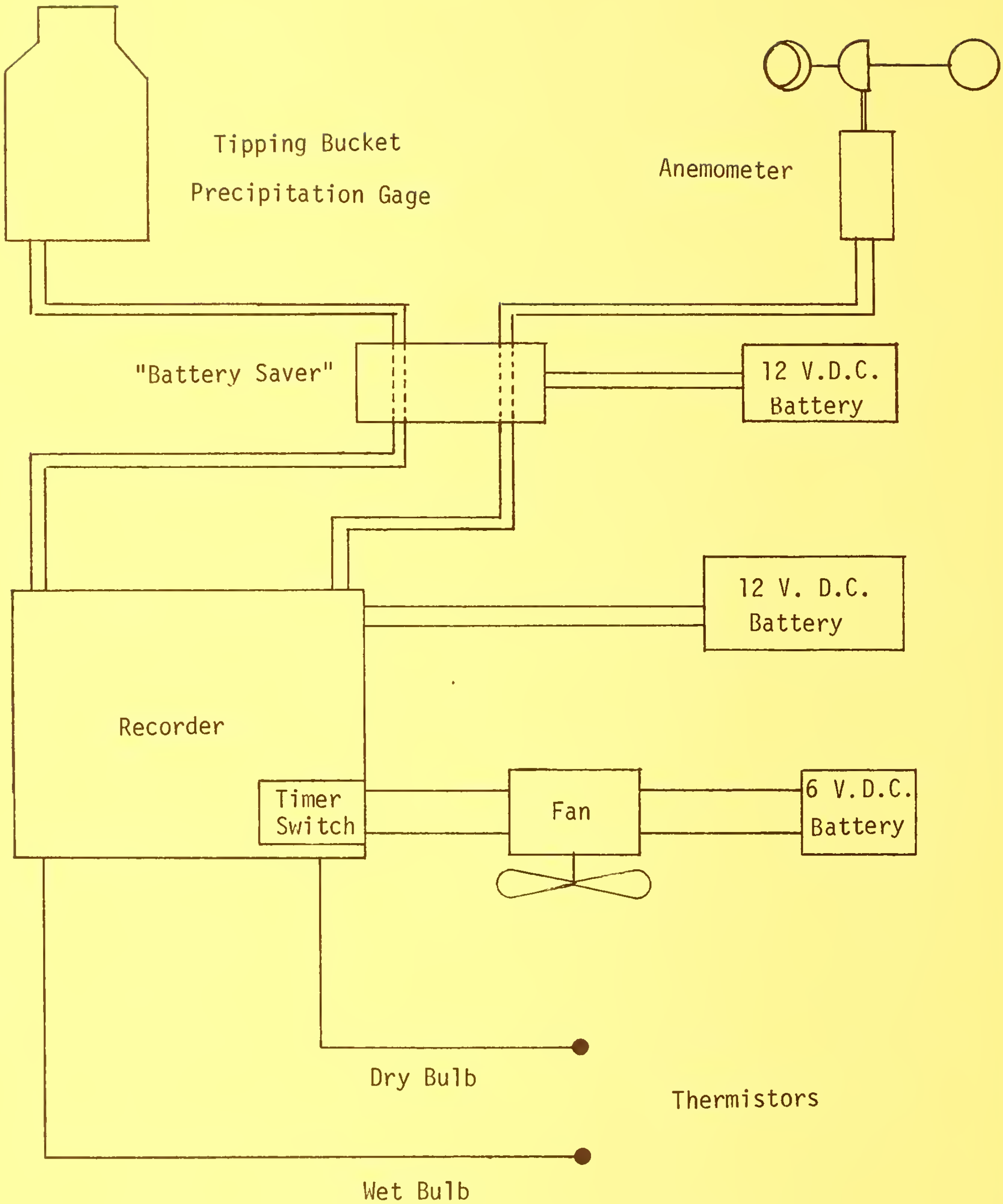

Figure 3.--Schematic of weather station hookup.

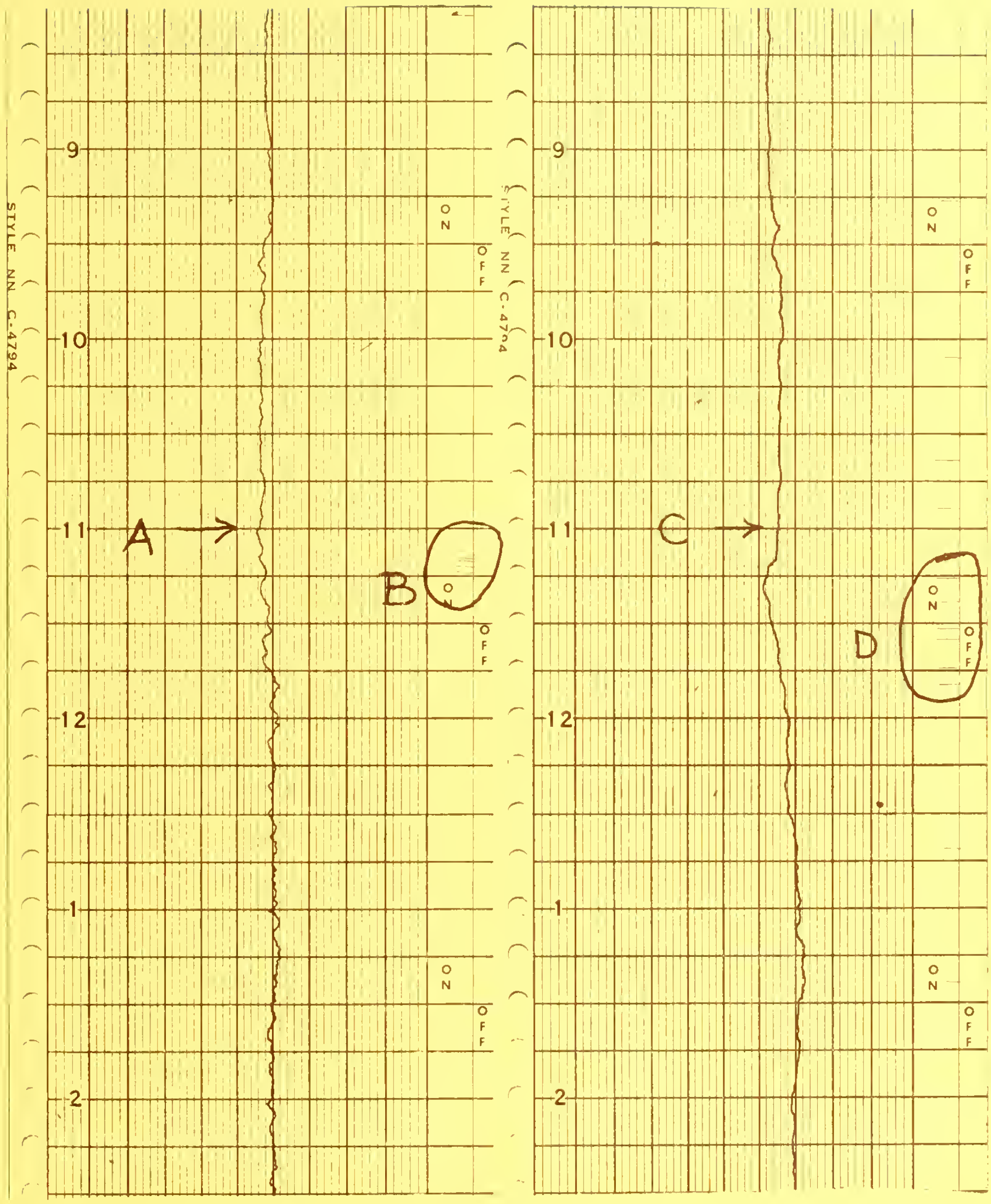

Figure 4.--Example of actual recording weather station chart (full size).

GPO 986-532

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
USDA FOREST SERVICE RESEARCH NOTE

PNW-186 September 1972

ROAD AND LANDING CRITERIA FOR MOBILE-CRANE YARDING SYSTEMS

by

J. Doyle Burke, *Civil Engineer*

ABSTRACT

Rising logging costs and increased environmental concern have been instrumental in bringing about the trend to mobile-crane, grapple yarding. This system is designed around the three-line running skyline and is characterized by low manpower requirements, increased safety of personnel, reduced average yarding distance, separate loading operation, and decreased soil disturbance. Log size is the most important variable affecting costs.

Roads should be located to take advantage of the yarder's mobility to reduce average yarding distance, must have adequate width for yarder operation independent of the loader, and should provide for uphill and downhill yarding. Landing areas should be such that logs will not roll or slide and the combined road and landing should provide sufficient room for the loading and trucking operations.

The usual types of landings are those continuous and adjacent to the road, split landings, and terminal landings. The continuous landing is the most common and least expensive, and the terminal landing is the least desirable.

Keywords: Logging, grapple yarding, cranes.

INTRODUCTION

Today's public is demanding that timber harvesting be conducted with minimal environmental impact; at the same time, the logging industry is faced with rising costs. These trends have prompted increased use of the mobile-crane, grapple-yarding system.

Since the early 1960's, mobile-crane, grapple-yarding systems have intrigued the logging industry. Much has been said and written about the peculiarities of the system, the equipment, and the increased production per man. Little has been said about the road and landing requirements.

The purpose of this note is to discuss the characteristics of the mobile-crane, grapple-yarding system and to present the major criteria for making road and landing decisions for operating the system. This information should be useful for those engaged in logging planning and layout, and those considering a mobile-crane, grapple-yarding system.

DESCRIPTION OF THE YARDING SYSTEM

The most common and most successful grapple-yarding system is designed around the three-line running skyline[1/][2/] and tracked or wheeled undercarriage for mobility, as shown in figure 1.

The yarder used with a three-line running skyline must provide a means for tensioning the receding line during yarding; i.e., the haulback while inhauling, or the main and operating lines while outhauling. Since large amounts of horsepower are involved in tensioning the lines, some mechanism is usually provided to transfer all or a portion of this power to the driven drum. This mechanism is usually referred to as an interlock.

The necessity to exchange horsepower between drums of varying effective diameters and line-speeds complicates the design of the interlock. This accounts for the sophisticated interlock mechanisms that are an important element of modern running skyline yarders.

The operating principle of the grapple system is as follows:

1. The grapple is opened to release the log at the landing by

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1/ Ward W. Carson, Donald Studier, and Hilton H. Lysons. Running skyline design with a desk-top computer/plotter. Portland, Oreg., Pac. Northwest Forest & Range Exp. Stn., USDA Forest Serv. Res. Note PNW-153, 21 p., illus., 1971.

2/ Charles N. Mann. Mechanics of running skylines. Portland, Oreg., Pac. Northwest Forest & Range Exp. Stn., USDA Forest Serv. Res. Pap. PNW-75, 11 p., illus., 1969.

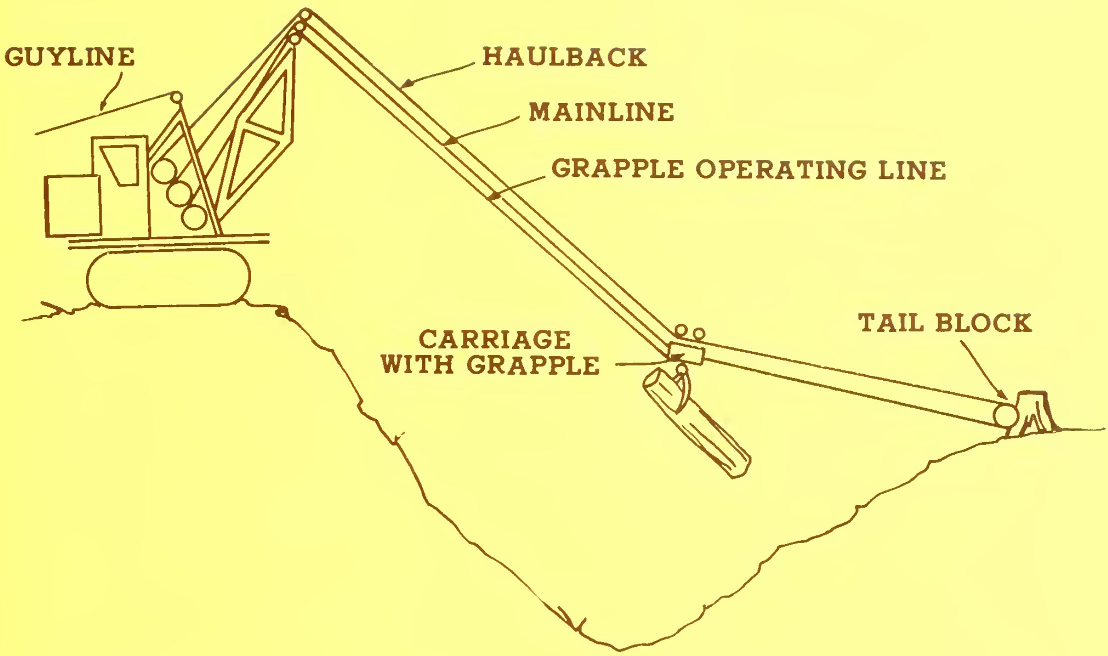

Figure 1.—Mobile-crane grapple-yarding system.

tightening the grapple operating line.

2. The grapple is outhauled by taking up on the haulback line and receding on the main and grapple operating lines.

3. The haulback line is slacked to place the grapple over the log, and the grapple operating line is slacked to close the grapple.

4. The log is yarded to the landing by hauling in on the main and grapple operating lines, while tension is maintained in the haulback line with the interlock. The swinging boom facilitates decking the yarded logs near the road.

This system can also be used with a slack pulling carriage, tagline, and chokers, where the operating line and main line are used to feed and retrieve tagline slack. However, this note will limit discussion to the grapple system.

With the grapple system, the

tail block either is fixed to a tree or stump or is rigged to a crawler tractor to give added mobility for changing the yarding road.

CHARACTERISTICS OF MOBILE-CRANE GRAPPLE YARDING

The major characteristics of mobile-crane yarding systems are:

1. Manpower requirements decreased. Average manpower requirements are two to three men, contrasted with five to seven for a high-lead yarding side. Most operations require only a yarder engineer and spotter; however, a third man is sometimes used for simultaneous rigging layout if a mobile tail block is not used.

2. Loading separated from yarding. The mobility of the yarding crane allows continuous decking of logs along the road. It is generally not necessary to work a loader with the yarder. This separates the loading operation from the yarding operation and facilitates continuous high efficiency trucking after sufficient logs are available.

3. Production increased. Log production per man is high. Average production per yarder varies between 170 and 210 logs per 8-hour shift. It is important to note that this system yards one log at a time, making log size the most important cost factor.

4. Chokers eliminated. Use of the grapple eliminates the choker setter, the chaser, and the problems associated with broken chokers.

5. Delay in setup and moving minimized. The mobility of the yarding crane and tail block makes road changes possible in a matter of minutes. The simple guyline system and outriggers on some machines reduce the delay of rigup.

6. Average yarding distances reduced. Yarding in parallel roads and moving the yarder around the tail block reduces average yarding distances.

7. Night operation practical. The elimination of choker setters and chasers and separate loading operations, plus the ease of grapple operation, allows night operation. Many operators double shift by illuminating the work area. Double shifts allow faster depreciation of equipment and increase efficiency of the loading operation since, under normal conditions, two yarding shifts can produce enough logs for one loading shift.

8. Snow operations possible. Operating in snow is possible since the grapple can penetrate the snow, and choker setters and chasers are not required. The only requirement is that the spotter be able to see the grapple and the log. He then spots the grapple by means of radio communication with the yarder operator.

9. Soil disturbance lessened. Soil disturbance is reduced, as with any skyline system, because of the lift provided the front end of the log. This eliminates or reduces damage caused by erosion and resulting stream siltation.

10. Safety increased. Safety is greatly enhanced because of the

reduced exposure of men to hazardous conditions. Increased safety is one of the greatest advantages of grapple yarding.

11. Grapple yarding is suitable only for clearcutting or partial cutting by means of clearcut strips.

ROAD CONSIDERATIONS

As a minimum, the roads must provide the load capacity and necessary dimensions to allow efficient yarder operation, loader operation, and support hauling. Drainage structures, such as bridges and culverts, must be designed or strengthened to support the weight of the larger mobile cranes.

With cable-yarding systems, the limiting factors for road location are yarding distance and topography. With mobile cranes, yarding distance is limited by topography (and its effect on deflection of the skyline) and yarder size. In general, yarding distance with present mobile-crane systems is under 1,000 feet slope distance.

Mobile-crane yarding systems have the capability to yard uphill or downhill. There are fewer hangups and less soil disturbance during downhill yarding because of the lift provided the front end of the log. The only requirements are that the grapple be placed over the log and that the skyline achieve sufficient deflection to support the grapple.

Mobile-crane systems provide two advantages in reducing average yarding distance. First, in yarding perpendicularly to the road with a continuous roadside landing, the average yarding distance is one-half the effective yarding distance (fig. 2).

With conventional systems, yarding to a fixed landing in a rectangular setting, the average yarding distance is always greater than 1/2 *a* as shown in figure 3.[3/]

[3/] U.S. Department of the Interior. Logging, transportation, and contractual costs, schedule 16, table 1. Portland, Oreg., Bur. Land Manage., Serv. Center, 1970.

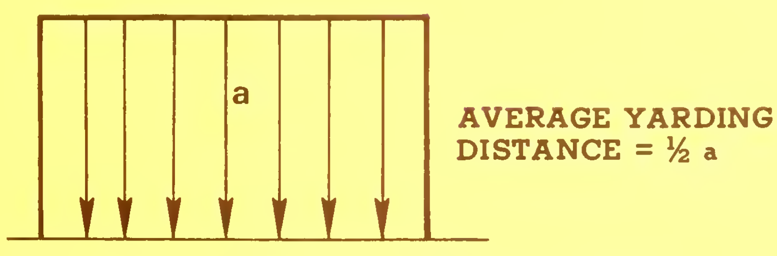

Figure 2.—Rectangular setting yarded perpendicularly to road.

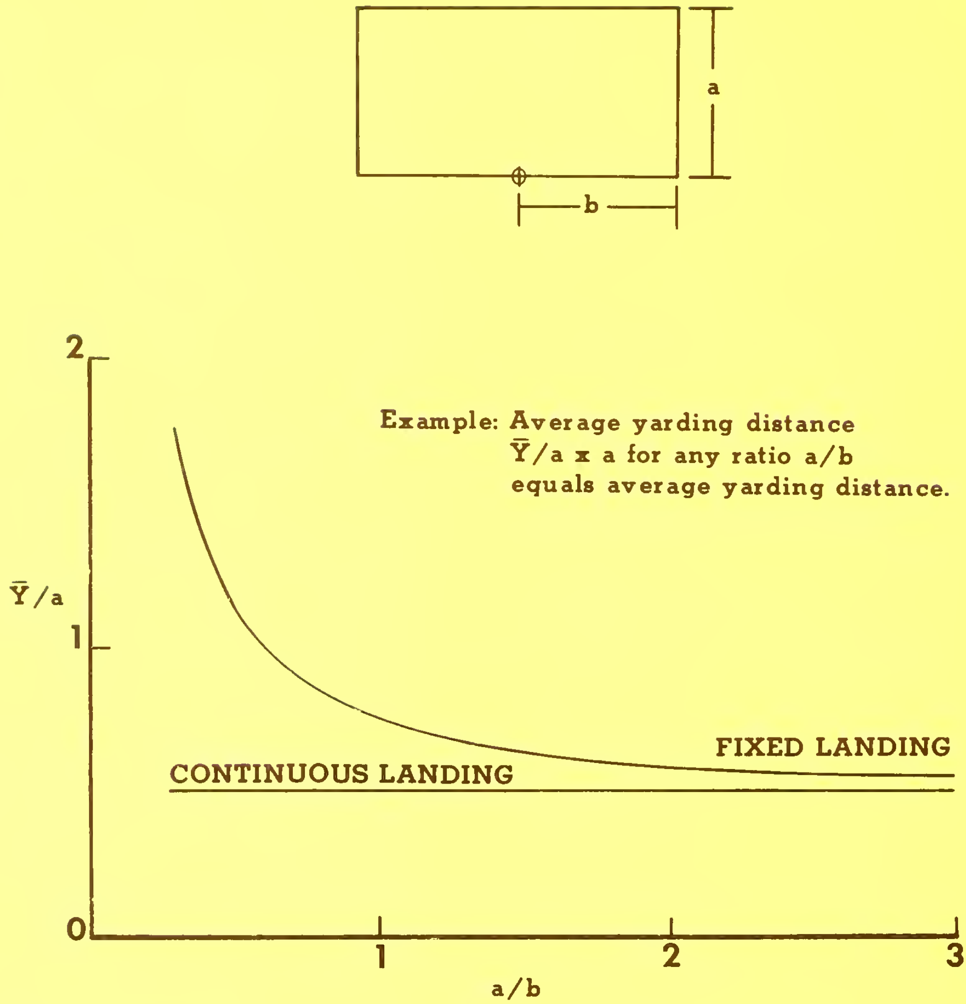

Figure 3.—Rectangular setting yarded to a fixed landing.

Second, the mobile crane's ability to move around a fixed tail block provides one-half the average yarding distance of high-lead, where the tail block is moved around the yarder, as shown in figure 4.

These characteristics point to the following road location considerations when planning for mobile-crane grapple yarding:

1. Take advantage of the yarder's ability to reduce average yarding distances by utilizing its mobility.
2. Provide adequate road dimensions for yarder operation independent of loader.
3. Take advantage of the capability to yard uphill and downhill.

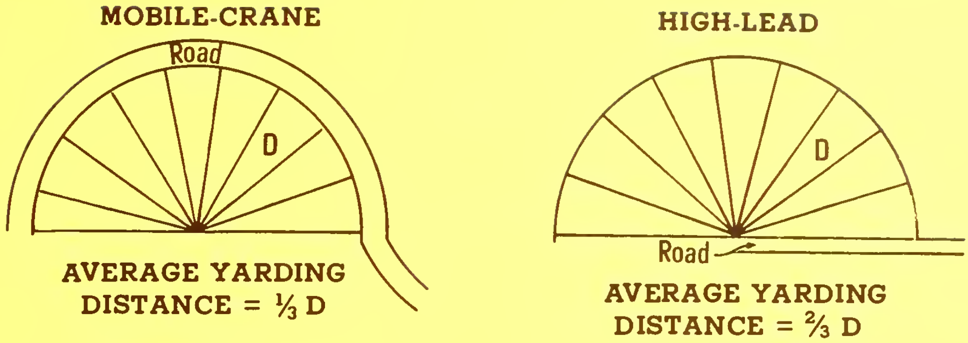

Figure 4.—Average yarding distance diagrams.

ROAD AND SETTING EXAMPLES

Figures 5 and 6 illustrate the plan and profile of a harvest unit where the logs are yarded downhill on parallel roads and yarded uphill on roads with a fixed tail block. The logs are decked along the road, both uphill and downhill, in a continuous landing. The harvest units can be irregularly shaped and still afford minimal average yarding distance.

Care must be taken placing the tail block so that the outer yarding limit is as close to the block as possible. For example, placing the block back on a bench could create a ground lead condition and difficulty in placement of the grapple. This should be kept in mind on benches and near the crest of ridges, as shown in figure 7. Figures 8 and 9 illustrate the plan and profile of a harvest unit that crosses an intermittent stream drainage, with both uphill and downhill yarding. This type of setting allows the deflection necessary for the skyline (fig. 10).

Mobile-crane grapple yarding is one of the most effective ways to yard logs across a drainage. Logs can be lifted over the water course with little, if any, disturbance to the stream or streambanks.

Figure 11 illustrates the location of a road for yarding timber around an intermittent stream drainage. Cutting unit layout of this type allows an irregularly shaped setting and provides the advantage of reduced average yarding distances. In this illustration, all yarding is uphill.

If all timber is to be removed, the same tail block near the intermittent stream could be used for yarding the opposite side of the draw.

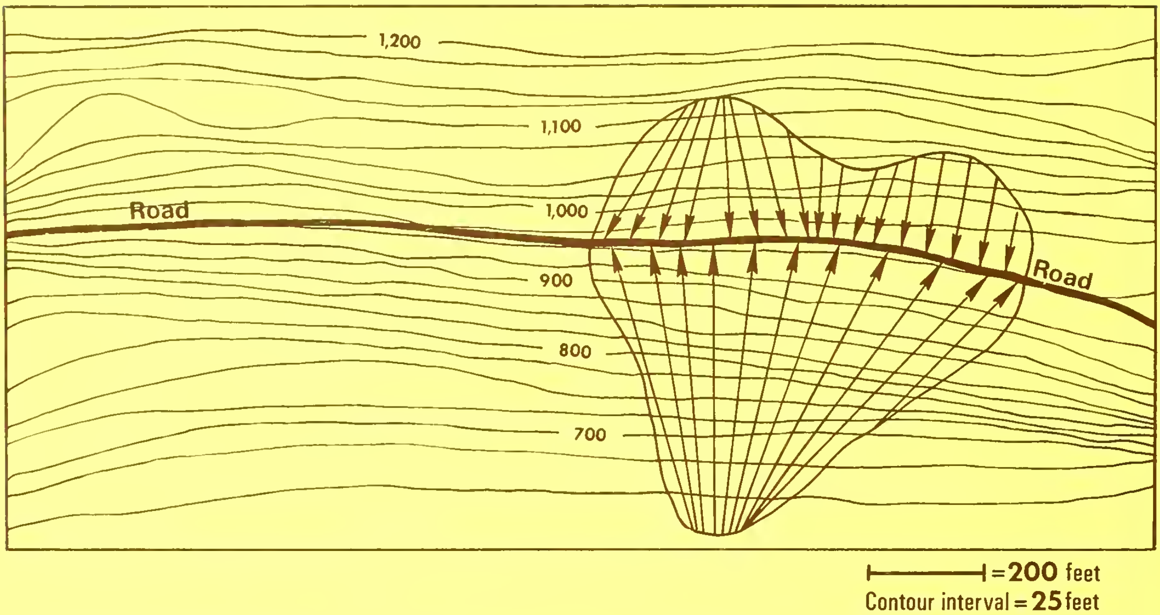

Figure 5.—Uphill and downhill yarding perpendicularly to road on a uniform slope.

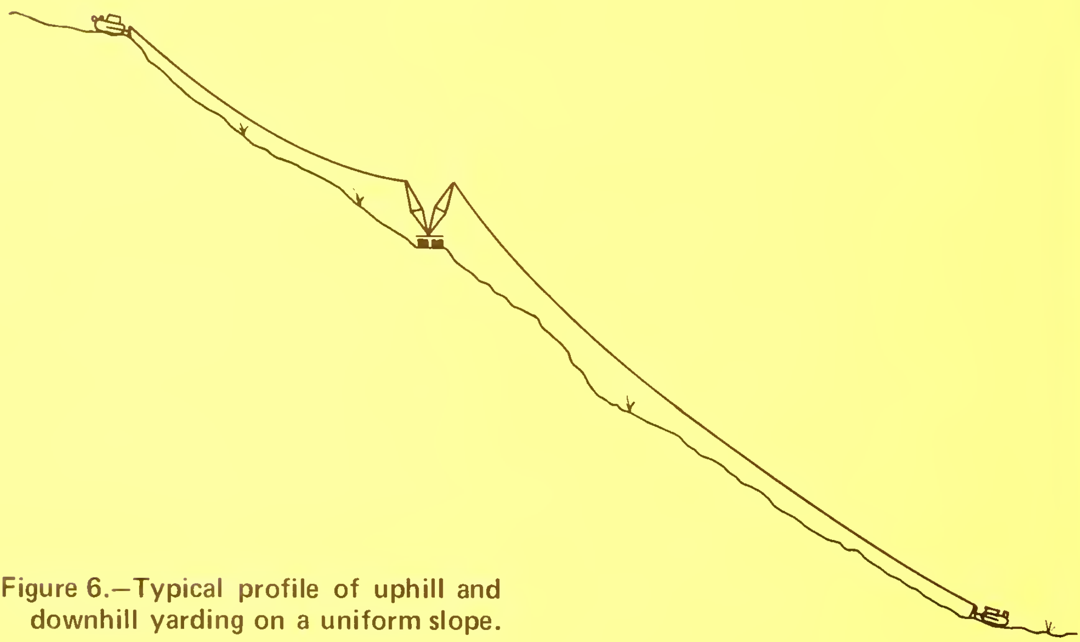

Figure 6.—Typical profile of uphill and downhill yarding on a uniform slope.

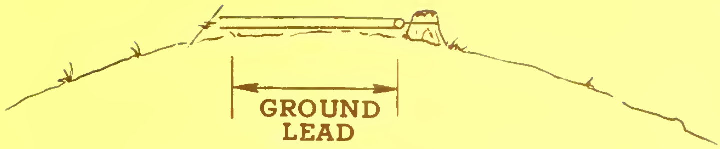

Figure 7.—Ground lead condition on crest of ridge.

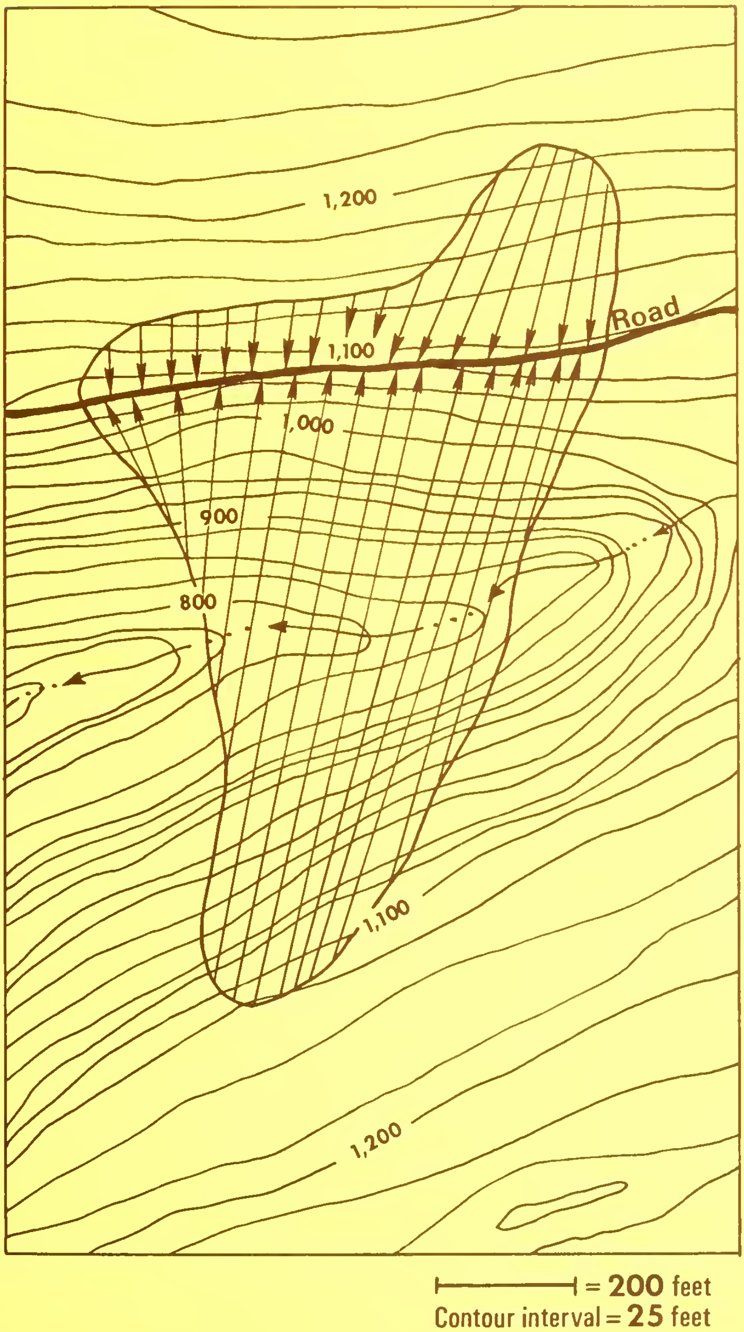

Figure 8.—Uphill and downhill yarding of U-shaped drainage.

Figure 9.—Typical profile of downhill and uphill yarding across drainage.

Figure 10.—Yarding across an intermittent stream drainage with the mobile tail block at a higher elevation than the yarder. This type of yarding profile provides optimum deflection and distance.

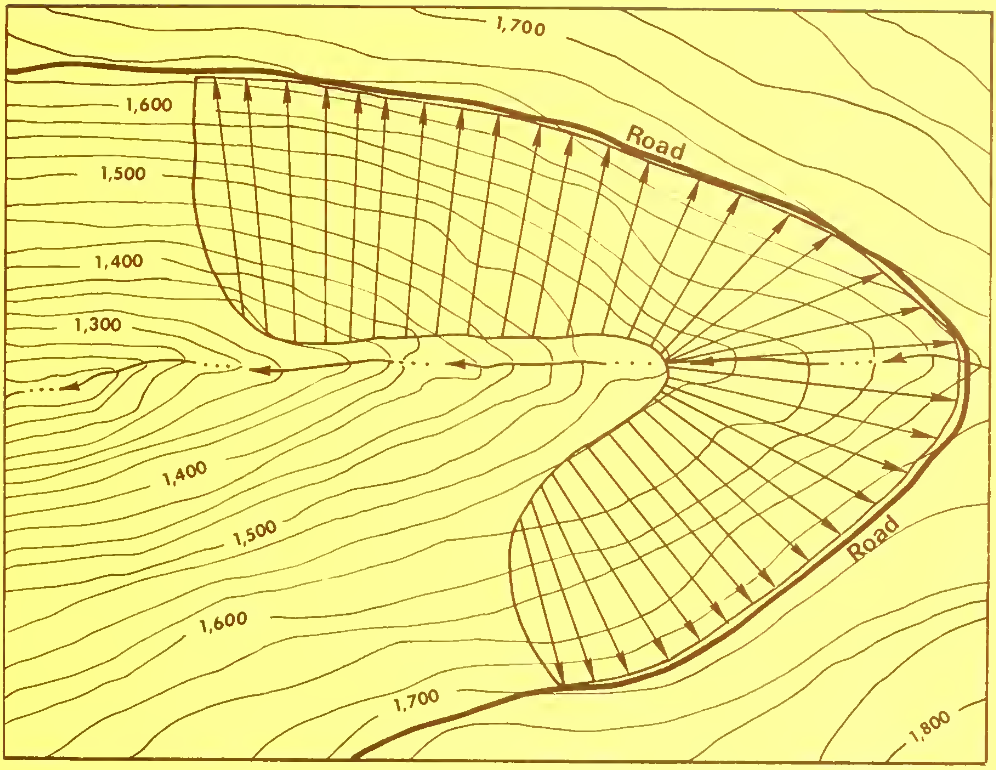

Figure 11.—Road location for yarding the head of an intermittent stream drainage.

LANDING CONSIDERATIONS

In mobile-crane grapple yarding, the loading can be separated from the yarding because the need for concentrated landings is eliminated. This is more efficient since the loading operation is approximately twice as fast as the yarding operation, and loading and hauling can be done in a continuous operation when there are sufficient logs stockpiled. Landings should complement this advantage.

There are two basic criteria for mobile-crane grapple-yarded landings. First, the slope of the ground should be such that the decked logs will not roll or slide after being released from the grapple. If the natural ground does not provide this, then the decking area must be modified by split landings or widened roadbeds. Second, the road and landing combination must provide sufficient swing room for the loader and clearance for the trucks. In steep terrain where the side slopes may be excessive, the major problem is the angle of the cut slope.

In mobile-crane yarding there are three types of landings:

a. Continuous landing adjacent to the roadway. This is the usual landing situation, and in level to moderately steep terrain there are no additional construction costs. The requirements are that the slope hold the logs and that there is room for efficient loader operation. Figure 12 shows a yarder decking beside the road on a widened subgrade. Figure 13 shows the resulting continuous landing adjacent to the roadway.

Figure 12.—Landing adjacent to road consisting of widened subgrade.

Figure 13.—Continuous landing adjacent to roadway.

b. Split landing. This type of landing requires additional construction costs. In the usual case, a separate yarder "road" is constructed at a level higher than the landing "road," as in figure 14. The yarder road must be able to support the weight of the yarder, and the loader road must be able to support the loader and trucks. Either can be temporary construction and "put to bed" after the harvest unit is complete. This type of landing is best suited to steep terrain where simple widening of the subgrade results in excessive road cuts and fills or wastage of soil materials on the downslope side of the landing.

c. Terminal landing. Terminal landings typically occur at the end of a road where the yarder location is fixed and a continuous landing is no longer possible. A terminal landing is necessary where yarding occurs in a radius around a road terminus in a manner typical of high-lead. In this case, the advantage of yarder mobility is lost.

Terminal landings require loading and hauling during yarding operations because logs accumulate at the concentrated landing. This in turn requires construction of a larger landing or a skidding tractor to keep the landing clear. The following considerations are important for a terminal landing:

1. Landing must be large enough that the yarder output is not restricted and log decks are not piled high.

2. Landing should be well drained.

3. Landing must be large enough to provide space for the yarder, clear of trucks and loader, and provide good visibility for the yarder operator.

The terminal landing is obviously the least desirable of the landings for mobile-crane grapple yarding.

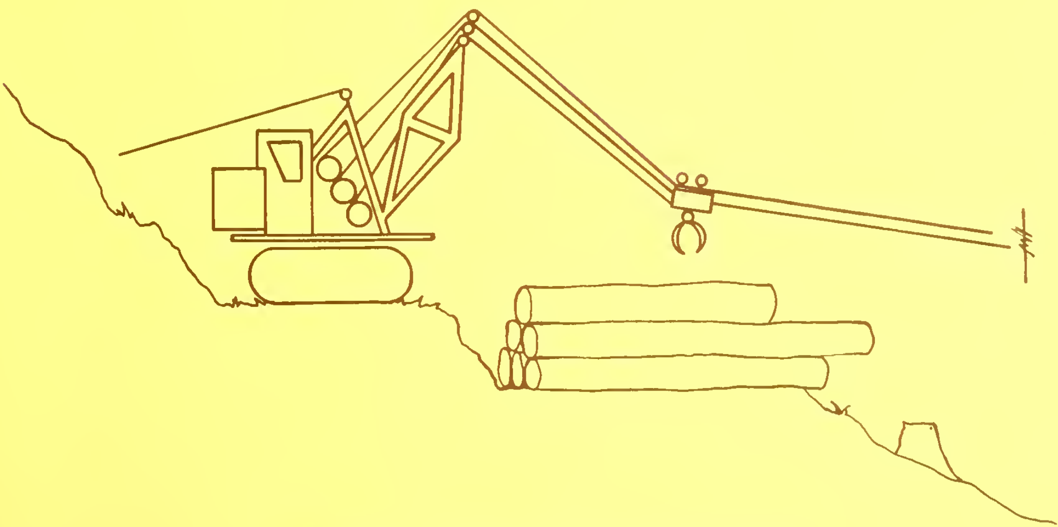

Figure 14.—Illustration of a split landing.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-187 September 1972

FREEZING DECAYED WOOD TO FACILITATE RING COUNTS AND WIDTH MEASUREMENTS

by

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and

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ABSTRACT

Accurate ring counts and radial growth measurements on decayed transverse wood sections are possible when rotted wood is frozen. Technique was successfully used during stem analysis studies of old-growth mixed conifers in the Oregon-Washington Cascade Range.

Keywords: Tree rings, forest measurement, wood decay.

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

To count rings of old-growth trees is difficult even under the best conditions, but to count such rings in rotten or partially decayed transverse sections of wood is nearly impossible, even when ring pattern is not completely obliterated.

The technique of freezing small, rotten wood samples to provide thin sections for microbiological investigation has been known for many years.[1] [2] However, stem analysis research using the freezing technique to facilitate annual ring count and examination on large, rotten wood sections does not seem to be reported. Although other embedding and non-embedding techniques useful in preparation of rotten wood samples for microtome sectioning are favored over the freezing method,[3] freezing is well suited for the less exacting sequential count and measurement procedures used in tree stem analysis work.

Among other techniques facilitating growth-ring counts and measurements in the field is that of wax impregnation. Ghent[4] used that method for collection of study material from badly deteriorated trembling aspen. However, his wax treatment also was designed more for facilitating growth-ring measurements from slides than from larger transverse wood sections.

During the course of research work, gathering old-growth stem analysis data for site index studies in the Oregon-Washington Cascade Range, we encountered occasional heart rot on a stump or breast-high section. No trees with visible indications of internal decay were selected, but because external indicators are not always present, occasional trees with rotten butt sections were felled. Regardless of rot, it was essential that ring counts and width measurements be made as accurately as possible.

Quite by accident the freezing method was "rediscovered." A large, central portion of a 400-year-old Douglas-fir that had been felled for stem analysis had a brown cubical butt rot[5] (fig. 1). Using conventional techniques in a rainstorm, we attempted to count the rings and measure sequential radial growth in the rotten heartwood. The decayed wood tissue crumbled easily and,

1/ Donald Alexander Johansen. Plant microtechnique. New York, McGraw-Hill Book Co., Inc., p. 106, 1940.

2/ John E. Sass. Botanical microtechnique. Ames, Iowa State Univ. Press, ed. 3, p. 93-94, 1958.

3/ Wayne W. Wilcox. Preparation of decayed wood for microscopical examination. Madison, Wis., Forest Prod. Lab., USDA Forest Serv. Res. Note FPL-056, p. 7, 1964.

4/ Arthur W. Ghent. The treatment of decayed wood from dead trembling aspen trees for growth-ring analysis. For. Chron. 30: 280-283, 1954.

5/ *Phaeolus schweinitzii* (Fr.) Pat. (= *Polyporus* Fr.). Cultural identification made by Paul E. Aho, Plant Pathologist, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oreg. Successful culture was made after 32 months of 0° F. cold storage, during which time the specimen partially dried.

Figure 1.--The 70-inch Douglas-fir stump near Mount Rainier from which the frozen, decayed wood sample for ring count and measurement was taken.

even though the thinnest, sharpest razor blade available was used, ring measurements and counts could not be made.

The following morning the rotten stump and breast-high-cut butt sections were frozen. Sequential radial ring-growth measurements and counts were made with ease. Razor knife cuts through the frozen, rotten wood clearly revealed the rings that had given so much trouble previously.

Following this, whenever rotten wood was encountered, provision was made to collect a radial transverse section containing an average or representative radius. The only difference between the collection of a radial section containing rot and one without rot was the thickness. Ordinarily, only 1-inch-thick rectangular sections, carefully cut with a chain saw, were collected for laboratory examination. Where decay was encountered, a 4- to 6-inch-thick rectangular piece was taken (fig. 2). This was then carefully sandwiched between quarter-inch plywood to forestall breakage and was transported to the laboratory. Before ring measurements and counts were attempted, the section was submerged in water for several hours and then frozen.

In addition to Douglas-fir, partially rotten radial sections of western white pine, western hemlock, and Pacific silver fir all have been successfully analyzed by the freeze method. Rings in rotten wood sections of other coniferous tree species, and perhaps even those of hardwoods, can be measured and counted accurately if the rotten wood still contains identifiable rings and is not unduly distorted.

Freezing wood sections, whether

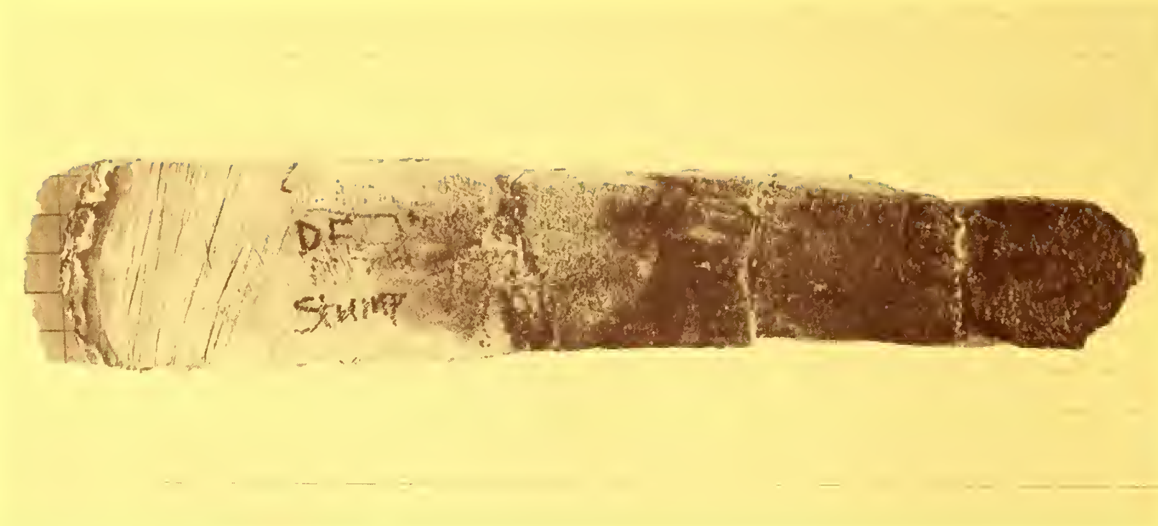

Figure 2.--Partially decayed Douglas-fir radial section which was frozen to provide accurate ring measurement data.

rotten or sound, changed wet-green radial dimensions but little. Radial dimension change within the decayed portions seemed to be more influenced by the amount of innate moisture present than by subsequent soaking and freezing. Rotten wood of the dry, cubical type in advanced stage of deterioration such as reported here was expanded radially only a small and indeterminate amount by soaking and freezing. Measurement errors incurred following these procedures are more reasonably assigned to the rot itself than to the freezing technique. Influence of soaking and freezing on dimensions other than radial was not observed.

Possibly the only precaution that must be taken is that sequential radial growth measurements and accompanying annual ring counts must be made quickly, before the frozen, decayed wood thaws. Should thawing obliterate the radius under observation, the section containing the decayed wood must be refrozen and a new razor-knife-cut surface prepared. Another solution, although not actually tried, would be to make the necessary counts and measurements in a room with temperature below 32° F.

Besides facilitating stem analysis and tree ring research in old-growth coniferous trees, the decayed wood freezing technique might prove advantageous for workers examining rotten wood for cull and defect prediction. Similarly, wherever ring measurements or counts are necessary, as in dendrochronological and tree growth studies, the freezing of rotten wood might provide answers that otherwise might not be available.

* * * * * *

GPO 986-579

ALASKA OREGON WASHINGTON PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-188 September 1972

AN INEXPENSIVE WATER SAMPLER

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W. B. Fowler, *Meteorologist*

Abstract

A stream sampler with no exterior energy requirements or moving parts has been designed and tested. A basic model has been described that has many options to fit particular sampling needs. Basic cost of the unit, excluding sampler mounting and structures needed to provide stream control, is less than $10.

Keywords: *Water analysis, sample designs (forestry), Poiseuille's Law, streams.*

INTRODUCTION

Increasing interest in maintaining the high standards of water quality in our forest streams has precipitated development and installation of a number of efficient stream water monitoring systems.[1/] [2/] Due to complexity and power requirements or both, these systems are not readily adaptable for monitoring in remote areas nor capable of simple and rapid installation.

Although samplers may be used in a variety of situations, several common requirements appear. These include:

(1) definable sample rate, either at a constant volume or proportional to changing stream head,
(2) dynamic sampling, i.e., no material maintained in an extended static presample status,
(3) freedom from inlet blockage, especially at low sampling rates.

Operation in remote locations requires additionally:

(4) minimal or no electrical power requirements,
(5) minimum of mechanical components,
(6) insensitivity to temperature changes,
(7) low cost.

A sampler meeting these requirements has been designed and field tested.

DESIGN

The collection rate selected for this sampler is between 0.1 and 20.0 cubic centimeters per minute. This rate is a direct function of the hydraulic head above the sample intake and rate of air released from the sample collection bottle. Hydraulic heads of less than 1 meter are desirable for operation of the sampler.

1/ R. L. Fredriksen. *A battery-powered proportional stream water sampler.* Water Resour. Res. 5(6): 1410-1413, 1969.

2/ Robert D. Doty. *A portable, automatic water sampler.* Water Resour. Res. 6(6): 1787-1788, 1970.

The basic system as shown in figure 1 consists of the following:

(1) 20-liter polyethylene carboy;
(2) rubber stopper;
(3) two glass tubes, 6-centimeter length, 3-millimeter inside diameter;
(4) flexible tubing; and
(5) small diameter capillary.

The carboy is submerged to the desired depth. Water enters the carboy through the 3-millimeter inside diameter glass tube. This tube is large enough to minimize clogging by suspended material, yet small enough to prevent water inflow by capillary action. For water to enter the airtight carboy, an equal volume of air must be released. The sampling rate for a given waterhead is dictated by a small diameter capillary, which is inserted at the end of the exhaust tube. Increasing the waterhead on the intake tube increases the carboy air pressure and, consequently, increases the air outflow and water inflow. The outlet airflow can be calculated from Poiseuille's Law for viscous flow of liquids (also air) through a tube. Given ℓ as the length of the tube in centimeters, r its radius in centimeters, p the difference of pressure along the tube in dynes per square centimeter, and η the coefficient of viscosity in poises or dynes second per square centimeter (the value for air at 20° C. is 1.82×10^{-4} poise), the volume of air escaping in cubic centimeters per second will be:

$$V = \frac{\pi p r^4}{8 \ell \eta}. \qquad (1)$$

The pressure head is the hydraulic head (1 cm. water = 1,000 dynes/cm.^{2}) at the outlet or lower end of the intake tube. Figure 2 shows the sample volume-hydraulic head relationship for a sampler controlled by one useful size of capillary (5.08-cm. (2-inch) 33-gage hypodermic needle).

The advantage that accrues from capillary control of the air at the outlet rather than water at the inlet is principally due to cleanliness of the displaced air and air's predictable flow characteristics through small orifices.

The sampler must be located at a stream control, natural or artificial, for sampling at a rate proportional to streamhead. A relationship between streamhead and streamflow would be required to determine total material carried by the stream. On small streams

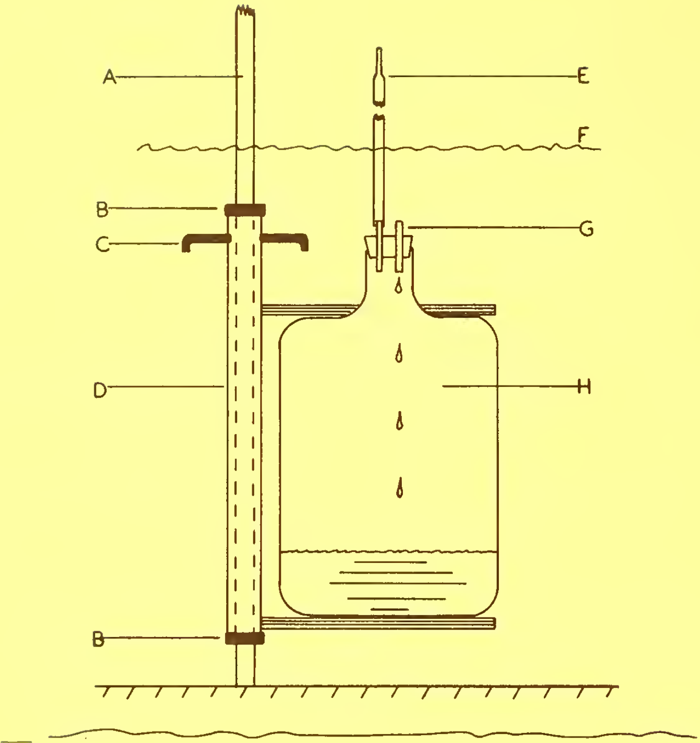

Figure 1.--Proportional water sampler: *A*, Stand pipe; *B*, position hold collars; *C*, position control handles; *D*, sampler support carriage; *E*, air pressure control capillary; *F*, stream surface; *G*, sample inlet; *H*, carboy. Elevation difference between the stream surface (*F*) and the bottom of the sample inlet tube (*G*) equals hydraulic head.

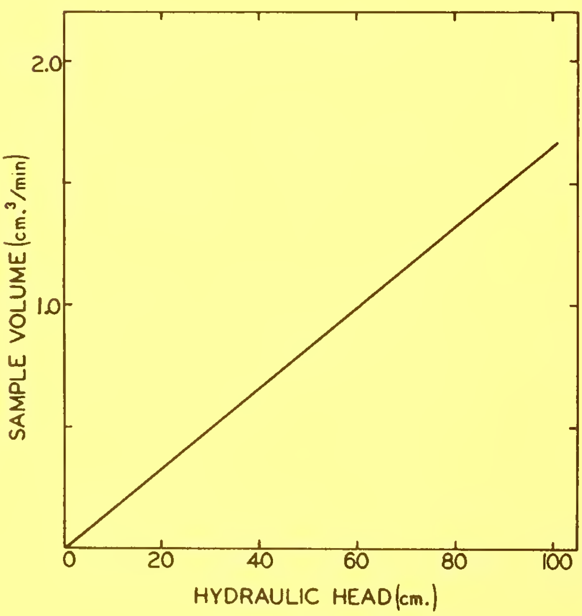

Figure 2.--Sample volume-hydraulic head relationship for a control capillary 5.08 cm (2 inches) long and 0.508 mm (0.002 inch) radius.

a control can easily be provided with a temporary weir. If the relationship between head and streamflow volume is not needed, a small rock dam or several wooden planks would be adequate. A number of modifications of the basic sampling system can be made to fit the particular sampling need and location.

The sampler is easily protected from climatic extremes. For some nutrient studies the collected samples should be kept at stream temperatures. Keeping the carboy in the stream provides this temperature control.

The sampler is calibrated in the laboratory. The stopper with its inlet tube and air release capillary is placed over a graduated cylinder. Varying the hydraulic head produces corresponding sample volumes per unit time in the graduated cylinder. These measurements provide the basis for a calibration similar to that shown in figure 2. The graduated cylinder or the collection vessel must be pressurized to equal the hydraulic head before initiating sampling. A rubber squeeze bulb temporarily connected to the collection bottle is used for this purpose.

Samplers are currently being used on three forest streams in north-central Washington. Two models are being used. The first is a continuous sampler as described above; the second, an intermittent sampler. The intermittent sampler uses a larger air release capillary (22-gage) and a solenoid valve in the air release line. This valve is periodically activated by a recorder mechanism and allows a volume of air to escape from the sample collection bottle. The capillary is required to prevent complete loss of pressure and unequal sample volumes as the collection bottle fills. No detectable difference between the two methods has been found in the water sample.

This sampler is incapable of adequate sampling of suspended sediments. Orifice diameter and flow rates are below required minimums.[3/] Any material carried by the input flow, however, is collected and represents some (unknown) fraction of the suspended load. This sample may be of some qualitative aid in evaluating sediment production from adjacent streams.

[3/] *St. Anthony Falls Hydraulic Laboratory. A study of methods used in measurement and analysis of sediment loads in streams. Minneapolis, Minn., Fed. Interagency Sedimentation Proj., Laboratory Investigation of Pumping Sampler Intakes, Rep. T, 1966.*

Reviewers pointed out three concerns with the sampler. One concern is that a 3-millimeter-diameter intake may clog in some streams. We have not experienced this difficulty. Quite possibly screens could be used to prevent clogging. Second, the horizontal stream velocity over the sampler intake tube was not taken into account in assuming a straight-line relationship between hydraulic head and sampling rate. Behind stream controls used for flow measurement, horizontal stream velocity is not recommended to exceed 0.5 foot per second.[4/] A 0.5-foot-per-second horizontal stream velocity across the intake tube would cause a water pressure head decrease of 0.1184 centimeter or a decrease in sampling rate of approximately 0.0013 cubic centimeter per minute. Higher velocities would cause larger error, but we believe this effect is negligible and need not be considered. Earlier we have pointed out that the sampling rate is proportional to streamhead. The sampling rate is proportional to stream volume only under conditions where water volume passing the stream control is proportional to streamhead.

4/ *Orson W. Israelsen and Vaughn E. Hansen. Irrigation principles and practices. New York, John Wiley & Sons, 447 p., 1962.*

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ALASKA OREGON WASHINGTON
PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION
· USDA FOREST SERVICE RESEARCH NOTE

PNW-189 September 1972

KEY TO ADULT BARK BEETLES COMMONLY ASSOCIATED WITH WHITE SPRUCE STANDS IN INTERIOR ALASKA

by

Roy C. Beckwith, *Principal Entomologist*

ABSTRACT

A dichotomous key enables the determination of adult Scolytidae commonly found in white spruce stands in interior Alaska including the Kenai Peninsula. Schematic drawings are included.

Keywords: Scolytidae, bark beetle, *Picea glauca*, white spruce, Alaska.

The family Scolytidae contains some of the more destructive forest insects in North America, especially in western coniferous forests. Many species of bark beetles infest spruce in interior Alaska; however, their distribution and importance are not well documented due to the difficulty of collecting over the large, often inaccessible land area. The insects are small, and their subcortical habitat makes them inconspicuous. Most species are collected from dead and dying trees during investigations of damaged stands.

Proper identification of a species is necessary to determine its present or potential importance. Some, such as the spruce beetle, *Dendroctonus rufipennis* (Kby.), can kill living trees, particularly those weakened by some factor or combination of factors. Other species are not of economic importance and simply aid in the breakdown of woody material.

The following simplified key was devised to help those interested in identifying bark beetles associated with white spruce stands in interior Alaska. The terminology follows that used by Swaine.[1/] The various species of *Ips* were separated according to Hopping.[2/] All characters are easily seen with an ordinary dissecting microscope. The material for the key was collected over a 3-year period in the Tanana River Valley and on the Kenai Peninsula. Species collected in interior Alaska and the known Alaskan hosts, including hosts in southeastern Alaska, are listed below:

SPECIES	HOST
Scolytus piceae	*Picea glauca; Larix laricina*
Crypturgus borealis	*Picea glauca; P. sitchensis*
Polygraphus rufipennis	*Picea glauca; P. sitchensis; P. mariana; Pinus contorta*
Phloeotribus puberulus	*Picea glauca*
Dendroctonus rufipennis	*Picea glauca; P. sitchensis; P. Xlutzii*
Phloeosinus alaskanus	*Picea glauca*
Scierus annectens	*Picea glauca*
Trypodendron lineatum	*Picea glauca; P. sitchensis; Tsuga heterophylla*
Cryphalus ruficollis	*Picea glauca*
Pityophthorus spp.	*Picea glauca*
Ips perturbatus	*Picea glauca; P. sitchensis*
Ips amiskwiensis	*Picea glauca*
Ips semirostris	*Picea glauca*
Ips borealis	*Picea glauca*
Dryocoetes affaber	*Picea glauca; P. sitchensis; Tsuga heterophylla; Pinus contorta*
Dryocoetes autographus	*Picea glauca; P. sitchensis*
Orthotomicus caelatus	*Picea glauca; P. sitchensis; P. mariana; Pinus contorta*

[1/] J. M. Swaine. Canadian bark beetles. Part II. A preliminary classification, with an account of the habits and means of control. Tech. Bull. Dominion Can., Dep. Agric. 14, 143 p., 1918.

[2/] G. R. Hopping. The North American species in group VI of Ips De Geer (Coleoptera: Scolytidae). Can. Entomol. 97: 533-541, illus., 1965.

G. R. Hopping. The North American species in group VII of Ips De Geer (Coleoptera: Scolytidae). Can. Entomol. 97: 193-198, illus., 1965.

G. R. Hopping. The North American species in group VIII of Ips De Geer (Coleoptera: Scolytidae). Can. Entomol. 97: 159-172, illus., 1965.

KEY TO ADULT BARK BEETLES

1. Fore tibia terminating in a prominent curved spine at the outer apical angle (fig. 1); abdominal venter ascends abruptly; medial spine present on the second abdominal sternite (see also fig. 12)[3/] . . . . *Scolytus piceae* (Sw.)

1. Fore tibia not terminating in a prominent curved spine at the outer apical angle (fig. 2); abdominal venter convex, not ascending abruptly; medial spine absent 2

   2. Base of head visible from above (fig. 3); pronotum not noticeably roughened in front . . . . (Hylesininae) 3

   2. Head concealed from above (fig. 4); pronotum noticeably roughened in front . . . . (Ipinae) 7

3. Eye divided; antennal club unsegmented (fig. 14) . . . . *Polygraphus rufipennis* (Kby.)

3. Eye not divided; antennal club segmented 4

   4. Antennal funicle seven-segmented . . . *Scierus annectens* Lec.

   4. Antennal funicle five-segmented 5

5. Antennal club sublamellate (fig. 15) . . . . *Phloeotribus puberulus* LeC.

5. Antennal club connate (figs. 16, 17) 6

   6. Fore coxae narrowly separated (fig. 5); elytral interspaces not elevated . . . . *Dendroctonus rufipennis* (Kby.)

   6. Fore coxae widely separated (fig. 6); elytral interspaces elevated, especially on the declivity . . . . *Phloeosinus alaskanus* Blkm.

7. Eye divided; antennal club unsegmented. . . *Trypodendron lineatum* (Ol.)

7. Eye not divided; antennal club usually segmented 8

   8. Antennal funicle two-segmented (fig. 13); small species, about 1 mm. long . . . *Crypturgus borealis* Sw.

   8. Antennal funicle more than two-segmented; moderate (1.5 mm.) to large in size 9

9. Antennal funicle four-segmented . . . .*Cryphalus ruficollis* Hopk.

9. Antennal funicle five-segmented 10

   10. Elytral declivity unarmed 11

   10. Elytral declivity armed with three or more tubercles or teeth (figs. 9, 10, 11). 13

[3/] For convenience of readers in making comparison, figures are not mentioned consecutively.

11. Pronotum evenly convex, not declivous anteriorly (fig. 7), granulated on entire surface . . . . (Dryocoetes) 12

11. Pronotum precipitous anteriorly (fig. 8), punctured on caudal area. . . . . *Pityophthorus* spp.

12. Pronotum widest near middle, sides arcuate; large species, greater than 3.5 mm. long . . . . *Dryocoetes autographus* Ratz.

12. Pronotum widest at base, sides nearly parallel; medium size species, less than 3.5 mm. long . . . . *Dryocoetes affaber* (Mann.)

13. Antennal club obliquely truncate; third declivital tooth displaced mesally . . . . *Orthotomicus caelatus* (Eichh.)

13. Antennal club flattened; all teeth on summit of lateral margin . . (*Ips*) 14

14. Lower part of frons protuberant; third declivital spine conical (fig. 11) 15

14. Lower part of frons not protuberant (figs. 9, 10) 16

15. Lower part of frons covered by a dense brush of hair or a short compact pile . . . . *Ips amiskwiensis* Hopp.

15. Lower part of frons without setal brush, a few scattered setae may be present . . . . *Ips semirostris* Hopp.

16. Third declivital spine capitate and acute at tip (fig. 9); face rough appearing, usually two larger tubercles in the medial area; larger species, greater than 4 mm. long . . . . *Ips perturbatus* (Eichh.)

16. Third declivital spine triangular (fig. 10); face smooth and shiny; small species, less than 4 mm. long. . . . . *Ips borealis* Sw.

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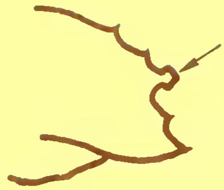

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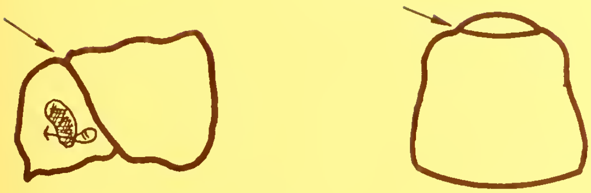

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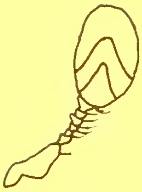
EXPLANATION OF FIGURES:

1. Fore tibia of *Scolytus piceae*
2. Fore tibia of *Ips* sp.
3. Schematic drawing of a Hylesininae
4. Schematic drawing of an Ipinae
5. Schematic drawing of *Dendroctonus* coxal cavity
6. Schematic drawing of *Phloeosinus* coxal cavity
7. Profile of *Dryocoetes* pronotum
8. Profile of *Pityophthorus* pronotum
9. Declivital armature of *Ips perturbatus*
10. Declivital armature of *Ips borealis*
11. Declivital armature of *Ips amiskwiensis*.



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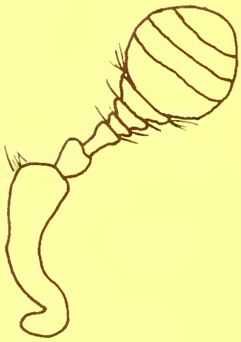

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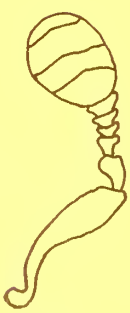

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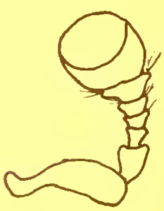

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FIGURES 12-24, Scolytid antenna

12. *Scolytus piceae*
13. *Crypturgus borealis*
14. *Polygraphus rufipennis*
15. *Phloeotribus puberulus*
16. *Dendroctonus rufipennis*
17. *Phloeosinus alaskanus*
18. *Scierus annectens*
19. *Trypodendron lineatum*
20. *Cryphalus ruficollis*
21. *Pityophthorus* sp.
22. *Ips* sp.
23. *Dryocoetes* sp.
24. *Orthotomicus caelatus*.

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ALASKA OREGON WASHINGTON
PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION
USDA FOREST SERVICE RESEARCH NOTE

PNW-190 *October 1972*

AN INEXPENSIVE METEOROLOGICAL RADIATION SHIELD FOR THERMISTORS AND THERMOCOUPLES

by

Richard J. Barney

Principal Fire Control Scientist

ABSTRACT

An inexpensive, easily fabricated meteorological radiation shield for thermistors or thermocouples is described. Comparisons made with standard wooden "Cotton Region" type shelters showed good agreement.

Keywords: Temperature, measuring equipment, thermistors, thermocouples.

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

INTRODUCTION

Many biological research and management activities require ambient air temperature measurements. It is also often desirable to make temperature measurements which are not affected by solar radiation. Comparability with standard wooden National Weather Service "Cotton Region" shelter or Stevenson screen measurements is often desirable or necessary. Wooden instrument shelters are costly and usually impractical to install in intensive sampling networks when only ambient temperatures are desired. Commercial radiation shields for use with thermistors or thermocouples are often too expensive in any quantity for many budgets.

This note describes a low-cost radiation shield. The shield is easily fabricated from locally obtainable items. Comparability and accuracy of this device are well within the range of several standard temperature transducers normally exposed in the classical wooden instrument shelter.

RADIATION SHIELD

The shield is basically a naturally ventilated variety. Several versions were constructed, one model fabricated from small aluminum pans, another from miniature aluminum piepans, and one version from small anodized aluminum ashtrays. The ashtray model was selected for field use primarily for esthetic reasons (fig. 1).

Figure 1.—Three models of radiation shields: left to right, small pan model, miniature piepan model, ashtray model.

CONSTRUCTION

We found that four pans or ashtrays made the shield deep enough, but five miniature piepans were necessary to insure adequate depth of the assembly. Aluminum bar stock, 3/4 by 1/8 inch and approximately 2 feet long (minimum), is needed for the braces, main support, and bottom radiation shield bracket (optional). The remaining materials are aluminum "pop rivets," backing washers, coathanger wire, primer, and paint.

Cut the aluminum bar into two 5-inch, one 4-inch, and one 10-inch (or longer) pieces. Using an appropriate size hold saw, cut the bottoms out of all but one of the pans. Drill three equally spaced holes in the pan rims. The pan edges can be bent down or flattened at the drilling point to facilitate this process. Determine the vertical distance between the holes in the pans while they are loosely nested. Drill the 10-inch and the two 5-inch bars to support the pans, as shown in figure 2.

The cutout bottom of one of the pans may be used as an optional bottom shield. Attach this bottom shield with the remaining 4-inch bar bent into an "L" bracket with pop rivets. A support for the thermistor or thermocouple is made from a piece of coathanger or other stiff wire. The wire should be long enough to secure to the main support by threading through two holes

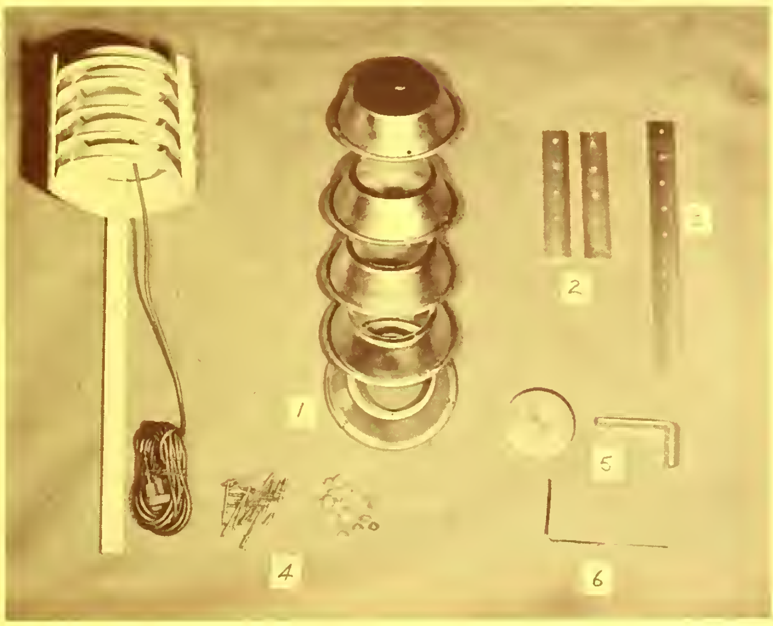

Figure 2.—Radiation shield parts ready for assembly, and an assembled model with a thermistor attached. 1—piepans, 2—braces, 3—main support, 4—"pop rivets" and washers, 5—bottom radiation shield and mounting bracket (optional), 6—thermistor or thermocouple mounting bracket.

about 1 inch apart and then reaching up into the middle of the radiation shield.

After it is assembled, the shield should be primed and painted with a gloss white enamel or lacquer. Sufficient coats of paint should be applied to insure an even and durable finish.

COMPARISON TESTS

A wooden "Cotton Region" shelter, three versions of the radiation shield, and an aluminum instrument shelter were fitted with thermistors to evaluate the radiation screens and compare them with a standard exposure. The five thermistors were fed into a 16-point sequencing Grant recorder.[1/] Observations were recorded hourly, and all five points recorded within 40 seconds for about a 2-week period in late May.

The Cotton Region shelter (fig. 3) was accepted as a standard and the other four shields were compared with this standard in a series of

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1/ *Use of brand names is for the convenience of the reader and does not necessarily indicate endorsement by the U.S. Department of Agriculture.*

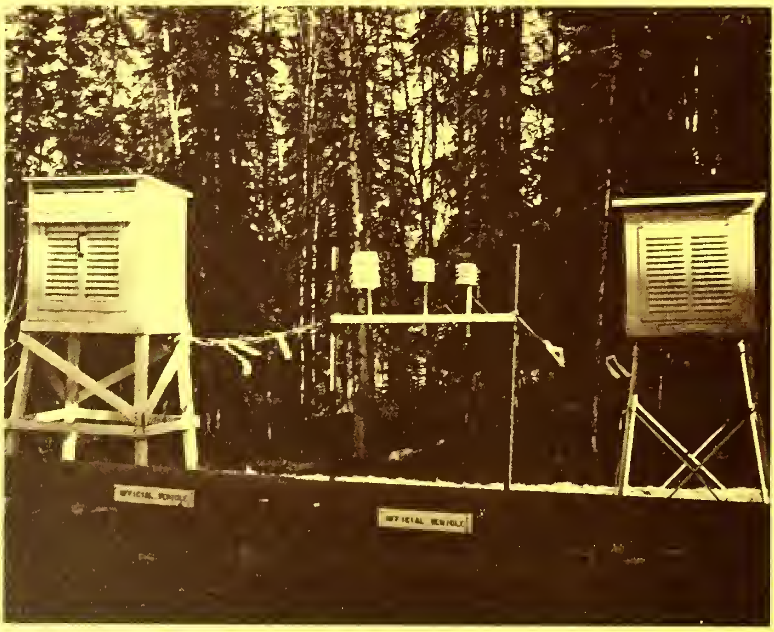

Figure 3.—Comparative test arrangement. Left to right, Cotton Region shelter, pans, miniature piepans, ashtrays, and aluminum instrument shelter.

chi-square accuracy tests.[2/] For these tests it was specified that the other shield would be acceptable if it could give temperatures which would be within 1.0° C. of the standard at the 95-percent probability level. All the other shields qualified under these criteria. None of the other shields qualified when the 1.0° C. criterion was reduced to 0.5° C.

Another field test was run in a different location using random observations over a 3-month summertime period, May through July. These data were used to compare the three radiation shields we built with the aluminum instrument shelter to see if they behaved similarly. Measurements were made with a Yellow Springs telethermometer calibrated in degrees F. The instrument was quite accurate and readable to 0.5° F. All three of our own radiation shields were within the ±1° F. (P=0.95) accuracy limitation established for the analysis when compared with the large aluminum shelter. Therefore, we assume the same general response characteristics in both our radiation shields and the aluminum shelter.

In a detailed report discussing the aluminum weather instrument shelter, the Forest Service compared this shelter with the standard Cotton Region type.[3/] Their results showed an increase in dispersion at daily maximum temperatures up to +2° F. and less than ±0.5° F. variation at minimum temperatures. Between 0° and 50° F., the aluminum shelter gave 1° F. higher readings than the standard Cotton Region shelter, and the difference was 2° higher between 51° and 100° F. This same general relationship also appears to exist with our radiation shields. Vogel and Johnson,[4/] in their tests of an aluminum shelter versus the standard wooden shelter, showed that greater differences occurred at the higher temperatures. Their aluminum shelter also gave generally higher readings than the wooden shelter. Essentially, the wooden shelter acts as an insulator and apparently responds less rapidly to temperature changes than do aluminum shields. Figure 4 shows the average dispersion by time of day and temperature established for the Cotton Region shelter. These deviations are well within the accuracy limitation of most of the standard temperature devices. Usually the accuracy of these instruments is ±1° C. or F.

2/ *Frank Freese. Testing accuracy. Forest Sci. 6: 139-145, 1960.*

3/ *USDA Forest Service. Aluminum weather instrument shelter. Missoula, Mont., Equip. & Test. Center, ED&TC Rep. 5100-13, 10 p., illus., 1964.*

4/ *T. C. Vogel and P. L. Johnson. Evaluation of an economical instrument shelter for microclimatological studies. Hanover, N.H., U.S. Army Cold Reg. Res. & Eng. Lab. Spec. Rep. 84, 4 p., illus., 1966.*

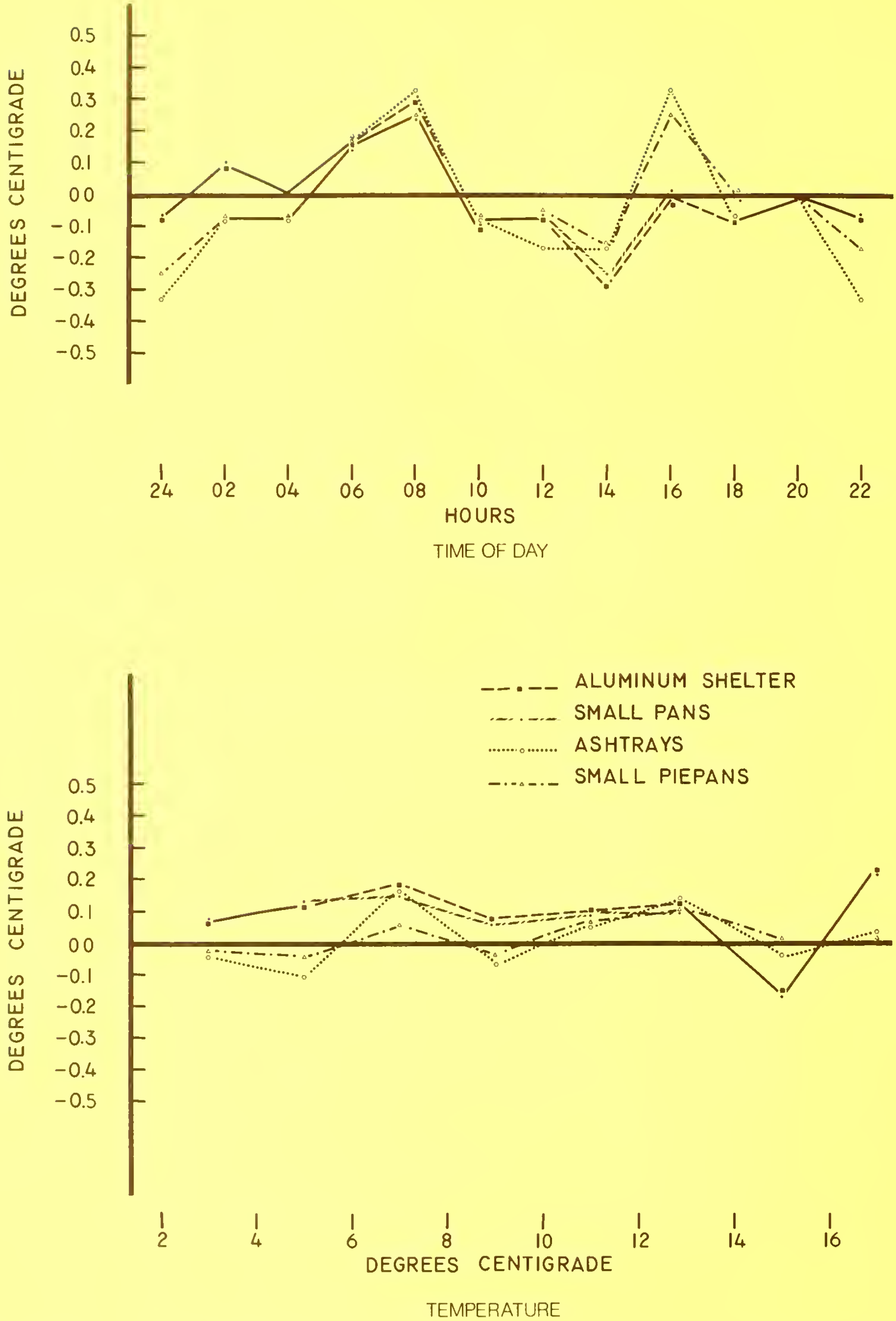

Figure 4.—Average temperature deviation for each of the four radiation shields as they vary from the Cotton Region shelter by time of day and temperature. The horizontal black line at zero represents the Cotton Region shelter temperature. (Note: When two or more traces coincided, a black line was used in plotting.)

SUMMARY

The inexpensive radiation shields discussed meet the requirements and standards of many research and management applications. Their low cost, ease of assembly, and general agreement with the standard radiation shields qualify them for repetitive temperature measurements in the field.

GPO 986-991

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PNW-191 November 1972

DRY VENEER VOLUME LOSSES IN PRODUCTION OF RED AND WHITE FIR PLYWOOD

by

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and

W. Y. Pong
Forest Products Technologist

ABSTRACT

Losses of rough, dry veneer between drying and panel trimming expressed as percentages provide a means to estimate output from dryer production volumes. Approximately 16 percent of the dry veneer volume was lost during production of plywood.

Keywords: Veneers (recovery), plywood, *Abies magnifica*, red fir, *Abies concolor*, white fir.

INTRODUCTION

This report presents a method for estimating the loss of dry veneer in manufacturing red and white fir plywood. Loss factors were developed from a volume loss study conducted at a typical veneer mill in northern California peeling red fir (*Abies magnifica* A. Murr.) and white fir (*Abies concolor* (Ford. and Glend.) Lindl.). Volumes used to determine the loss factors were measured at plywood production operations between the veneer dryer and the panel press.

The loss factors developed in this study can be used by the veneer mill production manager to estimate recovery of a known volume of random width strip and half and full sheets of dry veneer from red and white fir. The yield from dry, untrimmed veneer, as measured at the dryer, can be expressed in terms of the final square-foot volume, 3/8-inch basis, that will be available for layup. The losses of veneer volume on a 3/8-inch basis can also be determined at specific stages in panel production. Similar factors have been developed and reported for the manufacture of Douglas-fir veneer in Oregon and Washington.[1]

METHOD

Veneer from 983 peeler blocks with diameters ranging from 7 to 47 inches was used in this study. Table 1 presents the number and size of the study blocks by grade. Approximately 418,100 square feet, 3/8-inch basis, of dry untrimmed veneer was produced from these blocks. The peel consisted of three thicknesses: 1/10-inch (138,800 square feet), 1/8-inch (202,400 square feet), and 3/16-inch (76,900 square feet).

After it was peeled, all veneer was processed through normal plywood production channels: drying, reclipping, patching, glue spreading-panel layup, and panel trimming. Recovered volumes and incurred losses at each operation between the dryer and the press were measured and tabulated.

The loss factors shown in table 2 were calculated as follows: All full and half sheets were counted and recorded by veneer grade.

1/ Douglas L. Hunt and Richard O. Woodfin, Jr. Estimate of dry veneer volume losses in Douglas-fir plywood manufacture. Portland, Oreg., Pac. Northwest Forest & Range Exp. Stn. USDA Forest Serv. Res. Note PNW-134, 10 p., illus., 1970.

The width of each veneer strip was measured and tabulated by grade. These veneer tallies were later converted to a 3/8-inch thickness basis. All tallies were maintained by cartload lots, equivalent to approximately a 30-inch pile of full sheets. Recovery and loss volumes were determined for each of these loads as they were processed through the various stages of plywood production. Volume losses from these loads of veneer at each stage of production were later combined into a single value from which the loss factor for the entire operation was determined.

Volume loss for each cartload of veneer processed at the glue spreader was determined from the ratio of output to input. The output volume was determined by a count of the untrimmed glue-spread-layers of panel size. This count was converted into total inches of width.

Table 1.--*Number of study blocks by size and grade*[1/]

Small-end block diameter class (inches)	Blocks by grade				
	1	2	3	4	Cull
7- 9	1	2	29	0	1
10-12	2	9	133	5	0
13-15	5	4	121	23	0
16-18	4	7	87	31	2
19-21	6	7	67	39	0
22-24	5	11	47	30	0
25-27	7	12	37	31	0
28-30	3	8	26	24	0
31-33	6	12	14	19	2
34-36	1	6	16	12	1
37-39	0	7	11	12	0
40-42	3	3	8	6	0
43-45	5	4	2	4	0
46-48	0	2	1	0	0
Total	48	94	599	236	6

[1/] See "Lumber grade recovery from old-growth white fir on the Sequoia National Forest, California," by H. F. Wise and R. H. May, USDA Forest Serv. Calif. Reg. and Calif. Forest & Range Exp. Stn., Berkeley, 11 p., 1958.

Table 2.--*Average loss and recovery factors for dry veneer at different stages of plywood production*

Veneer item and stage of production	Distribution of veneer[1]	Loss factor	Recovery factor	Loss factor, standard error[2]
	- - - - - - - - - -	-*Percent*-	- - - - - - - - - -	
1/10- and 1/8-inch, D grade, full sheets:				
To reclipping	5.0	--	--	--
To layup	95.0	--	--	--
1/10- and 1/8-inch and A, B, and C grade, full sheets:				
To reclipping	5.0	--	--	--
To patching	95.0	--	--	--
1/10-inch, patched volume:				
To reclipping	4.4	--	--	--
1/8-inch, patched volume:				
To reclipping	3.5	--	--	--
All grades:				
To reclipping	--	14.17	85.83	--
Grades to glue spreader:				
1/8-inch, C grade, half sheets	--	3.16	96.84	2.93
3/16-inch, all grades, half sheets	--	2.32	97.68	1.37
1/10-inch, random width	--	13.62	86.38	2.36
1/8-inch, random width	--	16.31	83.69	3.30
3/16-inch, random width	--	15.35	84.65	3.90
All grades to panel trimming	--	10.54	89.46	--

1/ Percentage of veneer sent or returned to a production stage.
2/ Standard error is a measure of the variation among sample means.

Actual veneer losses of overhang and discards were tallied in inches of width. Veneer layer overhang is that extending beyond a maximum untrimmed panel size. Discards are veneer sheets too thin or too rough to be used.

LOSS FACTORS

Loss factors were developed for each production step from dryer to press; however, not all veneer grade items incurred losses at each stage. For example, only about 5 percent of the full sheet volume was reclipped (table 2). The remaining 95 percent of the volume of 1/10- and 1/8-inch, grade D veneer went directly to panel layup. The remaining volume of 1/10- and 1/8-inch, grades A, B, and C veneer was sent to the patch line. Approximately 4 percent of the 1/10-inch and 3 percent of the 1/8-inch patched volumes were sent to be reclipped (table 2, and item 6 in tables 4 and 5). The reclipping loss factor of 14.17 percent (table 2) was then applied to the patched-reclipped veneer. It was assumed that none of this veneer would return again to reclipping.

The application of the table 2 loss factors to the study volumes is shown in tables 3, 4, and 5 by veneer item and production stage. Table 3 shows the loss and recovery volumes of full sheets of 1/10- and 1/8-inch grade D veneer after reclipping, glue spreading, and layup. Tables 4 and 5 show the loss and recovery volumes of full sheets of 1/10- and 1/8-inch veneer, respectively, for grades A, B, and C.

Reclipping.--Reclipping losses were determined only for full sheets from tallies of the input to the reclipping operation and the output of usable veneer. The loss factor of 14.17 (i.e., approximately 14 percent--see table 2) was calculated from a ratio of the output to input tallies. Half sheets and random-width strips were not reclipped at this mill. Production equipment did not include an edge jointing and gluing operation.

Glue spreading-panel layup.--From the ratio of output to input at the glue spreader, a loss factor was determined which reflected actual veneer loss by thickness during glue spreading. In table 6, items 3 and 6 give the loss and factors for C grade, 1/8-inch, half sheets and for all grades of 3/16-inch, half sheets sent through the spreaders; in table 7, items 2, 4, and 6 give the loss and factors for 1/10-, and 1/8-, and 3/16-inch, random-width strip and fishtail veneer.

Table 3.--*Loss factors*[1] *applied to volume of full sheets of veneer, 1/10- and 1/8-inch, grade D*

Item and loss factor	Veneer volume	
	Recovery	Loss
	Square feet, 3/8-inch basis	
(1) Base volume[2]	63,200	--
(2) 5 percent to reclipping	3,160	--
(3) 95 percent to panel layup (item 1 minus item 2)	60,040	--
(4) Reclipping loss on item 2 (14.17 percent x 3,160)	2,712	448
(5) Spreader loss on reclipping (16.31 percent x 2,712)	2,270	442
(6) Volume to layup (item 3 + 5)	62,310	--
(7) Volume loss (item 4 + 5)	--	890

1/ Calculated from known square-foot volumes of veneer processed through the various stages of plywood production.

2/ The volume of veneer to which loss factors are applied.

Panel trimming.--Untrimmed panel size was approximately 51 by 101 inches. The trimming loss factor was calculated by multiplying the trimmed panel length (96 inches) by its width (48 inches) and then dividing this product by the product of the dimensions of the average untrimmed panel. The average loss was 10.5 percent (i.e., a loss factor of 0.1054, see table 2).

Full sheets of veneer are used in the condition and size they are when stacked out of the veneer dryer or at the patching equipment. The only production loss measured for full sheets was when the laid-up panel was trimmed to finished panel size. Losses from damage caused by poor handling procedures in the plant were not measured as a separate loss. Therefore, the volumes of full sheets were reduced only by the trimming loss.

Table 4.--*Loss factors*[1] *applied to volume of full sheets of veneer, 1/10-inch, grades A, B, and C*

Item and loss factor	Veneer volume	
	Recovery	Loss
	Square feet, 3/8-inch basis	
(1) Base volume[2]	32,000	--
(2) 5 percent to reclipping	1,600	--
(3) Reclipping loss on item 2 (14.17 percent x 1,600)	1,373	227
(4) Spreader loss on reclipping (13.62 percent x 1,373)	1,186	187
(5) 95 percent of (1) to patch line	30,400	--
(6) Patched volume to reclipping (4.4 percent x 30,400)	1,338	--
(7) Patched volume to layup (item 5 minus item 6)	29,062	--
(8) Reclipping loss on item 6 (14.17 percent x 1,338)	1,148	190
(9) Spreader loss on reclipping (13.62 percent x 1,148)	992	156
(10) Volume to layup (item 4 + 7 + 9)	31,240	--
(11) Volume loss (item 3 + 4 + 8 + 9)	--	760

[1] Calculated from known square-foot volume of veneer processed through the various stages of plywood production.

[2] The volume of veneer to which loss factors are applied.

Table 5.--*Loss factors*[1] *applied to volume of full sheets of veneer, 1/8-inch, grades A, B, and C*

Item and loss factor	Veneer volume	
	Recovery	Loss
	Square feet, 3/8-inch basis	
(1) Base volume[2]	46,900	--
(2) 5 percent to reclipping	2,345	--
(3) Reclipping loss on item 2 (14.17 percent x 2,345)	2,013	332
(4) Spreader loss on reclipping (16.31 percent x 2,013)	1,685	328
(5) 95 percent of (1) to patch line	44,555	--
(6) Patched volume to reclipping (3.5 percent x 44,555)	1,559	--
(7) Patched volume to layup (item 5 minus item 6)	42,996	--
(8) Reclipping loss on item 6 (14.17 percent x 1,559)	1,338	221
(9) Spreader loss on reclipping (16.31 percent x 1,338)	1,120	218
(10) Volume to layup (item 4 + 7 + 9)	45,801	--
(11) Volume loss (item 3 + 4 + 5 + 9)	--	1,099

[1] Calculated from known square-foot volumes of veneer processed through the various stages of plywood production.

[2] The volume of veneer to which loss factors are applied.

Table 6.--*Loss factors*[1] *applied to volume of half sheets of veneer*

Item and loss factor	Veneer volume	
	Recovery	Loss
	Square feet, 3/8-inch basis	
(1) Base volume,[2] 1/10-inch (all grades to layup)	36,800	--
(2) Base volume, 1/8-inch, grade C	3,900	--
(3) 1/8-inch spreader loss (3.16 percent x 3,900)	3,777	123
(4) Base volume, 1/8-inch, grades A, B, and D (all to layup)	47,400	--
(5) Base volume, 3/16-inch, all grades	54,800	--
(6) 3/16-inch spreader loss (2.32 percent x 54,800)	53,529	1,271
(7) Volume to layup (item 1 + 3 + 4 + 6)	141,506	--
(8) Volume loss (item 3 + 6)	--	1,394

[1] Calculated from known square-foot volumes of veneer processed through the various stages of plywood production.

[2] The volume of veneer to which loss factors are applied.

Table 7.--*Loss factors*[1] *applied to volume of random width (fishtail and strip)*

Item and loss factor	Veneer volume	
	Recovery	Loss
	Square feet, 3/8-inch basis	
(1) Base volume,[2] 1/10-inch, all grades	45,500	--
(2) 1/10-inch spreader loss (13.62 percent x 45,500)	39,303	6,197
(3) Base volume, 1/8-inch, all grades	65,500	--
(4) 1/8-inch spreader loss (16.31 percent x 65,500)	54,817	10,683
(5) Base volume, 3/16-inch, all grades	22,100	--
(6) 3/16-inch spreader loss (15.35 percent x 22,100)	18,708	3,392
(7) Volume to layup (item 2 + 4 + 6)	112,828	--
(8) Volume loss (item 2 + 4 + 6)	--	20,272

[1] Calculated from known square-foot volumes of veneer processed through the various stages of plywood production.

[2] The volume of veneer to which loss factors are applied.

Production loss factor.--A single overall loss factor is determined from a ratio of the final output volumes of all veneer by grade and size (as determined by the individual loss factors) to the original input volumes. This factor is 15.8 percent and represents the loss from the total volume of dry, untrimmed veneer tallied at the dry chain to the plywood panel volume at the shipping point. The calculation is illustrated below.

Veneer item and loss factor	Veneer input volumes	Veneer output volumes as determined by loss factors
	---Square feet,	*3/8-inch basis---*
Random width (strip and fishtail), 1/10-, 1/8-, and 3/16-inch, grades A to D	133,100	112,828
Half sheets, 1/10-, 1/8-, and 3/16-inch, grades A patch to D	142,900	141,506
Full sheets, all grades	142,100	139,351
Untrimmed total to layup	--	393,685
Trimmed total to layup, 393,685 minus panel trimming (10.54 percent x untrimmed total to layup)	--	352,191
Total input	418,100	--

$$\frac{352,191}{418,100} = 0.842 \qquad 1.000 - 0.842 = 0.158 \text{ loss factor}$$

Patch stock in a veneer mill is generally produced from several sources or purchased. The practice at this mill was to use random width, A-grade veneer, 15 inches and wider, for patch stock. Since no veneer of this grade and size was clipped from our study blocks, no loss factors are included for patch stock in this example.

Plywood panel sanding loss was not measured during these tests.

CONCLUSIONS

This study showed that approximately 16 percent of the dry, untrimmed veneer volume in red and white fir plywood production was lost between drying and panel trimming. This result is comparable to that found in similar studies of Douglas-fir, indicating that losses of 16 percent may be generally applicable to this phase of plywood production.

Several uses can be made of the loss and recovery factors reported here. A veneer mill peeling a comparable range of peeler block sizes and grades into similar veneer thicknesses can use these factors to estimate recovery or loss for specific veneer items and production stages.

The loss factors associated with each veneer thickness may offer guidelines to a veneer mill considering a change in thickness of peel or plywood panel composition. Production stages having higher loss factors can be identified. These could then receive the greatest attention for quality control.

A mill interested in determining the extent of its losses at the various processing points can apply these factors or conduct similar tests and compare results with those shown here.

When the study results are used, care should be taken to account for other factors which can affect levels of veneer loss but which were not examined in this study.

Two likely factors which could cause significant variation are low quality logs and any mill inefficiency. Low quality logs produce veneer with defects such as large knots; this generally results in a reduction in the total dry veneer volume recovered because of greater green veneer removal at the clipper. Though these losses may be quite substantial, this particular aspect of veneer production was not investigated for this report. Veneer losses attributable to mill inefficiency are often difficult to separate. For example, lack of control on veneer thickness would result in thick and thin veneer being produced. Such mismanufactured veneer would become apparent at the glue spreader, resulting in an increased loss from discarded veneer at that operation.

GPO 986-990

ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-192 November 1972

IMPROVED ADAPTER FOR INCREMENT BORER RATCHET ASSEMBLY

by

Francis R. Herman, *Mensurationist*

ABSTRACT

A stronger adapter for small-diameter increment borer ratchet assemblies can be fabricated easily. A thicker walled adapter can be machined, or a seamless carbon-steel sleeve can be shrunk around a custom-fitted standard square-holed sleeve. Mechanics' hand cream is recommended for lubricating during increment borer use.

Keywords: *Tree rings, tree diameter measurement.*

Modified ratchet wrenches facilitate taking of cores for studies of tree growth.[1/] A ratchet assembly suggested for small-diameter increment borers uses a square-holed sleeve and a stainless steel wire clip.[2/] Because variation in quality and durability of square-holed sleeves sometimes results in breakage, modification of the sleeve-adapter is recommended.

Modification can be accomplished in two ways: (1) standard square-holed sleeves can be reinforced or (2) a thicker walled adapter can be machined by use of a square broach. Because a square broach is expensive, a large number of adapters would have to be machined to justify its purchase.

Where few increment borer ratchet assemblies are needed, the

1/ John W. Duffield. A ratchet wrench for over-size increment borers. Forest Sci. 3: 21, illus., 1957.

2/ Francis R. Herman. A ratchet wrench and cleaning equipment for increment borers. J. For. 69: 26-27, illus., 1971.

standard square-holed sleeve regardless of quality can be strengthened to eliminate breakage of adapters. Figure 1 shows a strengthened square-holed sleeve adapter. Figure 2 shows details of an improved sleeve-adapter with a fitted seamless sleeve around the square-holed sleeve to provide additional strength. Such fitting, of course, would be unnecessary if thicker walled adapters were machined using a square broach.

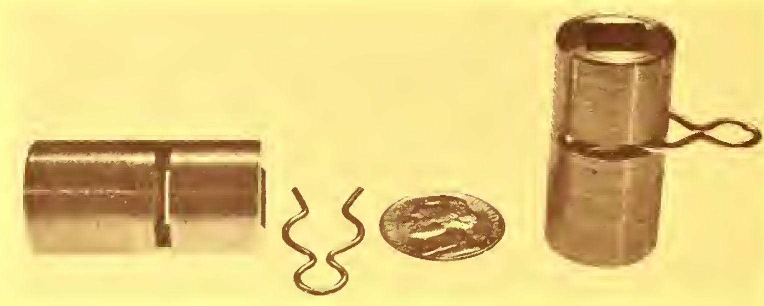

Figure 1.--Improved square-holed sleeve adapter with reinforcing sleeve and custom-fitted stainless-steel clip.

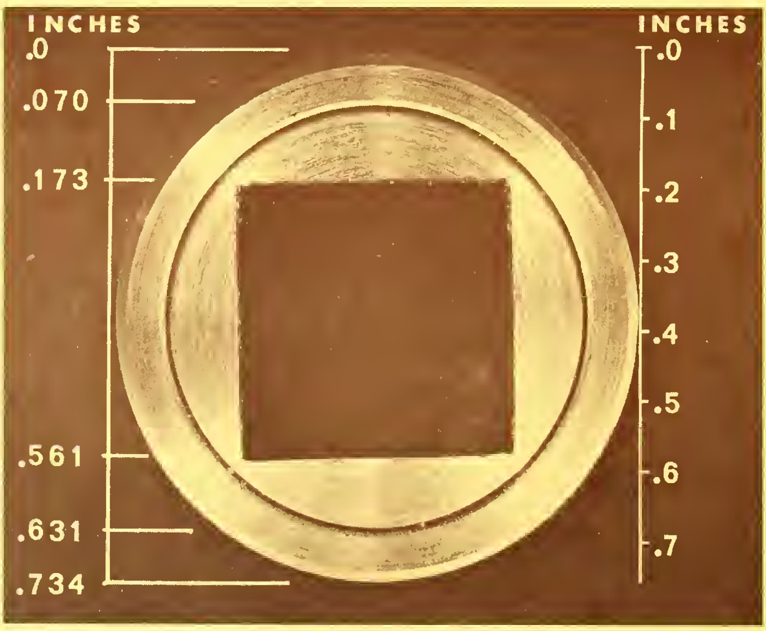

Figure 2.--End view of improved sleeve adapter. Measurements are in thousandths of an inch.

Variations in dimensions through the photographed cross sections of the adapter (fig. 2) are shown only to demonstrate machining tolerance. The thickness of the reinforcing wall around the outside of the standard 3/8-inch square-holed sleeve is optional. However, it should be no thinner than one-sixteenth inch (0.062 inch) according to consulting machinists.[3]

Length of adapter and positions of slots for stainless steel retaining clip must be determined for each increment borer. Clip should be custom-fitted to eliminate slack along thrust-axis of borer bit.

Figure 3 shows a 0.177-inch diameter, 26-inch-long ratchet-equipped increment borer assembly with improved square-holed sleeve adapter.

In addition to keeping a borer bit cleaned and well-oiled[4] (also see footnote 2), a borer lubricant can be used to further ease the boring operation and reduce strain on increment borer equipment. Mechanics' hand cream[5] applied to a borer bit at point of stem entry reduces torque required to both drive bit into and remove it from the stem. Bit may be dipped in a small container of the

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[3] The square-holed sleeve was modified for the author by the Physics Department of Oregon State University at Corvallis. A seamless carbon-steel sleeve with an inside diameter 1- to 1.5-thousandth inch smaller was shrunk around a standard 3/8-inch-square-holed sleeve. The temper of the square-holed sleeve was undisturbed because only the carbon-steel reinforcing sleeve was heated to facilitate its fitting. By using information in this note and referring to the original article (see footnote 2), any good machinist can fabricate similar adapters.

[4] Herschel G. Abbott. A technique for cleaning increment borers. J. For. 55: 909, illus., 1957.

[5] Credit is given to Harlow B. Scott, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, Olympia, Washington, for the suggestion that hand cream facilitates boring operations.

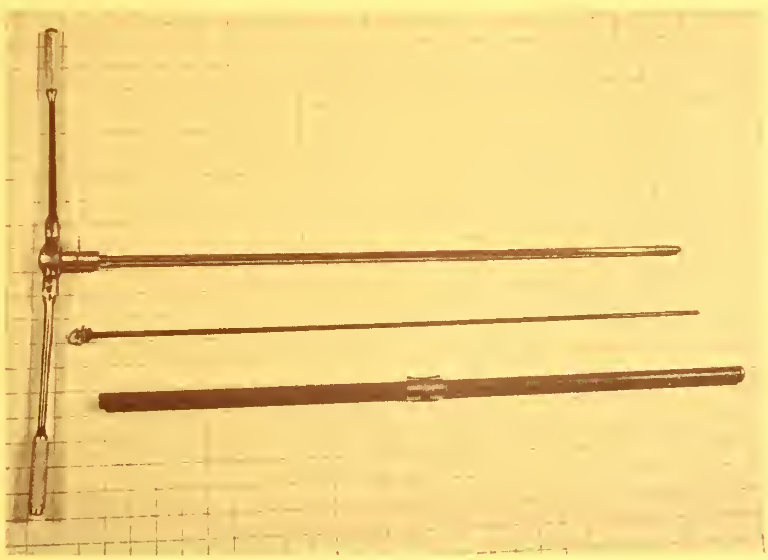

Figure 3.--A 26-inch-long increment borer with improved adapter and ratchet assembly.

hand cream. A portion of cream inside the hollow auger end at the beginning of each boring operation lubricates the core and minimizes troublesome core fracturing.

Select a hand cream that is stable in warm weather and doesn't contain pumice or other abrasive. Those hand creams that liquefy upon exposure to warm air temperatures are not as desirable for lubrication of borer and core as are those that maintain a creamy consistency. A cleaning cream, if used consistently, also keeps resin and varnish deposits soft so that cleaning is quickly accomplished. Incidentally, such hand creams are efficient for cleaning resin from all kinds of tree measurement equipment with no damage to painted or polished surfaces.

GPO 987-022

ALASKA OREGON WASHINGTON
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
USDA FOREST SERVICE RESEARCH NOTE

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SOUND INSULATION IN A MODULAR MOTEL

by

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and

T. B. Heebink, *Structural Engineer*

ABSTRACT

Field-measured resistance to sound transmission in a two-story modular motel assembled from factory-built, three-dimensional wood-framed units was generally acceptable. Walls and floors separating rental units had field sound transmission classes (FSTC) of 47 and 49, respectively; floors had impact insulation classes (IIC) of 71 and 42 for carpeted and tile covered areas, respectively. A series of laboratory tests was conducted on the motel wall as built and as modified in four ways, to determine the best arrangement of structural materials for sound insulation. The tests demonstrated that the exterior sheathing, which improves the rigidity and resistance to weather of three-dimensional units during transportation and erection, may reduce sound insulation slightly.

Keywords: *Acoustic insulation, prefabricated buildings, wood construction.*

INTRODUCTION

Modular motels--built from three-dimensional units which are completely factory finished so as to require only connection in the field--have gained popularity with some builders. It could be assumed that motels constructed with factory-built modules will provide excellent resistance to sound transmission because of the double partitions that are formed when modular units are joined horizontally or vertically.

In October 1971, we had an opportunity to measure the sound insulation achieved in a two-story motel complex assembled from 102 factory-fabricated modules. Almost every module represented a single living unit, and these were arranged as shown in figure 1.

The resistance to airborne sound transmission of the party wall formed between two second-story units and that of a floor-ceiling assembly formed between a first- and second-story unit was measured in the field in accordance with the detailed procedures described in American Society for Testing and Materials (ASTM) Designation E336-71.[1/] Resistance of the floor-ceiling assembly to impact sound transmission also was measured in accordance with the procedures of International Organization for Standardization (ISO) R/140.[2/]

The floor-ceiling combination and the party wall that resulted from stacking individual modules is illustrated in figure 2. The party wall between units was composed of two separate walls an inch apart and could be expected to provide excellent resistance to sound transmission because the inner wall surface of one living unit is so well isolated from the inner wall surface of an adjacent unit. Likewise, excellent resistance to vertical noise transmission might be expected because of the isolation between the floor frame of a second floor unit and the ceiling frame of a first floor unit.

In fact, both the party wall and the floor-ceiling assembly did provide an acceptable level of airborne sound insulation with field sound transmission classes (FSTC) of 47 and 49, respectively. The impact insulation class (IIC) of the floor-ceiling assembly, when determined with carpet and pad in place, was an acceptable 71.

However, experience indicates that these same levels of sound insulation could have been obtained with simpler construction or less material. The designer had hoped for somewhat higher levels of sound insulation.

1/ American Society for Testing and Materials. Designation E336-71. Annual ASTM Standards, Part 14, 1971.

2/ International Organization for Standardization. Designation ISO R/140. Field and laboratory measurements of airborne and impact sound transmission, 1960.

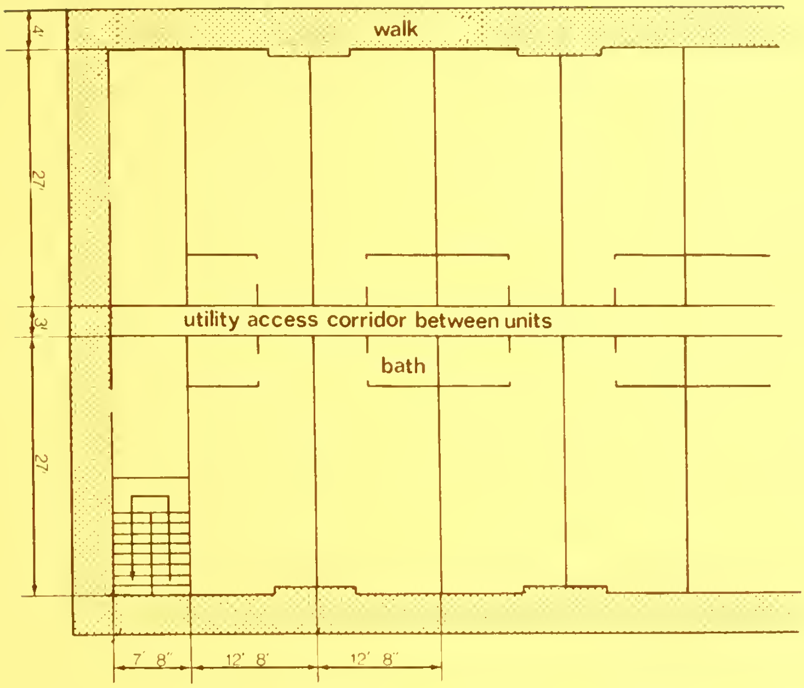

Figure 1.--Floor plan (first and second floors).

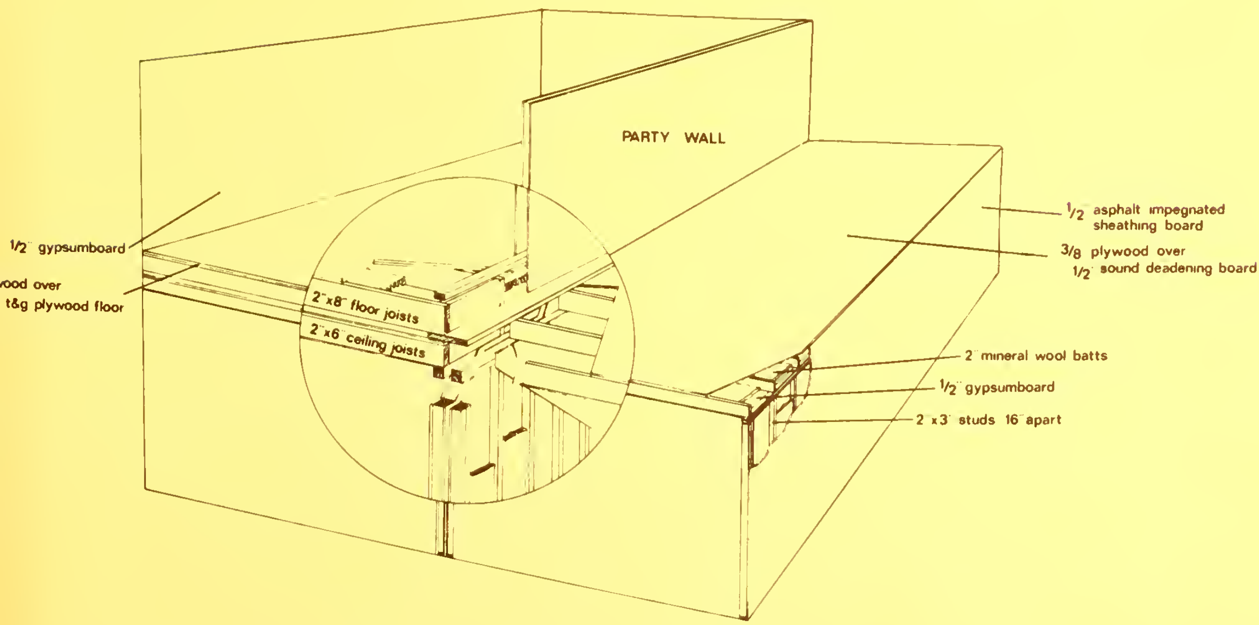

Figure 2.--Construction details of three modules as assembled.

It was hypothesized that the exterior materials which were used to stiffen the modules and protect them from weather during transportation and erection may have reduced rather than increased the overall resistance to sound transmission.

To demonstrate this possibility, we measured the airborne sound transmission of the party wall as it was built in the field. Then we modified the wall in four ways and measured the airborne sound transmission in an acoustical laboratory.[3] The modifications included: (1) removing the exterior fiberboard sheathing from each wall frame (fig. 3b); (2) adding 1/2-inch-thick sound-deadening board on one wall and laminating the gypsum board over it (fig. 3c); (3) replacing the fiberboard sheathing of the original wall with nail-glued 3/8-inch plywood sheathing (fig. 3d); and (4) adding 2½-inch-thick insulation in the 2-inch space between the plywood sheathing of the wall illustrated in figure 3e. The nail-glued plywood sheathing was investigated because designers occasionally use this construction to obtain girder-like action from the module wall and thereby eliminate the need for continuous support.

DISCUSSION OF RESULTS

Party Wall Tests

The wall as assembled (fig. 3a) and tested in the field had an FSTC of 47. When fabricated and tested as a 9- by 14-foot wall in the laboratory, the STC was 49. This minor difference between field and laboratory performance is in keeping with field testing experience and indicates that no serious flanking of the wall occurred in the field.[4] Flanking is sound transmission by paths other than directly through the partition.

After testing the simulated field assembly in the laboratory, we removed the fiberboard sheathing and reassembled the wall for a second test. In the second test, the STC of the wall was 51. The transmission loss curves for the wall, with and without fiberboard sheathing, are compared in figure 4. The STC of 51 agrees with previous laboratory tests of such a wall construction.[5] Thus, the removal of the sheathing improved the STC of the wall instead of reducing it.

The next modification of the original wall was to add 1/2-inch-thick sound-deadening board under the gypsum wallboard on one side--thereby representing a more effective

[3] The laboratory, made available through courtesy of Simpson Timber Co., was designed to measure sound transmission by the Acoustical Materials Association (now Acoustical & Insulating Materials Association) test procedure AMA-1-II. Sound transmission loss of all walls was measured in accordance with the AMA-1-II procedure. In addition, the sound transmission loss of the first wall was measured in accordance with ASTM E90-70. The room volumes of the laboratory (1,760 cubic feet) were smaller than those recommended for measurements of transmission loss at a frequency 125 Hertz but were acceptable. Both procedures gave an STC of 49.

[4] T. B. Heebink and J. B. Grantham. Field/laboratory STC ratings of wood-framed partitions. Sound & Vibration 5(10): 12-16, 1971.

[5] Western Wood Products Association. Sound control. Portland, Oregon, 1971.

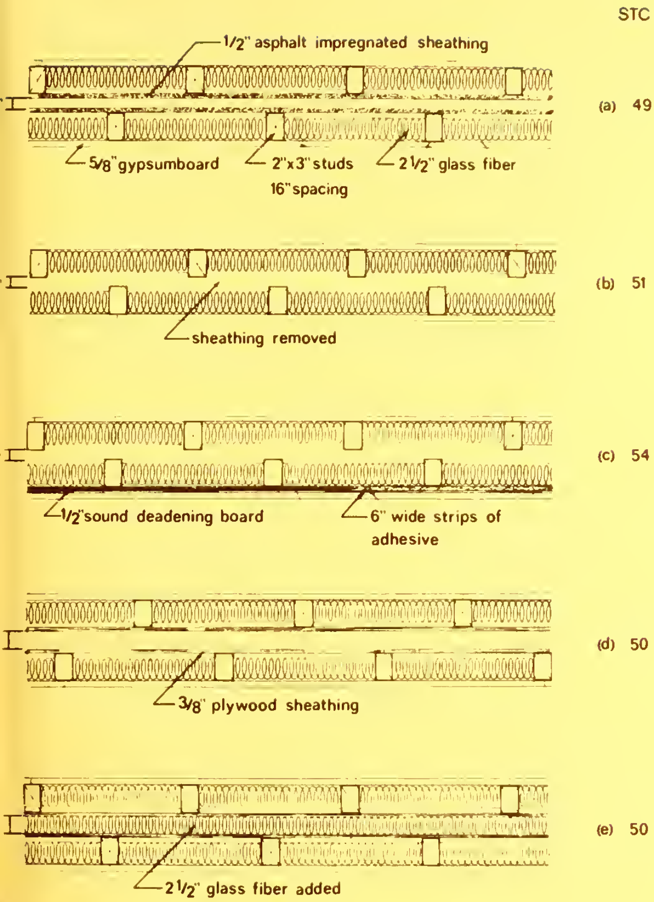

Figure 3.--Construction of the wall as formed in the field (a) and as modified in four ways for laboratory testing (b, c, d, e).

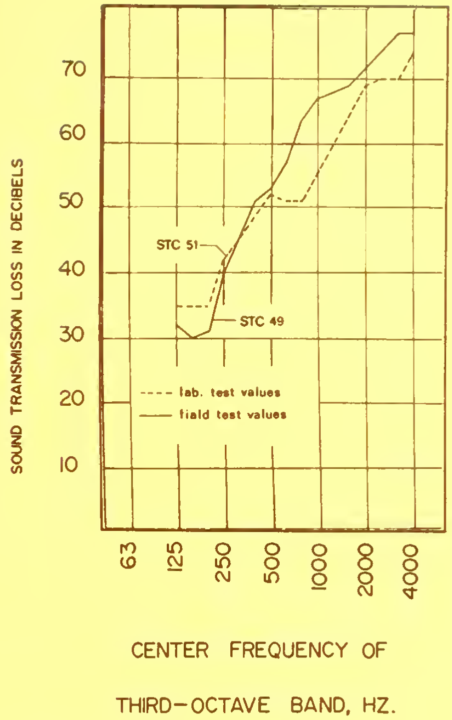

Figure 4.--Improvement in airborne sound insulation of a double wood-framed wall--achieved by increasing the transmission loss at low frequencies.

use of material (replacing two 1/2-inch-thick layers of fiberboard sheathing). The gypsum wallboard face was then strip laminated and nailed[6] over sound-deadening board. This modification was made without disturbing the wall frame. When the wall was tested, the STC was 54 (fig. 4). Thus, the removal of the two layers of fiberboard sheathing, plus the addition of one layer of fiberboard under the gypsum board, improved the STC from 49 to 54.

[6] The 7d nails were spaced 12 inches apart around the perimeter of the sheet and at the one-third points on the intermediate studs.

A further modification of the wall incorporated 3/8-inch plywood--to simulate plywood sheathing on the outside of the module. The nailed and glued plywood covered the full wall height. (In actual practice, the plywood would extend from the bottom of the floor joists to the top of the ceiling joists to give maximum strength and stiffness to the wall.) This wall construction was the same as for the field-tested wall (fig. 3a), except nail-glued plywood replaced the 1/2-inch-thick fiberboard sheathing and the space between the two parts of the wall (between sheathing) was increased from 1 to 2 inches. The STC of this wall was 50 or about the same as that of the wall used in the motel.

A minor modification of the plywood-sheathed wall was made by separating the wall and adding 2½-inch-thick glass fiber in the 2-inch space. The STC of the wall was unchanged by this addition.

Floor-Ceiling Tests

The floor-ceiling assembly formed when one modular unit was set atop another (as illustrated in figs. 2 and 5) was tested only in the field. The FSTC of 49 indicates good resistance to airborne sound transmission. Field-measured resistance to impact sound transmission gave an IIC of 71 for the carpeted floor and 42 for the small area of vinyl tiled floor. The above values are in line with the sound insulation provided in good motels but are not as high as might be expected for a double joist system--with separate floor and ceiling joists (fig. 5). A test was conducted at the Michael J. Kodaras Laboratories (their number KAL-224-15) of a relatively simple double-joist floor-ceiling system (see fig. 5). An IIC of 80 was realized without benefits of sound-deadening board or extra plywood over the ceiling joists. Comparing results, then, shows that neither the combined plywood sound-deadening-board top cover of the first floor modules nor the thermal insulation in the ceiling joist space contributed to the sound attenuating properties in the modular construction.

A review of laboratory ratings of floor-ceiling assemblies (see footnote 5) reveals that sound-deadening board is effective in reducing sound transmission if applied between the subfloor and underlayment (as could be accomplished in the floor of the upper units). For maximum acoustical benefit, the underlayment should be glued, not nailed, to the sound-deadening board. Benefits thus obtained are similar to those obtained in the wall illustrated in figure 3c as compared with the wall illustrated in figure 3b.

Mere omission of the plywood sound-board cover from the lower modules is believed to improve the resistance to low-frequency sound transmission and raise the field test

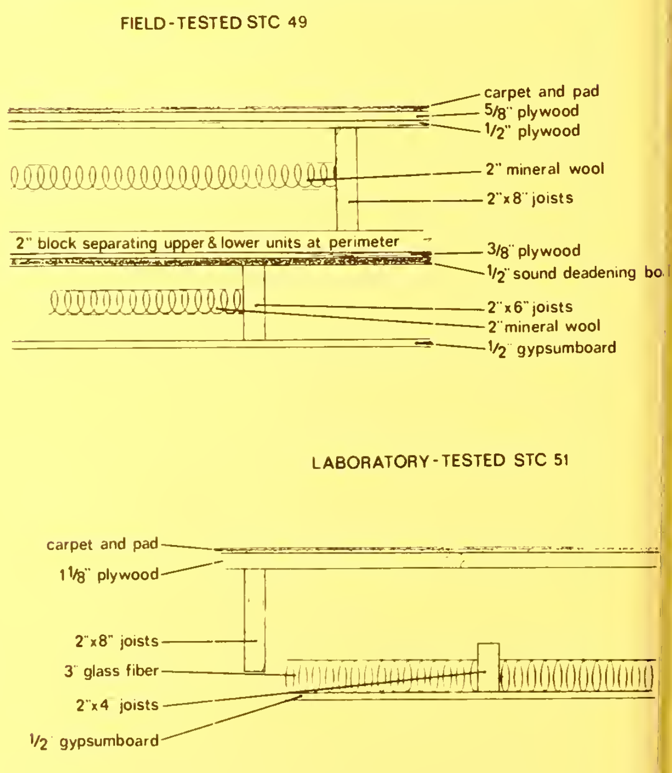

Figure 5.--Floor-ceiling assemblies with separate floor and ceiling joists.

values shown in figure 6 almost to those of the laboratory test values. A similar omission improved the wall rating from 49 to 51 (fig. 4). Omission also of the plywood sound-deadening-board cover may reduce the peak values of impact sound pressure level (fig. 7) and thereby improve the IIC ratings of the modular assemblies.

Omitting the plywood sound-deadening-board cover from first floor modules could improve the resistance to sound transmission but would decrease resistance to racking during transportation and erection. We hope the report of these tests will aid designers and builders of modular wood-framed buildings, in their choice of materials and assemblies, to provide the required (or desired) strength and sound insulation at lowest cost.

CONCLUSIONS

The possibility that covering materials used to stiffen and protect three-dimensional factory-built motel

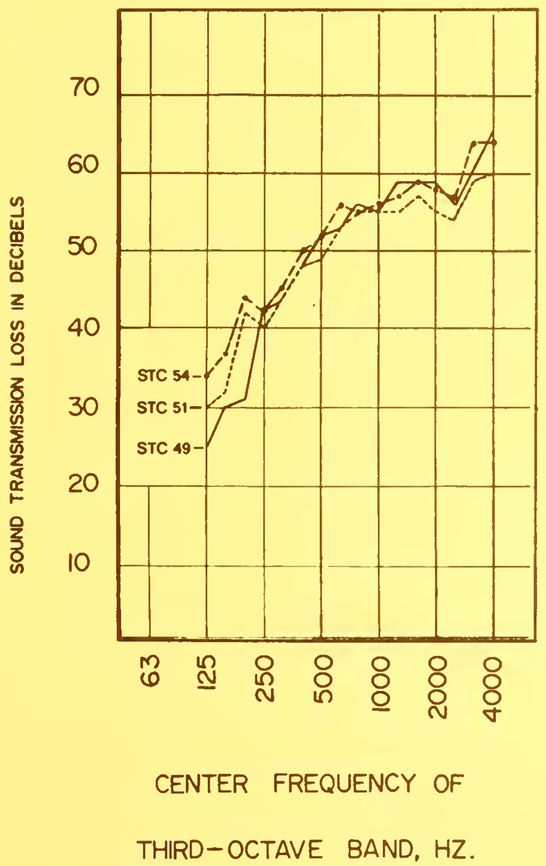

Figure 6.--Comparative resistance to airborne sound transmission of assemblies with separate floor and ceiling joists.

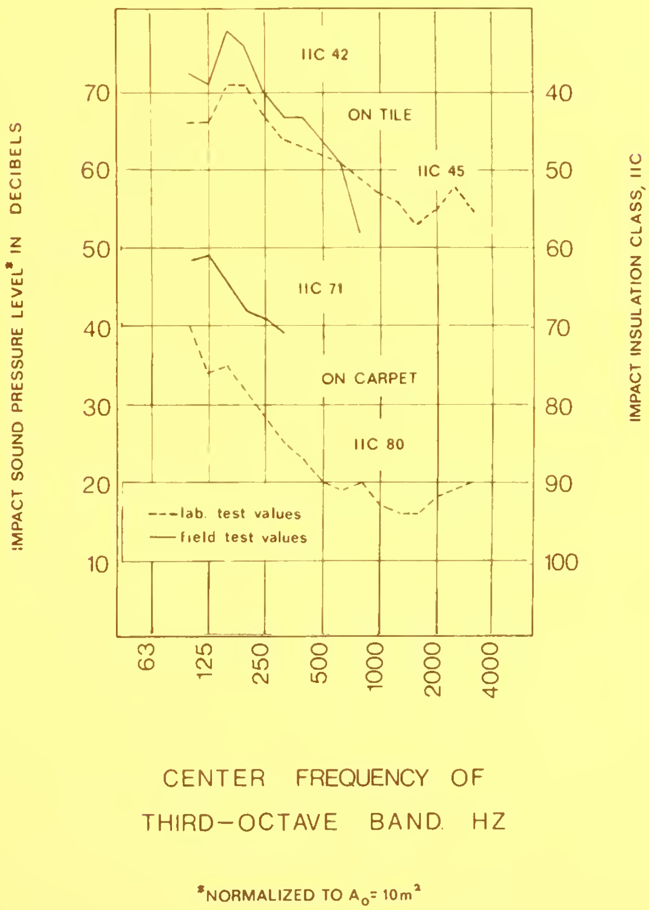

Figure 7.--Comparative resistance to impact sound transmission of assemblies with separate floor and ceiling joists.

units during transportation and erection may be ineffective in insulating against sound transmission has been demonstrated in one instance.

Acoustical measurements in a well-designed modular motel revealed that the airborne sound insulation of the dividing walls and floor-ceiling assemblies between living units was acceptable (STC 47 and 49, respectively), and the impact sound insulation of the carpeted floors was excellent (IIC 71). However, the contribution of the protective coverings used on the modular units, including a combination of plywood sound-deadening-board cover over the ceiling joists and 1/2-inch-thick asphalt-impregnated sheathing on the outer walls, did not improve sound insulation over what experience indicates should be expected without such covering materials.

As a test of this belief, the wall construction used in the motel was reconstructed in a laboratory and its resistance to airborne sound transmission determined as STC 49 under carefully controlled conditions. When retested with the 1/2-inch-thick sheathing removed, the sound insulation was improved (STC 51). When 1/2-inch-thick sound-deadening board was applied beneath the gypsum board to only one side of the double wall, the sound insulation was improved still further (STC 54).

Thus, the amount and disposition of construction materials which may be ideal for structural rigidity may not be the most effective arrangement for acoustical performance. The designer's task is complicated, therefore, by a need to achieve the best compromise between weather protection, strength, sound insulation, and cost.

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ALASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

· · USDA FOREST SERVICE RESEARCH NOTE

PNW-194 *February 1973*

TREE GROWTH AND WATER USE RESPONSE TO THINNING IN A 47-YEAR-OLD LODGEPOLE PINE STAND

by

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ABSTRACT

Results from a 5-year lodgepole pine levels-of-growing-stock study showed trees grew more rapidly in diameter but less rapidly in height after a first thinning at age 47. During this period, there was no substantial transfer of growth from the cut trees to the better remaining individuals. Soil moisture withdrawal was substantially reduced at lower stand densities. This unused soil moisture is potentially available for increased streamflow. Some of the site potential released by thinning may also show up as understory forage.

Keywords: Stand density, thinning (trees), soil moisture, lodgepole pine, tree diameter measurement, tree increment measurement.

INTRODUCTION

Gross wastage of valuable productive capacity occurs where overly dense stands produce large volumes of wood on many small trees that cannot reach usable size. When reduction in number of stems can increase growth rate of the remaining individuals, wood production on usable size trees increases, provided the thinning is not too drastic. Furthermore, during the first years after thinning before the reduced number of trees can fully occupy the site, the unused productive capacity will probably show up as increased water production, or as greater understory growth that may have forage value for grazing animals.

A series of levels-of-growing-stock and spacing studies have been installed in eastern and central Oregon lodgepole pine stands. These are designed to quantify relationships between stand density and wood, water, and forage production. First 5-year results from the Snow Creek levels-of-growing-stock study established in a 47-year-old stand are presented in this paper.

STUDY, SITE, AND METHODS

The study is located on the Deschutes National Forest about 50 miles southwest of Bend, Oregon.

Site is about average for central Oregon, 52 feet at index age 50 years.[1/]

[1/] Site index based on height of the tallest tree per one-fifth acre at index age 50 years as read from curves in Dahms (1964).

Vegetation is similar to the lodgepole pine/bitterbrush community described by Youngberg and Dahms (1970). Plants found included antelope bitterbrush (*Purshia tridentata*), wax currant (*Ribes cereum*), western needlegrass (*Stipa occidentalis*), bottlebrush squirreltail (*Sitanion hystrix*), Ross's sedge (*Carex rossii*), strawberry (*Fragaria virginiana*), and western yarrow (*Achillea lanulosa*).[2/]

The soil is a well-mixed pumice about 27 inches thick over a sandy loam mixed with gravel and cobbles that appear to be glacial outwash. The pumice contains well-rounded nonpumiceous pebbles mixed through the entire profile. Water table is high during the spring snowmelt period and on through much of June.

The stand was fairly dense prior to thinning. Crown competition factor values ranged from a low of 144 on one plot to a high of 219 on another (table 1). The prethinning range in basal area was from 110 to 140 square feet per acre. Crowns on most trees were short and narrow.

The experiment consists of ten 1/5-acre plots individually surrounded by a 1/2-chain buffer strip. Each of five levels-of-growing-stock treatments was randomly assigned to two plots per level. The first thinning was in the fall of 1962; the next thinning was at the end of 5 years, in 1967. Later thinnings are planned at 10-year or longer intervals.

[2/] Plant names as listed in Hitchcock et al. (1955-69).

Table 1.--*Stand statistics per acre before thinning and for material removed by thinning*

Growing stock level and plot	Number of stems	Average d.b.h.[1]	Basal area	Bole area	Volume[2]	Crown competition factor	Site index
		Inches	---*Square*	*feet*---	*Cubic feet*		
1 (lowest):							
3	1,325	4.1	135.0	30,374	2,475	206	50
9	1,830	3.3	125.3	27,932	2,210	219	45
Average	1,578	3.6	130.2	29,153	2,342	212	47
2:							
1	665	5.2	110.2	19,624	1,933	144	55
7	1,430	3.9	140.2	31,911	2,667	214	50
Average	1,048	4.6	125.2	25,768	2,300	179	53
3:							
8	868	4.9	128.8	25,953	2,425	173	54
10	1,900	3.1	118.3	24,416	2,109	214	49
Average	1,384	4.0	123.6	25,184	2,267	194	51
4:							
4	1,185	4.0	121.8	25,938	2,239	182	52
5	1,645	3.5	132.7	29,575	2,444	217	49
Average	1,415	3.8	127.2	27,756	2,342	200	51
5 (highest):							
2	1,250	4.1	130.2	25,528	2,431	194	52
6	920	4.4	112.0	23,510	2,075	159	58
Average	1,085	4.2	121.1	24,519	2,253	176	55
Average, all plots	1,302	4.0	125.5	26,476	2,301	192	51.5
Portion of stand removed by thinning:							
1	1,456	--	105.2	--	1,864	--	--
2	753	--	77.3	--	1,381	--	--
3	884	--	43.5	--	768	--	--
4	665	--	22.1	--	374	--	--
5	250	--	4.1	--	16	--	--

1/ Arithmetic mean.

2/ Total under bark volume of the entire stem from the ground line to the tip.

The levels-of-growing-stock treatments were defined in terms of bole area, first described by Lexen (1943). Bole area is a close approximation of main stem cambium area. Levels chosen at the time of the first thinning were 5,000, 10,000, 15,000, 20,000, and 25,000 square feet of bole area per acre. In terms of basal area, this amounted to 25, 48, 80, 105, and 117 square feet per acre, respectively (table 2). Trees removed were those diseased and less vigorous.

Diameter and height of all trees were measured in the spring of 1963 and again in the fall of 1967. Upper bole diameter measurements on a sample of trees were taken in both 1963 and 1967 to provide a basis for calculating volume and bole area equations at each date.

Soil moisture was measured with a nuclear probe.[3] Measurements were made to estimate soil moisture use in the year before thinning and in each year thereafter during the first 5-year postthinning period.

RESULTS

DIAMETER

Average diameter growth of all trees increased steadily with each decrease in stand density from the highest level to the lowest (fig. 1).

[3] Three mechanically spaced tubes were used as soil moisture sampling points on each plot. An attempt was made to insert 5-foot tubes at each of these points. However, the very coarse, gravelly nature of the soil below 4 feet made installation of 5-foot tubes extremely difficult. Therefore, many tubes were only 4 feet long and results are reported for 4 feet of soil. Calibration curves developed by Barrett (1970) were used to convert the difference in counts per minute from spring to fall into water use.

Table 2.--*Stand statistics per acre after fall 1962 thinning and at end of 1967 growing season*

Level	Number of trees	Entire stand							Volume of 100 largest diameter trees[2]
		Average spacing	Average d.b.h.[1]	Average height	Basal area	Bole area	Crown competition factor	Volume[2]	
		Feet	*Inches*	*Feet*	---*Square*	*feet*---		--------*Cubic*	*feet*--------
Beginning of 1963 growing season:									
1 (lowest)	122	18.9	6.1	41.0	25.0	4,842	31	478	428
2	295	12.2	5.4	38.8	47.9	9,936	64	919	496
3	500	9.3	5.4	37.0	80.1	15,841	106	1,499	585
4	750	7.6	4.8	35.6	104.1	22,118	145	1,968	602
5 (highest)	835	7.2	4.8	35.6	117.0	24,814	161	2,237	663
End of 1967 growing season:									
1 (lowest)	122	18.9	6.6	43.6	29.4	5,740	35	606	540
2	295	12.2	5.8	41.6	56.3	11,992	71	1,174	637
3	500	9.3	5.7	40.2	88.5	17,978	114	1,698	664
4	732	7.7	5.1	38.9	113.1	25,124	151	2,285	719
5 (highest)	792	7.4	5.0	38.6	119.0	26,424	163	2,387	753

[1] Arithmetic mean.

[2] Total under bark volume of the entire stem from the ground line to the tip.

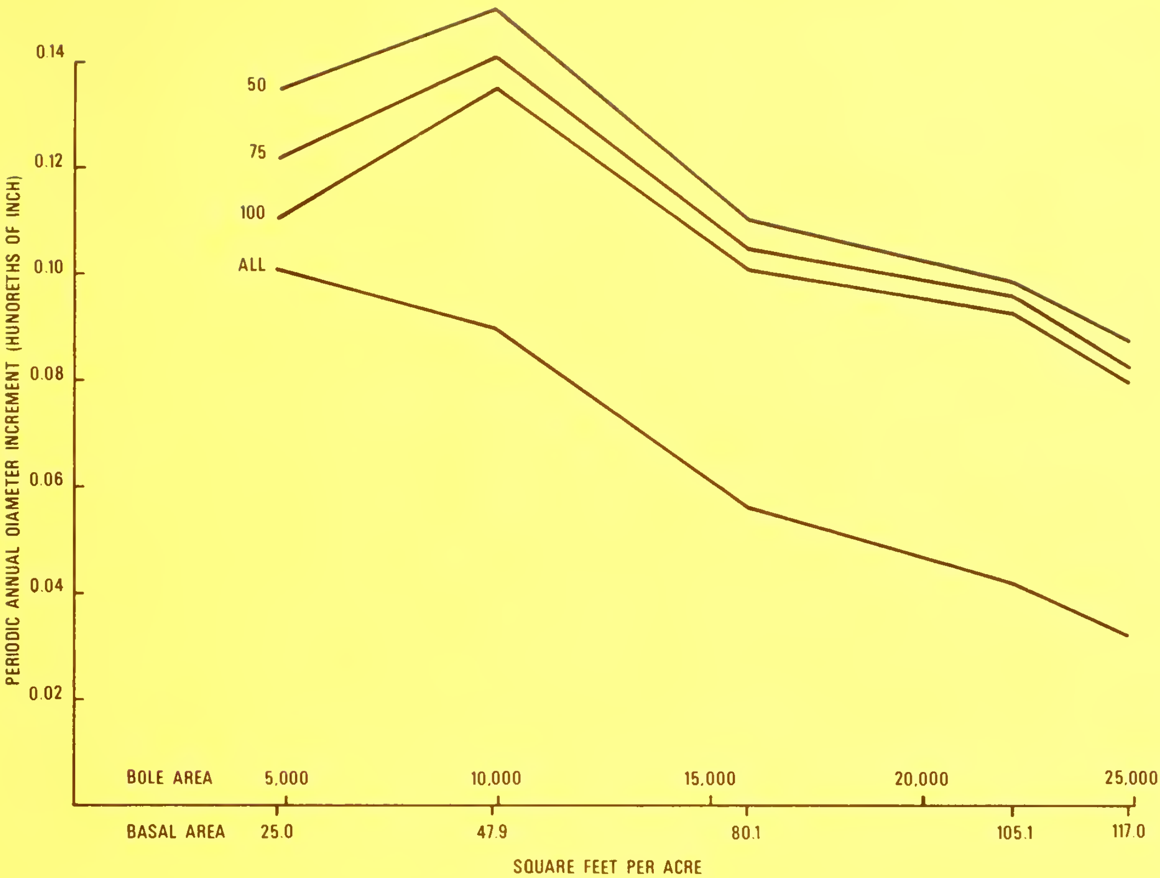

Figure 1.--Periodic annual diameter growth of the 50, 75, and 100 largest diameter trees per acre and all trees.

This linear relationship between stand density and diameter growth was highly significant in a statistical sense.

The same general trend of more rapid diameter increase with decreasing stand density also held for the 50, 75, and 100 largest diameter trees per acre except that the increase at the lowest density was less than that at the next-to-lowest density (fig. 1). Although this difference between levels 1 and 2 was not significant at the 5-percent level, the drastic reduction in height growth suffered by the most widely spaced trees (see fig. 2) suggests that the diameter growth decline of the largest trees at the lowest density may be a real effect of density.

There was also a tendency for larger trees to grow more rapidly in diameter than smaller ones. At all treatment levels, the 100 largest trees grew more rapidly than all trees, and the 50 largest trees grew faster than the 100 largest.

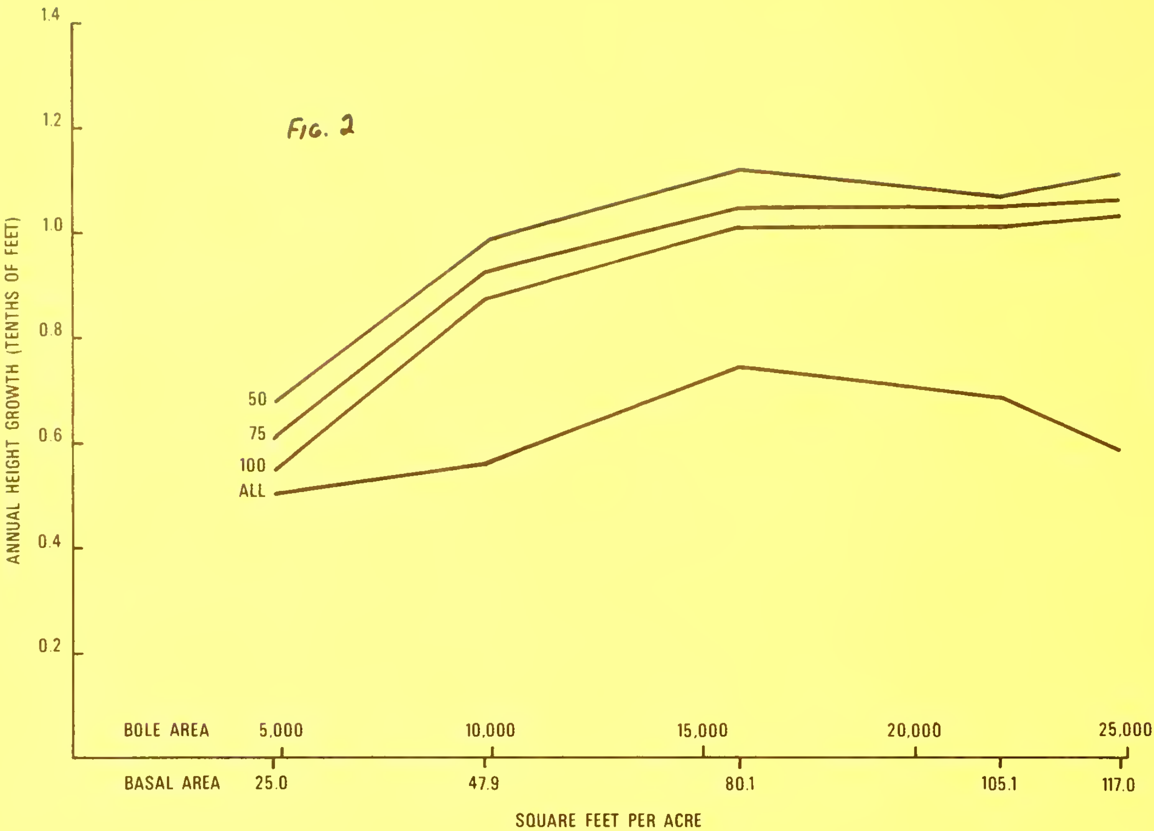

Figure 2.--Annual height growth of the 50, 75, and 100 largest diameter trees per acre and all trees, on an average-per-tree basis.

Linear regressions of periodic annual diameter increment on initial diameter were statistically significant on seven of the 10 plots. Regressions were nonsignificant on one plot at each of the three lower density levels. Regression on the plot where fit was best accounted for only 32 percent of total variation, but most did not do nearly that well. Thus, growth predictive value of initial diameter was not high.

HEIGHT

Height growth of the larger trees was definitely retarded by thinning. The 50, 75, and 100 largest diameter trees per acre were most affected at the lower two density levels (fig. 2). Statistical tests showed that a second-degree curve made a significant improvement over a linear regression for expressing the relationship of height growth of the larger trees as a function of stand density.

Height growth of the larger diameter trees was greater than that of the smaller trees. On every plot, the 100 largest trees grew more rapidly than all trees. Similarly, the 75 largest trees grew more rapidly than the 100 largest, and the 50 largest trees grew more rapidly than the 75 largest on all plots.

There was no difference in average height growth of all trees associated with stand density. The larger number of small, slowly growing trees present at the higher densities cancelled the greater height growth of the larger trees.

BASAL AREA

Basal area increment increased sharply as stand density increased from the lowest level to the next highest one (fig. 3). However, beyond the second level there was little relationship between gross basal area increment and

Figure 3.--Relationship between periodic annual basal area increment and stand density after thinning.

stand density. A regression of gross basal area increment on logarithm of basal area proved to be highly significant,[4] mainly because of the low increment at the lowest density.

Mortality accounted for 74 percent of gross basal area increment at the highest density level but only 12 percent at the next lower level. No mortality occurred at the three lower levels (table 3).

CUBIC VOLUME

Gross cubic volume increment increased irregularly as stand density increased (fig. 4). Despite large deviations from the general trend, a linear regression of volume increment on bole area accounted for 40 percent of the total variation and was statistically significant.

[4] Orthogonal comparisons in regression showed that a second-degree curve would account for 81 percent of the total variation in basal area increment contrasted with 58 percent for the logarithmic expression. However, the logarithmic equation has long been used for estimating basal area increment and logically fits the situation.

The erratic progress of increasing volume increment with increasing stand density resulted from rather large differences between plots treated alike. For example, at the middle density level, one plot produced 54.6 cubic feet but the other, only 24.7. Plot 10, the low producer, had the greatest number of stems of any plot in the experiment before thinning (table 1). A probable reason for the poor performance is that trees on this plot were too suppressed to respond well, but it is also possible that site quality is lower. Similar results were experienced with another levels-of-growing-stock study at Twin Lakes in Oregon, but during the second 5-year period, the large differences between plots treated alike had mostly disappeared (Dahms 1971).

Mortality accounted for 41.5 percent of the gross volume increment at the highest density and 6.5 percent at the next highest density. No mortality occurred at the three lower densities.

Table 3.--*Periodic annual growth and mortality of lodgepole pine per acre after initial thinning at age 47*

Growing stock level	Entire stand												Volume increase of 100 largest diameter trees[1]
	Basal area			Bole area			Crown competition factor			Volume			
	Net	Mortality	Gross	Net	Mortality	Gross	Net	Mortality	Gross	Net	Mortality	Gross	
	Square feet			*Square feet*						*Cubic feet*			
1 (lowest)	0.897	0	0.897	179	0	179	0.8	0	0.8	25.5	0	25.5	22.4
2	1.674	0	1.674	411	0	411	1.4	0	1.4	51.0	0	51.0	28.3
3	1.678	0	1.678	427	0	427	1.6	0	1.6	39.6	0	39.6	15.8
4	1.610	.222	1.832	601	76	677	1.2	0	1.2	63.4	4.4	67.8	23.3
5 (highest)	.404	1.148	1.552	322	241	563	.4	0.4	.8	30.0	21.3	51.3	17.9

[1] Volume increase of 100 largest trees per acre is the difference in volume between those that were largest at the beginning of the period and those that were largest at the end.

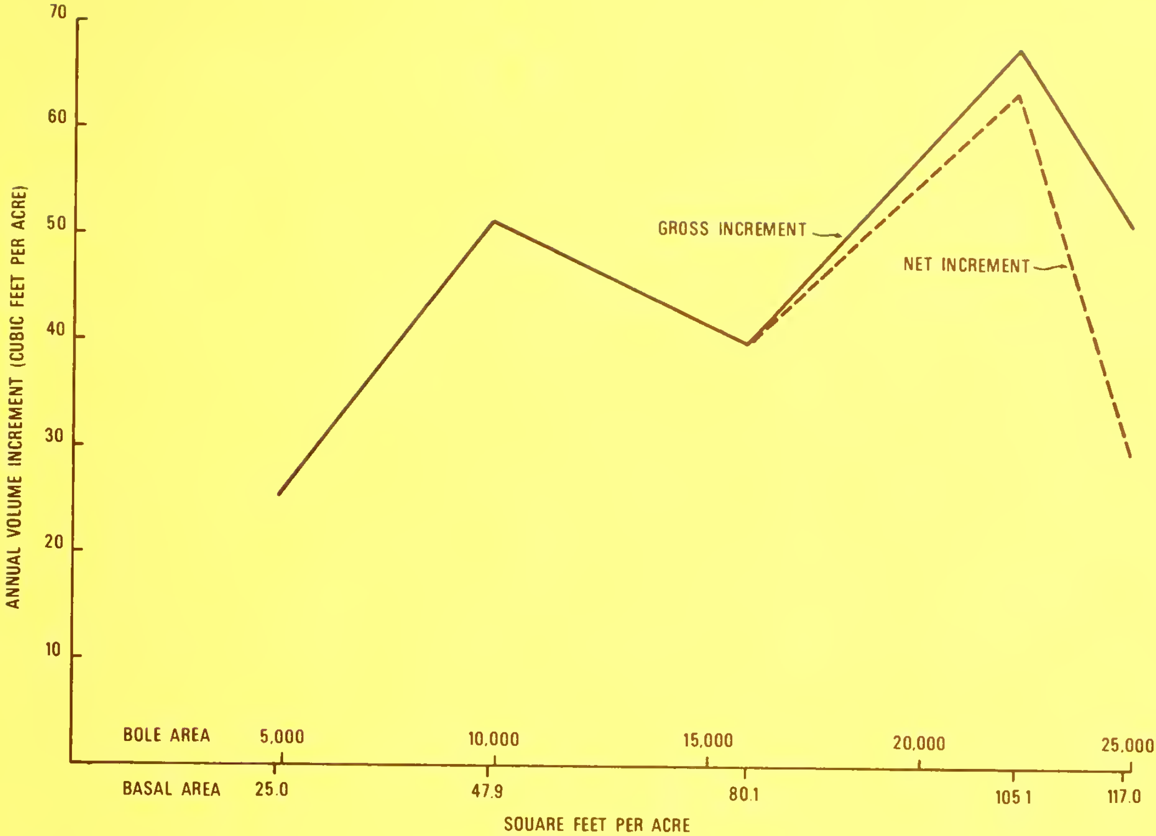

Figure 4.--Relationship between periodic annual volume increment and stand density after thinning.

Differences between treatments in volume added to largest trees did not logically relate to stand density and could easily be accounted for by random variation (table 3). Greater diameter growth at the lowest stand density was approximately offset by lesser height growth.

SOIL MOISTURE

Soil moisture withdrawal was definitely less after thinning than before on the two plots given the lowest stand density treatment. Additional water left in the top 4 feet of soil after thinning compared with prethinning ranged from 3.3 inches in 1967 to 7.2 inches in 1965 and averaged 5.0 inches for the 5-year period at the lowest stand density level (fig. 5). At the highest stand density, the range was from a 0.6-inch greater use in 1967 to a 2.6-inch lesser use in 1965, with an average lesser use of 0.6 of an inch. Water saving by the heavy thinning, or the difference between the high density and the low

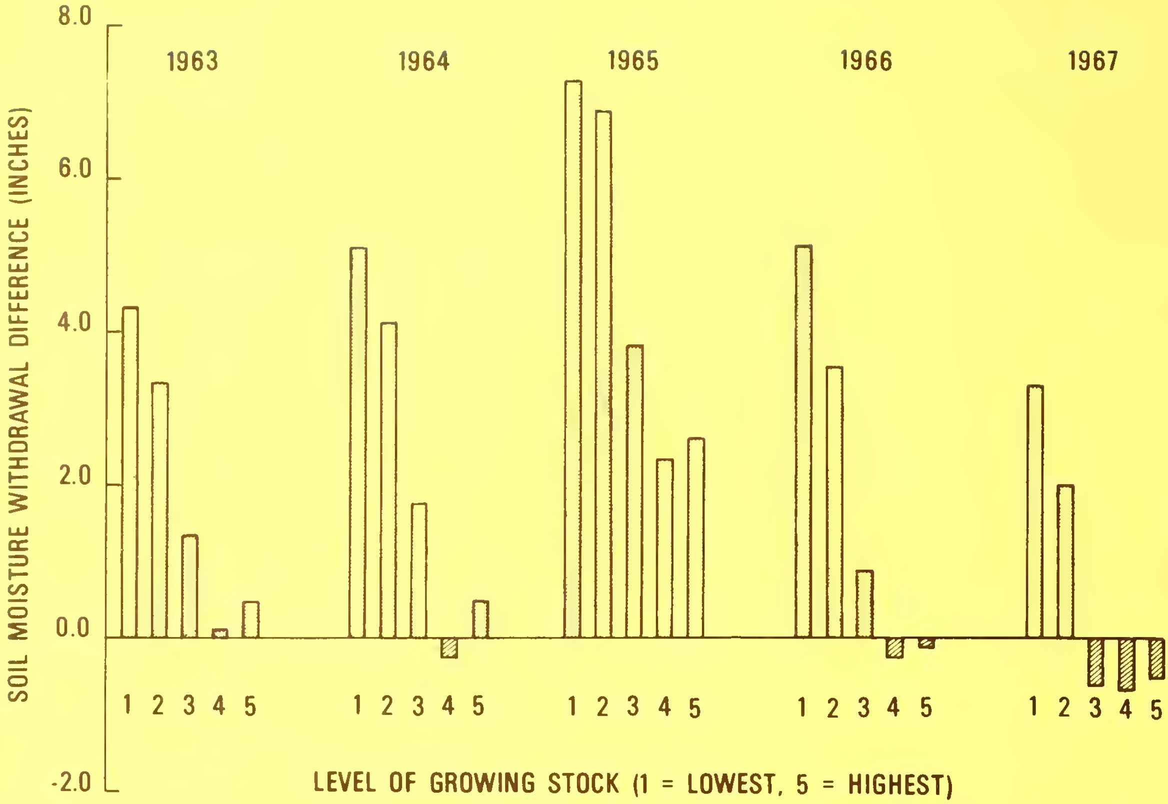

Figure 5.--Difference between prethinning (1962) and postthinning (1963-67) soil moisture withdrawal, by year and level-of-growing stock. (Difference is water use in postthinning years subtracted from prethinning use. Greater postthinning use in a few instances resulted in negative differences.)

density treatment, averaged 4.4 inches over the 5-year period.

There was no evidence to suggest that water use on the lowest density plots might be increasing relative to that on the higher density ones as the years since thinning passed. Failure of the year-treatment interaction during the 5 postthinning years even to approach statistical significance confirms the visual impression obtained from figure 5. These results are not the same as those from a similar study in a younger stand growing near Twin Lakes. There, soil moisture use increased at the lower densities relative to that at the higher levels during the first 5-year period (Dahms 1967).

Volume increment was closely related to amount of soil moisture withdrawn. A regression of gross volume increment on average annual soil moisture withdrawal over the 5 postthinning years accounted for 60 percent of the total variation in volume increment and proved to be statistically significant at the 1-percent level. This result is comparable to that obtained at Twin Lakes (Dahms 1967).

DISCUSSION

Delaying thinning until the Snow Creek stand was 47 years old caused a substantial waste of site productivity. A large volume of wood was grown on trees that had almost no chance to reach usable size. As an example, if we assume 208 trees (halfway between levels 1 and 2) will be able to reach usable size before another thinning is needed, about 70 percent of the standing volume in 1962 was in excess trees too small to use.[5]

Tree growth response to thinning was not large during the first 5 years. At level 2 (10,000 square feet of bole area per acre), diameter growth of the 100 largest trees per acre was 169 percent of that at the highest density level. However, height growth was only 85 percent of that at the highest level. At the lowest density level, diameter growth was only 140 percent of that at the highest level and height growth, 54 percent (figs. 1 and 2).

Insight into probable volume increment relationships is provided by soil moisture use patterns. If year-to-year trends of volume increment on low density plots relative to high density ones follow the pattern for soil moisture use, there is no tendency for volume increment at low densities to approach that at higher densities as time passes. Also, the very low volume increment on plot 10 coupled with the low soil moisture use both before and after thinning further suggests that this plot is of lower site quality or that stagnation may have set in.

Will trees as old as 47 years recover from the shock of a heavy thinning and resume normal height growth? Staebler's (1956) experience with shock (height growth suppression) in Douglas-fir and the subsequent resumption of a normal growth rate suggests that Snow Creek trees, too, can be expected to resume normal height growth.[6] The fact that Alexander et al. (1967) found no evidence of reduced height growth in natural stands of very low densities provides additional basis for hope.

Crown size reduced by density may always limit diameter growth to something less than what would

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[5] The 70-percent figure was obtained by averaging volumes cut from the two lowest levels as shown in table 1 and expressing the average as a percentage of the average prethinning volume of these levels.

[6] Resumption of normal growth on Staebler's trees after 6 to 8 years was confirmed by personal communication with Richard E. Miller, Pacific Northwest Forest and Range Experiment Station, Olympia, Wash.

have been possible with an earlier thinning (fig. 6). It does not seem possible that photosynthetic surface per unit of cambium area can ever be as great on these once-suppressed trees as on trees that have always had adequate growing space. Although this study has not produced solid evidence that thinning in lodgepole pine stands as old as 47 years will increase usable wood production, there are some grounds for optimism.

Probable water yield increases may be one of the biggest incentives for thinning an older lodgepole pine stand such as the one at Snow Creek. The much reduced evapotranspiration drain on soil moisture from the lower densities can reasonably be expected to show up as increased streamflow. As Herring (1968) points out, there are some if's in translating soil moisture savings into increased water runoff. However, Packer and Laycock (1969) maintain that reductions in density of vegetation almost always produce increased streamflow. Consequently, it is reasonable to expect thinning to increase water production until roots and crowns of the reserve trees reoccupy the site or until understory shrubs and grasses expand into the new growing space. Barrett (1970)

Figure 6.--Left, a low density plot at Snow Creek thinned at age 47 years. Notice the short, narrow crowns. Right, a low density plot at Twin Lakes thinned to the lowest density at age 26 years. Notice the much longer and wider crowns.

demonstrated that understory shrubs and grasses could be as water-demanding as trees.

Thinning offers the potential of diverting sites from production of wood on unusable trees into production of forage for grazing animals. This result on somewhat similar studies has been reported by Barrett (1970) and McConnell and Smith (1970). Dealy of the Big-Game Habitat Project at LaGrande is studying this aspect of stand density control at Snow Creek.

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FIRST-YEAR VEGETATION AFTER FIRE, RESEEDING, AND FERTILIZATION ON THE ENTIAT EXPERIMENTAL FOREST

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Abstract

Vegetative cover measurements were made on permanent belt transects during 1971 on four watersheds severely and uniformly burned in 1970 that received the following treatments: seeded and fertilized with 57 kg./ha. of nitrogen as ammonium sulfate; seeded and fertilized with 54 kg./ha. of N as urea; seeded only; and control (no seeding, no fertilizer). Results are a progress report of a study being conducted to evaluate regrowth and successional patterns of native species and to determine the success of erosion control seeding and fertilization using two different sources of N and one of sulfur.

Comparisons between seeded watersheds and the unseeded, unfertilized control indicate that erosion control seeding improved first-year vegetative cover by up to one-third. Of the seeded species, orchard grass, hard fescue, and timothy provided most of the first-year cover. Perennial rye and yellow sweetclover showed poor development.

Effectiveness of fertilizer was questionable the first year since total cover on the seeded-only watershed was nearly as great as on the watershed seeded and fertilized with ammonium sulfate and greater than on the watershed seeded and fertilized with urea. However, observations in the early summer of 1972 indicate that vegetal cover on the fertilized watersheds is substantially higher than on the control or seeded-only watershed. Also, vigor of seeded species appears to be much better on the fertilized watersheds.

Keywords: Soil-binding plants, fertilization (plants), forest regeneration (artificial)

INTRODUCTION

Fire has played an important role in the development, maintenance, and perpetuation of most forested communities of the Pacific Northwest. The ponderosa pine (*Pinus ponderosa* Laws.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests of north-central Washington are no exception. This region is highly susceptible to fire because of the hot, dry summer climate, steep topography, and explosive flammability of sclerophyllous understory vegetation. According to Keene (1940), fires have occurred on an average of every 18 years in the ponderosa pine zone of eastern Oregon. Daubenmire and Daubenmire (1968) found records of extensive fires in Washington and Idaho in 1910, 1916, 1931, and 1967.

After a severe forest wildfire, it appears desirable to establish vegetal cover as soon as possible to reduce soil erosion and restore nutrient cycles. Both objectives are important for maintaining productivity of forested ecosystems. However, the latter may be especially important because many of the nutrient elements once incorporated into plant and litter materials are converted to oxides upon combustion and scattered as ash. In this form they are susceptible to leaching and erosion loss from the ecosystem.

Native vegetation, particularly those species which sprout from underground organs, appears to regrow rapidly after fire (Weaver 1951, Daubenmire and Daubenmire 1968, Franklin and Dyrness 1969). Also, germination of snowbrush ceanothus (*Ceanothus velutinus* Dougl.) seed is apparently stimulated by fire.[1/]

Despite the apparent ability of native species to revegetate burned areas, the regrowth may be too slow or the density too sparse to provide immediate soil stability and restore nutrient cycles. For this reason, erosion control seeding procedures have been outlined (Friedrich 1947, Rummell and Holscher 1955, Lavin and Springfield 1955). The recommended procedure is to seed 5 to 10 kg./ha. of grass and legume seed into the ashes in the late summer or fall after the fire. However, Orr (1970) found that seeding on snow in April by helicopter was successful on a South Dakota burn. He concluded that

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[1/] Henry John Gratkowski. Heat as a factor in the germination of seeds of *Ceanothus velutinus* var. *laevigatus* T & G. Unpubl. Ph.d. thesis, Oreg. State Univ., 122 p., 1962.

growth of native and seeded species effectively reduced overland runoff and soil erosion within one to four growing seasons after the fire. Seeded species comprised more than half the vegetal cover during the 4 years studied.

In an earlier study in Montana, Friedrich (1947) found that fall seeding after fire was most successful where the original forest cover was dense and was least successful on open sites with sparse forest cover. He concluded that high quantities of twigs and litter in the dense forest produced the greatest amount of ash and a more favorable seedbed. Also, prefire vegetation under dense timber was normally sparse, and regrowth after fire offered little or no competition to seeded species. In contrast, open sites were more densely occupied by grasses and shrubs not easily killed by fire. He also felt that there was less damage to understory species in open stands of timber because fires were not so hot as in dense stands. Thus, surviving native species were able to compete more strongly with seeded species.

Neither the regrowth of native species after fire in the ponderosa pine-Douglas-fir zone nor success of erosion control seeding and fertilization has been extensively studied in the Pacific Northwest. Our field observations indicate that seeding and fertilization efforts have met with uncertain success in the past. One reason for failures may be a deficiency of N and S in the soil (Klock, Geist, and Tiedemann 1971). Such deficiencies may be amplified by gaseous losses of N and S contained in plant litter. DeBell and Ralston (1970) estimate that 62 percent of the N in pine litter and leaf materials is released upon ignition. Also many species used for erosion control seeding are marginally suited for this purpose because they cannot withstand frost heaving in the early spring, rapid soil drying in late spring, nor high soil temperatures during the summer. The lack of information regarding vegetative succession and the variable success of erosion control seeding and fertilization has prompted us to initiate a study to:

(1) measure the rate of regrowth of native species and patterns of succession following wildfire,

(2) determine the success of seeding a prescribed erosion control seed-mix relative to regrowth of native vegetation,

(3) evaluate the effect of two different sources of N and one of S on regrowth of native species and growth and development of seeded species.

The 17,000-ha. Entiat fire of August 1970, which severely and uniformly destroyed the vegetation on the watersheds of the Entiat Experimental Forest and adjacent Brennegan Creek in approximately 15 hours, provides an ideal setting to evaluate vegetation recovery. Information reported in this paper is a progress report on the first-year vegetation recovery following fire, erosion control seeding, and erosion control seeding and fertilization.

THE STUDY AREA

The physical setting, climate, and vegetation of the Entiat Experimental Forest have been elaborated by Berndt (1971) and Klock (1971). Briefly, the watersheds are typical of ponderosa pine-Douglas-fir forests of the east slope of the Cascade Range. Topography is steep, rising from 550 to 2,100 m. above a glaciated valley in an overland distance of 5 to 6 km. Soils are coarse and deep, developing in coarse ash or pumice over granitic bedrock. Summers are hot and dry (18° to 19° C. mean monthly maxima in July and August), with only 10 percent of the 46 cm. of precipitation falling between June and September. Brennegan Creek, an adjacent watershed to the east, was included in the study; it has similar characteristics and was burned also.

For purposes of this study we feel it necessary to expand the vegetation description of Berndt. Prior to the fire, vegetation at the lower, more xeric sites (550- to 920-m. elevations) consisted of an overstory of ponderosa pine with an understory of bitterbrush (*Purshia tridentata* (Pursh) DC.)[2/] and serviceberry (*Amelanchier alnifolia* Nutt.). Arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.), bracken fern (*Pteridium aquilinum* (L.) Kuhn.), spreading dogbane (*Apocynum androsaemifolium* L.), and bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. & Sm.) were prominent herbaceous species. This zone is probably representative of the *Pinus ponderosa/Purshia/Agropyron* habitat type of Daubenmire and Daubenmire (1968). At intermediate and higher elevations, 920 to 1,675 m., Douglas-fir became more prominent, often occurring in almost pure stands on moister sites. Lodgepole pine (*Pinus contorta* Dougl.) normally occurred only in small, dense thickets. However, the southwest slope of Fox Creek was an almost pure stand of "doghair" lodgepole pine.

[2/] Plants were identified by Drs. F. J. Hermann and Charles Feddema of the National Herbarium at Fort Collins, Colorado.

Snowbrush ceanothus, willow (*Salix* spp.) and Sitka alder (*Alnus sinuata* (Reg.) Rydb.) were common shrubs. Halfshrubs and low shrubs consisted primarily of Oregon boxwood (*Pachistima myrsinites* (Pursh) Raf.), birchleaf spiraea (*Spiraea betulifolia* Pall.), prince's pine (*Chimaphila umbellata* (L.) Bart.), and kinnikinnick (*Arctostaphylos uva-ursi* (L.) Spreng.). Of the herbaceous species, pinegrass (*Calamagrostis rubescens* Buckl.), Ross sedge (*Carex rossii* Boott), spiraea, dogbane, and bracken fern were prominent. The intermediate elevations are characteristic of the *Pseudotsuga menziesii/Calamagrostis rubescens* habitat type described by Daubenmire and Daubenmire (1968). At the highest elevations (over 1,770 m.), whitebark pine (*Pinus albicaulis* Engelm.) was commonly encountered.

METHODS

To evaluate natural vegetative regrowth and succession, the Fox Creek watershed (473 ha.) of the Entiat Experimental Forest was designated as the control. It remains roadless with no seeding or fertilization. Burns and McCree Creeks (564 and 514 ha., respectively), the other two Experimental Forest watersheds, and Brennegan Creek (740 ha.), an adjacent watershed, were seeded by fixed-wing aircraft with a mixture of 2.2 kg./ha. Latar orchardgrass (*Dactylis glomerata* L.), 1.1 kg./ha. durar hard fescue (*Festuca ovina* var. *duriuscula* (L.) Koch), 1.1 kg./ha. of Drummond timothy (*Phleum pratense* L.), 1.1 kg./ha. perennial ryegrass (*Lolium perenne* L.), and 1.1 kg./ha. yellow sweetclover (*Melilotus officinalis* (L.) Lam.). Burns Creek was fertilized by helicopter with 280 kg./ha. of ammonium sulfate (equivalent to 57 kg./ha. of elemental N). McCree Creek received 118 kg./ha. of urea (equivalent to 54 kg./ha. of elemental N). Brennegan Creek was not fertilized.

Foliar cover of each species was measured on permanent belt transects established midslope on the south- and west-facing aspects of each watershed. Transect dimensions are 2 ft. by 43.56 ft. (0.6 m. by 13.3 m.). Transects were established systematically from a random start at intervals of 180 m. between elevations of 1,700 and 730 m. Transect orientation conforms to the contour with steel posts used to mark head and tail stakes. Transects on Fox and Burns Creeks were established immediately following the fire in September 1970. Those on McCree and Brennegan Creeks were established in July and August 1971 at the time the first measurements were taken.

Vegetal cover was measured as a vertical projection of foliar material onto the ground surface for each species with a 1-ft. (0. 3 m.) belt along both sides of a tape stretched between the stakes forming the transect. A 1. 0-ft.^{2} (929 cm.^{2}) frame divided into 0. 50, 0. 25, 0. 15, 0. 10, and 0. 05-ft.^{2} (464, 232, 139, 93, and 47-cm.^{2}, respectively) sections was used to reference cover measurements. Tree seedlings and snowbrush ceanothus seedlings were counted on the transect when cover estimates were made. To account for phenological differences, transects below 1, 100 to 1, 200 m. were measured between July 20 and August 10, 1971. Those above this elevation were measured between August 10 and September 1. Because selection of this elevation was controlled by accessibility, there is no assurance that the environment at one aspect and elevation of a watershed is precisely similar to that on any other watershed. However, the overall range in habitat types and the relationship between habitat type, elevation, and aspect are similar among watersheds.

Frequency was computed as a ratio of the number of transects on which a given species was found to the total number of transects. Results are a summary by watershed, aspect, elevation, class of plant, and species. No statistical tests of the data were performed.

RESULTS AND DISCUSSION

By the end of the first growing season after the fire, an average of 8. 6 percent of the ground was covered by foliar material of native and seeded species. The most salient features of the first-year vegetation were the dominance of native species and the rapid development of orchardgrass (fig. 1). Although most of the native plants sprouted from rhizomes, lignotubers (basal buds of shrubs), bulbs, or other underground organs, annual plants were abundant on many of the lower elevation transects and the entire area abounded with snowbrush ceanothus seedlings from seed triggered by fire.

Burns Creek (seeded and fertilized with ammonium sulfate) displayed the greatest vegetative development of the four watersheds with a cover of 10. 8 percent. Vegetative cover on Brennegan Creek (seeded-only) was 10. 3 percent--surprisingly close to vegetation development on Burns Creek. Even though McCree Creek was fertilized with urea and seeded, vegetative cover was only 7. 5 percent. Fox Creek, the control watershed, had the poorest vegetative cover of any watershed--5. 6 percent.

Figure 1.--*Typical first-year growth of native and seeded species. Prominent species are willow, pinegrass, and orchardgrass.*

South-facing slopes generally had the best cover of vegetation, averaging 10.0 percent compared with 6.7 percent on the west-facing slopes. Vegetative cover among watersheds was also more uniform on the south aspects than on the west, ranging from 8.8 percent to 11.7 percent (fig. 2). On the west aspects, cover varied from 2.0 percent on Fox Creek to 9.9 percent on Burns Creek.

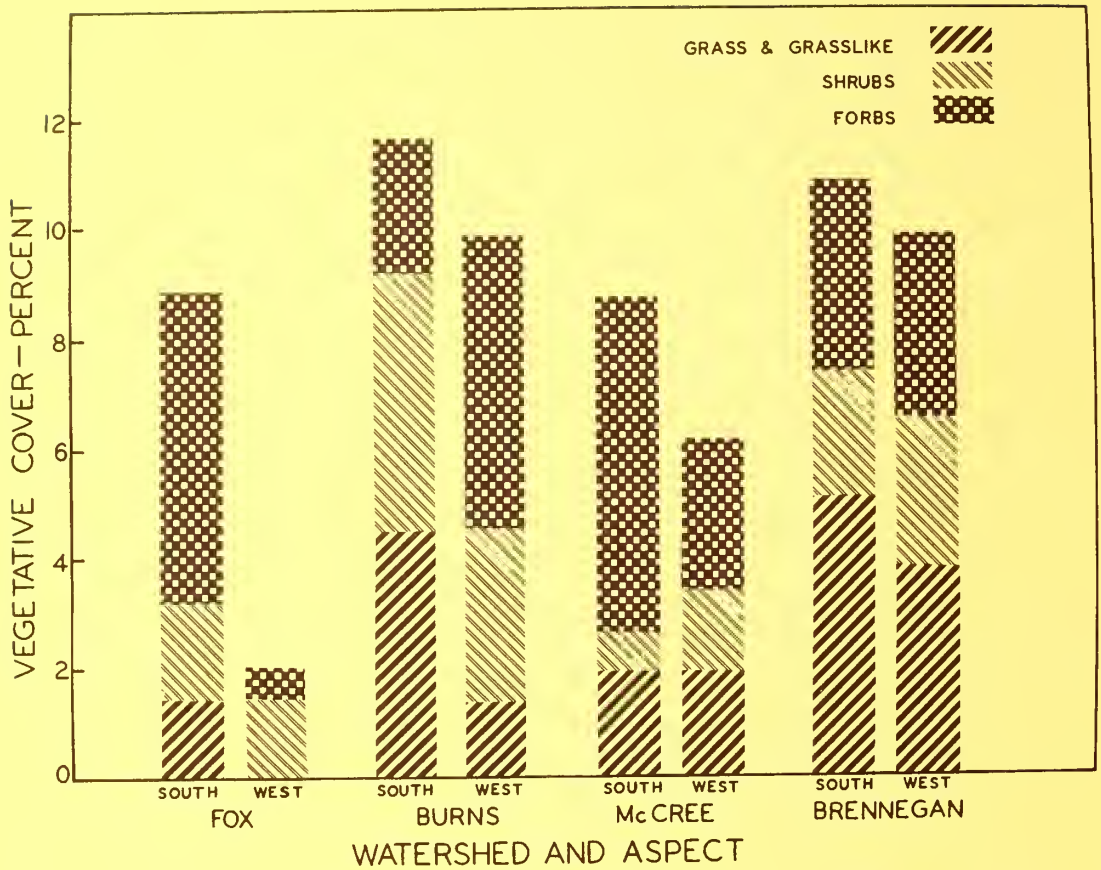

Figure 2.--*Vegetative cover of three classes of vegetation on south and west aspects of the four study watersheds.*

Understory vegetation on the west face of Fox Creek was probably sparse before the fire because much of this aspect was occupied by a dense stand of lodgepole pine (fig. 3). Also, bark was burned to the cambium on many stems, indicating that the fire reached extreme temperatures, possibly killing much of the understory vegetation.

Lower elevations of the watersheds had more vegetal cover (10.1 percent) than higher elevations (7.3 percent). Most of this difference occurred at Fox and McCree Creeks where cover at lower elevations was twice as great as that at higher elevations (fig. 4). Differences between elevations are probably the result of differences in species composition and differential stage of vegetation development. In addition, most of the area responsible for the sparse vegetal cover on the west aspect of Fox Creek was at higher elevations. In fact, the first transect at the upper end of the west aspect of Fox Creek had no vegetation.

Figure 3.--*Transect on the west aspect of Fox Creek. The fire was so intense that bark was burned to the cambium of many stems.*

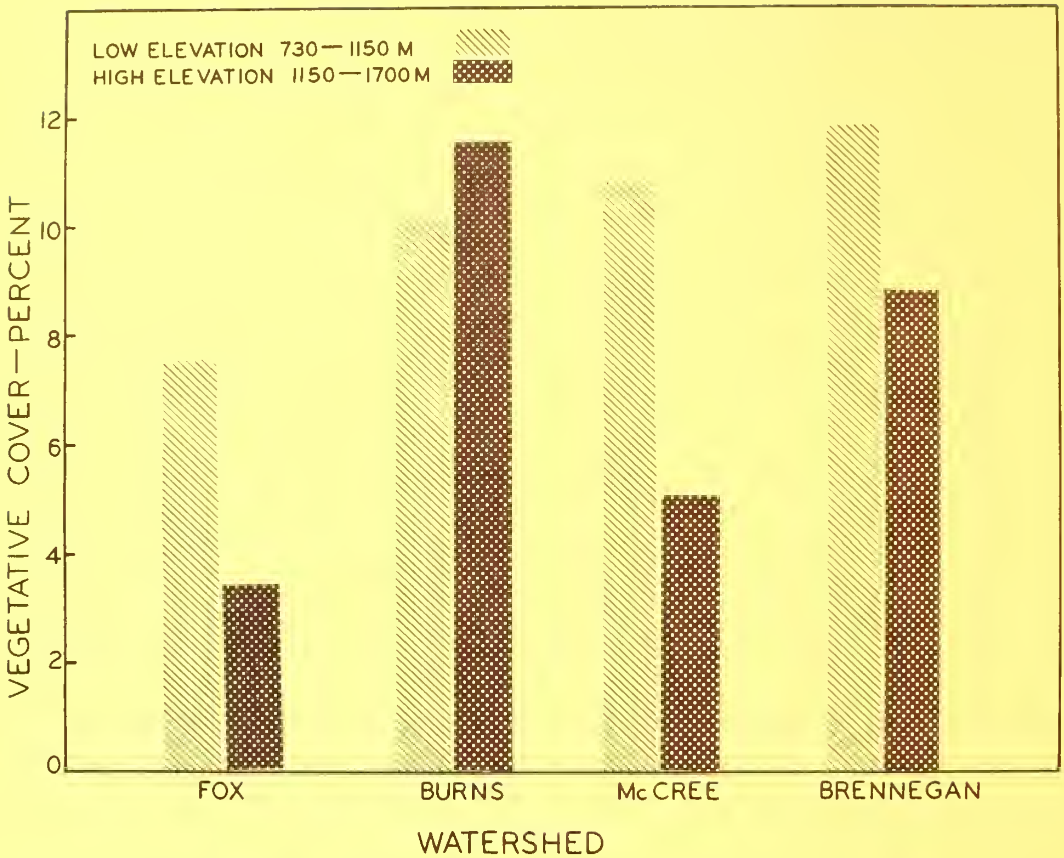

Figure 4.--*Total vegetative cover at low and high elevations on the four study watersheds.*

Forbs were the most abundant first-year vegetation on the watersheds, averaging 3.7-percent cover compared with 2.3- and 2.6-percent cover for grass and grasslike plants and shrubs, respectively.

However, the amount of vegetative cover provided by each class of vegetation and the proportion of the total vegetative cover that each class comprised varied greatly among watersheds and between aspects. Forbs attained their maximum ground coverage on McCree Creek (fig. 2), whereas grass and grasslike plants and shrubs had the greatest foliar coverage on Brennegan and Burns Creeks, respectively. On Fox Creek the cover of forbs on the west slope of 0.4 percent contrasted markedly with 5.7 percent on the south slope. Cover of the grass and grasslike class also varied widely, from 0.02 percent on the west aspect of Fox Creek to over 5 percent on the south face of Brennegan Creek. The lowest shrub cover (0.7 percent) was observed on the south slope of McCree Creek. Shrub cover was highest on the south slope of Burns Creek (4.7 percent).

Bracken fern, spreading dogbane, and fireweed (*Epilobium angustifolium* L.) were the dominant forbs (table 1), comprising 70, 89, 76, and 59 percent of the total forb cover on Fox, Burns, McCree, and Brennegan Creeks, respectively. Bracken fern was encountered on 24 to 40 percent of the transects and had the highest vegetative cover (1.1 to 2.2 percent) of any of the forbs.

Of the native grass and grasslike plants, the most abundant were pinegrass and Ross sedge. Vegetal cover of pinegrass varied from 0.2 percent on McCree Creek to 1.1 percent on Brennegan Creek. Ross sedge was the only grasslike plant encountered; despite its occurrence on 30 to 60 percent of the plots, it provided only 0.03- to 0.15-percent vegetal cover.

Sprouts of shrubs provided most of the first-year cover for this class of vegetation. Snowbrush ceanothus, the dominant shrub, was encountered on 71 to 92 percent of the transects and provided 0.53- to 1.35-percent cover. In addition to the sprouts, snowbrush ceanothus seedlings were abundant. These averaged $7.4/m.^2$, ranging from $5.5/m.^2$ on McCree Creek to $10.4/m.^2$ on Fox Creek. Many willow and Sitka alder shrubs had sprouted within 1 month after fire; and by the time transects were evaluated, their foliage covered an average of 0.49 and 0.20 percent, respectively, of the ground on the four watersheds. Birchleaf spiraea, a halfshrub, was encountered on 68 to 88 percent of the transects and provided 0.31- to 0.82-percent cover.

When compared with total vegetal cover, the first-year performance of seeded species appears to be poor. On the seeded watersheds, foliar cover of seeded species was only 18 to 32 percent of the total cover (table 2). However, when compared with the vegetative cover provided by grasses and grasslike plants, seeded grasses made up a large portion (64 to 78 percent) of that class of vegetation. Orchardgrass, in addition to being the most prominent seeded grass, was the most ubiquitous grass on the seeded watersheds. It was found on 77 to 80 percent of the transects and covered 1.22 to 2.24 percent of the ground. Hard fescue plants, although found on 53 to 92 percent of the transects, were small and only provided 0.21- to 0.61-percent cover. Timothy did not develop as well as orchardgrass and hard fescue. Nonetheless, it provided between 0.06- and 0.36-percent ground cover and was encountered on more than half the transects. Perennial ryegrass and yellow sweetclover performed poorly compared with the other three species. Vegetative cover ranged from 0.01 to 0.06 percent and frequency, from 13 to 38 percent.

Table 1.--*Cover and frequency of three classes of first-year understory vegetation by species*

Species	Fox		Burns		McCree		Brennegan	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
Shrubs	- - - - -	- - - - -	- - - - -	- - *Percent*	- - - - -	- - - - -	- - - - -	- - - - -
Ceanothus velutinus	0.73	91	1.35	93	0.53	71	1.22	92
Salix spp.	.45	6	.69	30	.10	25	.74	25
Alnus sinuata	.03	12	.65	7	.10	18	.02	4
Spiraea betulifolia	.36	73	.82	70	.31	68	.52	88
Pachistima myrsinites	.05	32	.29	23	.01	14	.01	21
Arctostaphylos uva-ursi	0	0	(1/)	7	.03	4	.02	21
Chimaphila umbellata	0	0	.24	13	0	0	0	0
Vaccinium spp.	.01	18	0	0	0	0	0	0
Purshia tridentata	0	0	0	0	(1/)	11	.01	8
Prunus emarginata	0	0	0	0	(1/)	7	(1/)	8
Rubus spp.	0	0	0	0	0	0	.01	4
Amelanchier alnifolia	(1/)	3	.01	13	0	0	0	0
Ribes spp.	(1/)	9	0	0	0	0	0	0
Total shrubs	1.64	--	4.03	--	1.09	--	2.55	--
Grasses and grasslike								
Calamagrostis rubescens	.67	41	1.03	33	.16	29	1.08	62
Carex rossii	.03	59	.05	43	.07	57	.15	29
Dactylis glomerata	.03	26	1.56	80	1.22	79	2.24	92
Phleum pratense	.01	15	.12	53	.06	57	.36	63
Festuca ovina	.01	23	.21	53	.21	75	.61	92
Lolium perenne	(1/)	9	.01	13	.01	18	.06	38
Poa sandbergii	0	0	(1/)	3	0	0	(1/)	4
Agropyron spicatum	0	0	(1/)	13	.04	21	0	0
Bromus carinatus	.02	6	0	0	.01	4	0	0
Oryzopsis exigua	0	0	0	0	.01	7	0	0
Stipa occidentalis	0	0	(1/)	3	.08	18	0	0
Bromus tectorum	0	0	(1/)	10	.06	4	(1/)	8
Total grasses and grasslike	.78	--	2.99	--	1.92	--	4.50	--

Pteridium aquilinum	1.59	24	1.65	40	2.18	39	1.15	38
Apocynum androsaemifolium	.47	26	1.41	73	1.06	82	.58	46
Epilobium angustifolium	.19	81	.31	73	.16	71	.18	54
E. paniculatum	(1/)	3	.01	10	.01	14	.01	4
Collinsia parviflora	.06	24	.03	27	.08	32	.08	25
Cryptantha simulans	.06	24	.09	23	.21	36	.33	38
Hieracium cynoglossoides	.01	9	.01	10	(1/)	4	.03	17
H. albiflorum	.01	6	.01	3	0	0	.01	4
Mentzelia dispersa	(1/)	3	.01	3	.22	25	.03	4
Gayophytum nuttallii	.06	21	.06	37	.22	39	.05	29
Achillea millefolium	(1/)	12	.01	7	.05	25	.02	25
Collomia grandiflora	0	0	0	0	.02	11	(1/)	4
Collomia tinctoria	.01	9	0	0	.08	25	(1/)	12
Balsamorhiza sagittata	0	0	0	0	.03	4	0	0
Phacelia hastata	.05	32	(1/)	3	.04	11	(1/)	8
Zigadenus paniculatus	0	0	0	0	.01	4	(1/)	4
Arnica cordifolia	.01	9	0	0	.02	4	.18	8
Lomatium brandegei	0	0	.02	3	.01	8	.01	12
Lupinus sulphureus	.35	21	0	0	.02	7	.29	25
Calochortus lyalli	0	0	0	0	(1/)	4	(1/)	8
Montia perfoliata	0	0	(1/)	7	.05	14	.01	12
Malvastrum spp.	(1/)	3	0	0	0	0	0	0
Anaphalis margaritacea	(1/)	3	(1/)	3	(1/)	7	(1/)	12
Luina nardosmia	.31	6	0	0	0	0	0	0
Senecio integerrimus	0	0	0	0	0	0	(1/)	8
Smilacina racemosa	(1/)	3	0	0	0	0	0	0
Sedum stenopetalum	0	0	.01	3	0	0	0	0
Erythronium spp.	0	0	(1/)	3	0	0	0	0
Hydrophyllum capitatum	0	0	0	0	0	0	.04	8
Melilotus officinalis	(1/)	6	.01	30	.01	32	.04	33
Eriogonum spp.	0	0	(1/)	3	(1/)	4	.12	25
Allium spp.	0	0	0	0	(1/)	4	0	0
Clarkia rhomboidea	0	0	0	0	0	0	.02	17
Polygonum majus	.01	6	0	0	(1/)	14	(1/)	8
Arenaria macrophylla	.01	15	.08	20	(1/)	11	0	0
Erysimum asperum	0	0	(1/)	3	.01	4	.04	8
Conyza canadensis	(1/)	3	(1/)	3	0	0	(1/)	3
Clematis ligusticifolia	.01	8	0	0	0	0	0	0
Unidentified forbs	(1/)	--	0	--	0	--	(1/)	--
Total forbs	3.24	--	3.79	--	4.48	--	3.24	--
Total, all classes	5.65	--	10.81	--	7.49	--	10.29	--

1/ Vegetative cover less than 0.01 percent.

NOTE: Individual values do not add up to totals shown because of rounding and because of exclusion of values less than 0.01 percent.

Table 2.--*First-year vegetative cover of seeded species*

Species	Fox	Burns	McCree	Brennegan
	- - - - - - - *Percent* - - - - - - -			
Dactylis glomerata	0.04	1.56	1.22	2.24
Festuca ovina var. *duriuscula*	.01	.21	.21	.61
Phleum pratense	.01	.12	.06	.36
Lolium perenne	(1/)	.01	.01	.06
Melilotus officinalis	(1/)	.01	.01	.04
Total cover seeded species	.06	1.91	1.51	3.30
Percentage of total vegetal cover	1.0	17.6	20.1	32.1
Percentage of grass and grasslike class of vegetation comprised by seeded grasses	7.7	63.5	77.7	72.6

1/ Vegetative cover less than 0.01 percent.

NOTE: Individual values do not add up to totals shown because of rounding and because of exclusion of values less than 0.01 percent.

All five seeded species were found in Fox Creek, apparently as a result of drift when seed was applied. However, in this watershed they comprised only 1 percent of the total vegetal cover.

The abundance of snowbrush ceanothus, willow, fireweed, birchleaf spiraea, and pinegrass conforms to results of other workers (Larsen 1929, Weaver 1951, Neiland 1958, and Mueggler 1965). According to Mueggler, a single broadcast burn causes a significant increase in the frequency of these species compared with an undisturbed forest. Although we observed that spreading dogbane and bracken fern had high frequencies and provided striking amounts of cover, Mueggler concludes that fire does not influence the frequency of these two species.

Of the five seeded species, establishment and development of orchardgrass and hard fescue conformed most closely to the performance description provided by Hafenrichter et al. (1968).

Orchardgrass is classified as a rapidly developing, long-lived grass, whereas hard fescue is a slowly developing, fine-leaved grass particularly well suited for erosion control. Despite its sparse vegetative cover, the occurrence of hard fescue on 53 to 92 percent of the transects on seeded watersheds supports the description.

First-year performance of timothy is difficult to evaluate in terms of other research--Hafenrichter et al. (1968) classify it as a meadow grass--and yet it appears to establish and grow well on harsh sites such as those on the Entiat watersheds. Orr (1970) observed that timothy became established more rapidly than smooth brome or Kentucky bluegrass and maintained dominance during a 4-year study. Timothy was not tested with orchardgrass in Orr's study. Perhaps orchardgrass suppressed the growth of timothy in our study. The poor first-year establishment and growth of perennial ryegrass was surprising, since it is described as a rapidly developing, short-lived grass. The poor performance of yellow sweetclover was anticipated, since it is best adapted to irrigated situations and to soil types other than those encountered on the Entiat Experimental Forest. Also because of their low frequency, it is doubtful that the vegetative cover of perennial ryegrass or yellow sweetclover will increase substantially in subsequent years.

Many species displayed distinct aspect and elevational distributions which give clues to the reasons for differences in total vegetal cover between aspects and elevations. Alder was prominent among shrubs in its preference for the west aspect at higher elevations (table 3). Willow was most abundant on west slopes at lower elevations. Snowbrush cover was nearly three times greater on south aspects than west and had slightly greater vegetative development at upper elevations.

The difference in cover and frequency between aspects was striking for pinegrass--on south-facing slopes, cover and frequency were 1.25 and 63 percent, respectively, compared with 0.15 and 16 percent on west aspects. Pinegrass, however, displayed no elevation preference.

Bracken fern reached its greatest cover development on south aspects at lower elevations. Cover and frequency were twice as great on south as on west aspects and five times greater at low than at high elevations. Both vegetative cover and frequency of fireweed were greatest on the south aspects at higher elevations.

Table 3.--*Vegetative cover and frequency distribution by aspect and elevation*

Species	Aspect				Elevation			
	South		West		Low		High	
	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency
	Percent							
Shrubs								
Purshia tridentata	(1/)	7	0	0	0.01	9	0	0
Ribes spp.	(1/)	5	0	0	(1/)	2	(1/)	3
Ceanothus velutinus	1.40	92	.46	82	.82	94	1.05	80
Pachistima myrsinites	.16	30	.02	18	.01	12	.16	34
Rubus spp.	0	0	(1/)	2	(1/)	2	0	0
Alnus sinuata	(1/)	2	.42	20	.01	5	.38	15
Salix spp.	.32	15	.66	27	.73	24	.26	18
Chimaphila umbellata	(1/)	5	.12	2	(1/)	2	.11	5
Arctostaphylos uva-ursi	(1/)	5	.03	9	.03	11	(1/)	3
Spiraea betulifolia	.52	72	.48	77	.36	76	.63	72
Vaccinium spp.	0	0	.01	2	(1/)	2	.01	8
Amelanchier alnifolia	(1/)	7	(1/)	2	(1/)	9	0	0
Prunus emarginata	(1/)	3	(1/)	4	0	0	(1/)	6
Total shrubs	2.40	--	2.20	--	1.97	--	2.60	--
Grasses and grasslike								
Poa sandbergii	(1/)	3	0	0	(1/)	2	(1/)	2
Bromus carinatus	.02	5	0	0	(1/)	2	.01	3
Calamagrostis rubescens	1.25	63	.15	16	.75	51	.70	31
Festuca ovina	.17	60	.30	55	.30	55	.17	61
Carex rossii	.05	60	.09	41	.08	62	.06	41
Dactylis glomerata	1.40	67	.92	66	1.01	65	1.31	67
Phleum pratense	.09	48	.16	41	.19	36	.06	52
Lolium perenne	.01	22	.02	14	.03	18	.01	18
Agropyron spicatum	.01	10	.01	7	.02	11	(1/)	7
Stipa occidentalis	.03	5	.01	5	.04	11	0	0
Bromus tectorum	.03	5	(1/)	5	.03	5	(1/)	5
Oryzopsis exigua	(1/)	2	(1/)	2	(1/)	4	0	0
Total grasses and grasslike	3.06	--	1.66	--	2.45	--	2.32	--

Forbs

Balsamorhiza sagittata	.01	2	0	0	.01	2	0	0
Zigadenus paniculatus	(1/)	3	0	0	(1/)	4	0	0
Malvastrum spp.	(1/)	2	0	0	0	0	(1/)	2
Luina nardosmia	.17	3	0	0	0	0	.17	3
Smilacina racemosa	(1/)	2	0	0	0	0	(1/)	2
Pteridium aquilinum	2.27	48	1.00	20	2.99	60	.45	11
Epilobium angustifolium	.29	68	.13	61	.18	69	.24	61
Mentzelia dispersa	.11	12	.01	5	.13	16	(1/)	2
Gayophytum nuttallii	.15	40	.04	21	.17	47	.03	16
Collomia grandiflora	.01	3	(1/)	4	.01	7	0	0
Collinsia parviflora	.08	3	.05	20	.11	41	.02	13
Sedum stenopetalum	0	0	.01	2	0	0	.01	2
Erythronium spp.	0	0	(1/)	2	0	0	(1/)	2
Hydrophyllum capitatum	0	0	.02	4	.01	2	(1/)	2
Lomatium brandegei	0	0	.01	11	.01	9	.01	2
Allium spp.	0	0	(1/)	2	(1/)	2	0	0
Clarkia rhomboidea	0	0	.01	7	.01	5	(1/)	2
Erysimum asperum	0	0	.02	7	.02	5	(1/)	2
Conyza canadensis	0	0	(1/)	5	(1/)	4	(1/)	2
Clematis ligusticifolia	0	0	(1/)	5	(1/)	2	(1/)	3
Eriogonum spp.	(1/)	2	.05	12	.05	9	(1/)	5
Lupinus sulphureus	.12	12	.22	14	.15	20	.18	7
Arenaria macrophylla	.01	5	.04	20	(1/)	7	.04	16
Cryptantha simulans	.17	32	.16	27	.31	47	.03	13
Apocynum androsaemifolium	.86	68	.90	46	1.02	56	.75	56
Epilobium paniculatum	.01	8	(1/)	7	.01	13	(1/)	3
Hieracium cynoglossoides	.01	8	.01	11	.02	14	.01	5
H. albiflorum	.01	5	.01	2	.01	4	.01	3
Arnica cordifolia	.07	3	.02	7	.01	5	.07	5
Calochortus lyalli	(1/)	3	(1/)	8	(1/)	5	0	0
Montia perfoliata	.01	7	.01	9	.03	16	0	0
Anaphalis margaritacea	(1/)	5	(1/)	7	(1/)	11	(1/)	2
Phacelia hastata	.04	15	.01	14	.03	18	.02	11
Senecio integerrimus	(1/)	2	(1/)	2	(1/)	2	(1/)	2
Collomia tinctoria	.04	13	.01	9	.04	14	.01	8
Achillea millefolium	.03	22	.01	11	.03	27	.01	7
Melilotus officinalis	.01	32	.02	16	.01	25	.02	23
Polygonum majus	(1/)	5	(1/)	9	(1/)	9	(1/)	5
Unidentified forbs	(1/)	--	(1/)	--	(1/)	--	(1/)	--
Total forbs	4.48	--	2.77	--	5.37	--	2.08	--
Total, all classes	9.94	--	6.63	--	9.79	--	7.00	--

1/ Vegetative cover less than 0.01 percent.
NOTE: Individual values do not add up to totals shown because of rounding and because of exclusion of values less than 0.01 percent.

Annual species, such as gilia (*Collomia grandiflora* Dougl. ex Lindl.), littleflower collinsia (*Collinsia parviflora* Lindl.), and cryptantha (*Cryptantha simulans* Greene), achieved their maximum cover at the lower elevations. Vegetative cover of annual plants was 0.87 percent there compared with 0.09 percent at higher elevations. Annuals, however, appeared to show no aspect affinity.

Of the seeded grasses, hard fescue and timothy showed the greatest cover development on west aspects at lower elevations; whereas orchardgrass appeared to grow equally well on both aspects and at low and high elevations.

Some species were restricted in their distribution between elevations and aspects. Bitterbrush, Sandberg bluegrass (*Poa sandbergii* Vasey), mountain brome (*Bromus carinatus* Hook. & Arn.), arrowleaf balsamroot, and luina (*Luina nardosmia* (Gray) Cronq.) were encountered only on the south aspect. Thimbleberry (*Rubus* spp.), huckleberry (*Vaccinium* spp.), stonecrop (*Sedum stenopetalum* Pursh), waterleaf (*Hydrophyllum capitatum* var. *capitatum* Hook), and lomatium (*Lomatium brandegei* (Coult. & Rose) Macbr.) were found only on west-facing slopes.

Species confined to low elevations included western needlegrass (*Stipa occidentalis* Thurb.), bitterbrush, serviceberry, arrowleaf balsamroot, and miner's lettuce (*Montia perfoliata* (Donn) Howell). Bitter cherry (*Prunus emarginata* (Dougl.) Walpers) and luina occurred only at higher elevations.

Differences in total vegetative cover between aspects appear to be mainly the result of higher cover and frequency on the south aspects of snowbrush ceanothus, pinegrass, and bracken fern. Greater abundance of willow, bracken fern, and annual forbs at low elevations probably explains the greater cover found there than at higher elevations. Also, sparse vegetal cover on the west aspect of Fox Creek at higher elevations was a primary factor in elevation differences.

Mueggler observed an affinity of alder for north slopes, whereas snowbrush ceanothus and bracken fern preferred southerly exposures Distributions observed on the Entiat watersheds are similar, with alder showing a preference for the relatively cooler, more mesic west exposure, and snowbrush and bracken fern an affinity for the more xeric south slopes. Mueggler found development of dogbane to be greatest on south exposures but apparently detected no aspect preference for pinegrass. Results of the Entiat study were in direct contrast--dogbane showed no aspect differences but pinegrass had a strong affinity for south slopes.

We found some elevation differences which correspond with those of Mueggler and some that were contrasting. Willow and western yarrow (*Achillea millefolium* L.) reached their greatest development at elevations below 1,100 m. in both studies. We found that bracken fern was most abundant at lower elevations, and pinegrass cover and frequency were similar at both elevations. In Mueggler's study, bracken was apparently the same at low (less than 1,100-m.) and high (greater than 1,280-m.) elevations, and pinegrass preferred low elevations.

Unidentified tree seedlings were encountered on nearly every transect, averaging 0.78 seedling/$m.^2$. Burns Creek had the lowest density of tree seedlings (0.3/$m.^2$), and Fox Creek had the highest (1.5/$m.^2$).

CONCLUSIONS

Comparison of the total vegetal cover on Fox Creek (control) with that on the seeded watersheds and the fact that seeded grasses comprised 64 to 78 percent of the grass and grasslike plants indicate that seeding is an effective means of supplementing regrowth of native species to provide vegetal cover after wildfire.

According to Friedrich's (1947) description, a site such as that on the west face of Fox Creek (unseeded, unfertilized watershed) is the type best suited for successful seeding. Comparison of the vegetal cover on similar sites in seeded watersheds tends to support this conclusion. Whereas the stream bottom and the west slope of Fox Creek were nearly devoid of vegetation, areas of the same habitat type with dense residual overstory of dead trees and slopes of 30 to 40 percent in the seeded watersheds supported vigorous stands of seeded species. For example, on one transect in McCree Creek, cover of orchardgrass was 8.5 percent. Thus, it is likely that vegetative cover of Fox Creek could have been improved by seeding.

The fact that McCree Creek had the lowest cover of seeded species of the three seeded watersheds may have been the result of a reduced seeding rate. In designing the study, we intended to seed only the upper two-thirds of McCree Creek so we could determine the effect of urea fertilization on regrowth of the native species on the lower third. Drift of seed into the lower third of the watershed was great enough to substantially reduce the seeding rate on the upper two-thirds.

Effectiveness of fertilizer treatments in promoting growth the first year is questionable at this point. Despite the greater total vegetal cover on Burns Creek (fertilized with ammonium sulfate), seeded species comprised a greater portion (32 percent) of the total vegetal cover in Brennegan Creek (unfertilized) than in any other watershed. These results are contrary to those of a pot study by Klock et al. (1971), which showed that orchardgrass yields on these soils fertilized with 50 and 200 p. p. m. of ammonium sulfate were two and seven times greater, respectively, than without fertilization. Perhaps the rate of fertilization was too low to give a detectable response the first year.

Vegetative composition is an important factor contributing to differences in total vegetal cover between Burns and McCree, the two fertilized watersheds. Whereas they both displayed about the same vegetal cover of seeded species, native grasses, and forbs, Burns Creek had a much higher percentage of shrubs than McCree Creek.

Observations in the early summer of 1972 indicated that the vegetal cover of Burns and McCree Creeks was substantially higher than on Fox or Brennegan Creeks. Also, vigor of seeded species appeared to be much greater on the fertilized watersheds than on unfertilized Brennegan Creek.

Although we have no way of assessing the benefit of seeding and fertilization relative to the cost of application of $38, 400 for the three watersheds (Perkins et al. 1971), observations indicate that seeded grasses helped reduce soil erosion resulting from overland flow during high intensity summer storms (fig. 5).

Acknowledgment: The assistance of Donald L. Gerber, forestry research technician, in the field phase of this study is gratefully acknowledged.

Figure 5.--*Vegetal cover resulting from seeding reduced channel scouring during a high-intensity rainstorm.*

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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IMPORTANCE OF TIMBER-BASED EMPLOYMENT TO THE DOUGLAS-FIR REGION, 1959 TO 1971

by

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ABSTRACT

Contrary to substantial increases in total employment in the Douglas-fir region from 1959 to 1971, employment in timber-dependent industries declined slightly. Only three of the 14 economic areas in the region matched national employment gains in these industries. Although economies that were highly dependent upon timber in 1959 still were in 1971, in nearly every instance a smaller proportion of economic base employment was concentrated in the timber-dependent industries.

Keywords: Employment, economic conditions, timber, forest products, Oregon, Washington.

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

In 1968 the Pacific Northwest Forest and Range Experiment Station evaluated the importance of timber-based industries to the economy of the Douglas-fir region.[2] This report expands that work to include trends in timber-based employment for a 12-year period for each of 14 economic areas of western Oregon and western Washington. We also trace the role over time of the timber-based industries as producers of goods and services for markets beyond those local areas.

REGIONAL EMPLOYMENT INCREASED BY 25 PERCENT IN THE 1960'S

The 1960's saw total employment in the Douglas-fir region rise by more than 25 percent--from 1,267,000 to 1,621,000 in 1970. The rate of increase in employment in the service or noncommodity-producing industries was about twice the rate of increase in the commodity-producing sectors. Employment in the latter, which includes timber-dependent industries, fluctuated more often than the noncommodity-producing sectors in response to changes in general economic conditions.

These trends in total employment during the 1960's are revealed in year-to-year changes in the numbers of "covered" employees, that is, those employees who are covered by unemployment insurance in Oregon and Washington (fig. 1). These figures, which are the most complete up-to-date annual series on employment available, include about two-thirds of the total employment reported for the region in the 1970 U.S. Census of Population. A smaller proportion of total service industry workers than total commodity-producing workers is included, however, in the covered employment series.[3] While the numbers of total employees for individual years can only be approximated, trends in total employment changes are accurately indicated.

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[2] Wilbur R. Maki, Con H. Schallau, and John H. Beuter. Importance of timber-based employment to the economic base of the Douglas-fir region of Oregon, Washington, and northern California. USDA For. Serv. Res. Note PNW-76, 6 p., illus., 1968. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

[3] Throughout this paper we rely on covered employment estimates because total employment estimates are available only for census years. Any adjustments to covered employment data for intervening years would be arbitrary.

Ratios of covered to total employment	*1960*	*1970*
Commodity	0.70	0.80
Service	.53	.58
All	.60	.65

Among commodity employees, agricultural-related forestry workers are notably under-represented in covered employment figures.

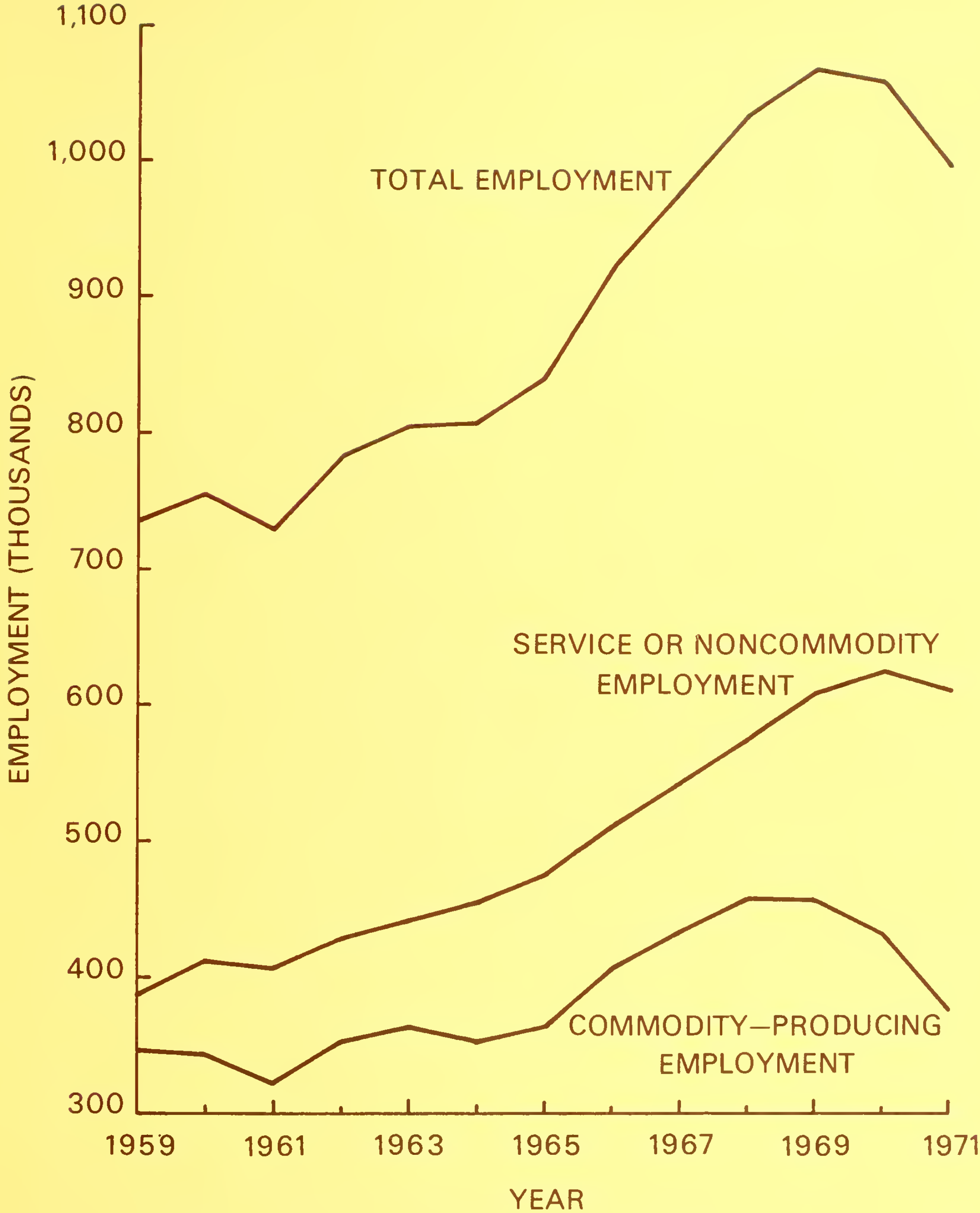

Figure 1.--*Covered employment in the Douglas-fir region of Oregon and Washington, 1959-71.*

EMPLOYMENT IN TIMBER-DEPENDENT INDUSTRIES DECREASED SLIGHTLY

The timber-dependent industries[4/] in the region did not share in the substantial growth in employment. In 1971 there were slightly fewer employees in these industries than there had been 12 years earlier. Although Oregon held its own, timber-industry employment decreased 8 percent in Washington, causing a 3-percent drop in the combined areas.

CHANGES IN EMPLOYMENT TRACED FOR 14 ECONOMIC AREAS

To explore employment changes in relatively small areas, we divided the 38-county region into 14 economic areas, based essentially on commuting distances and shopping patterns (fig. 2). The largest and most rapidly growing city in each economic area is identified as the growth center. The growth center and other communities in each economic area are linked together by a variety of economic ties.

In Oregon, employment trends from 1959 to 1971 were mixed. To illustrate, we selected covered employment in the lumber and wood products industries (including furniture and fixtures).[5/] Astoria and Corvallis suffered decreases of 26 and 18 percent, respectively, and Portland and Eugene showed increases of 9 and 12 percent in this industry group (table 1). In Washington, the trend was nearly all downwards: only Port Angeles showed a substantial gain.

To permit measuring the performance of these local industries against the performance of the national lumber and wood products industries, we broke down the employment figures further. We reasoned that some causes of employment changes were local, and others were the result of

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[4/] Here we define the timber-dependent industries in terms of the Standard Industrial Classification (SIC) categories, including "forestry" (SIC 08), "lumber and wood products" (SIC 24), "furniture and fixtures" (SIC 25), and "paper and allied products" (SIC 26).

[5/] We selected the two-SIC industry group (SIC 24 and SIC 25) because of its comparability with the industry grouping in the U. S. Census of Population reports for 1960 and 1970.

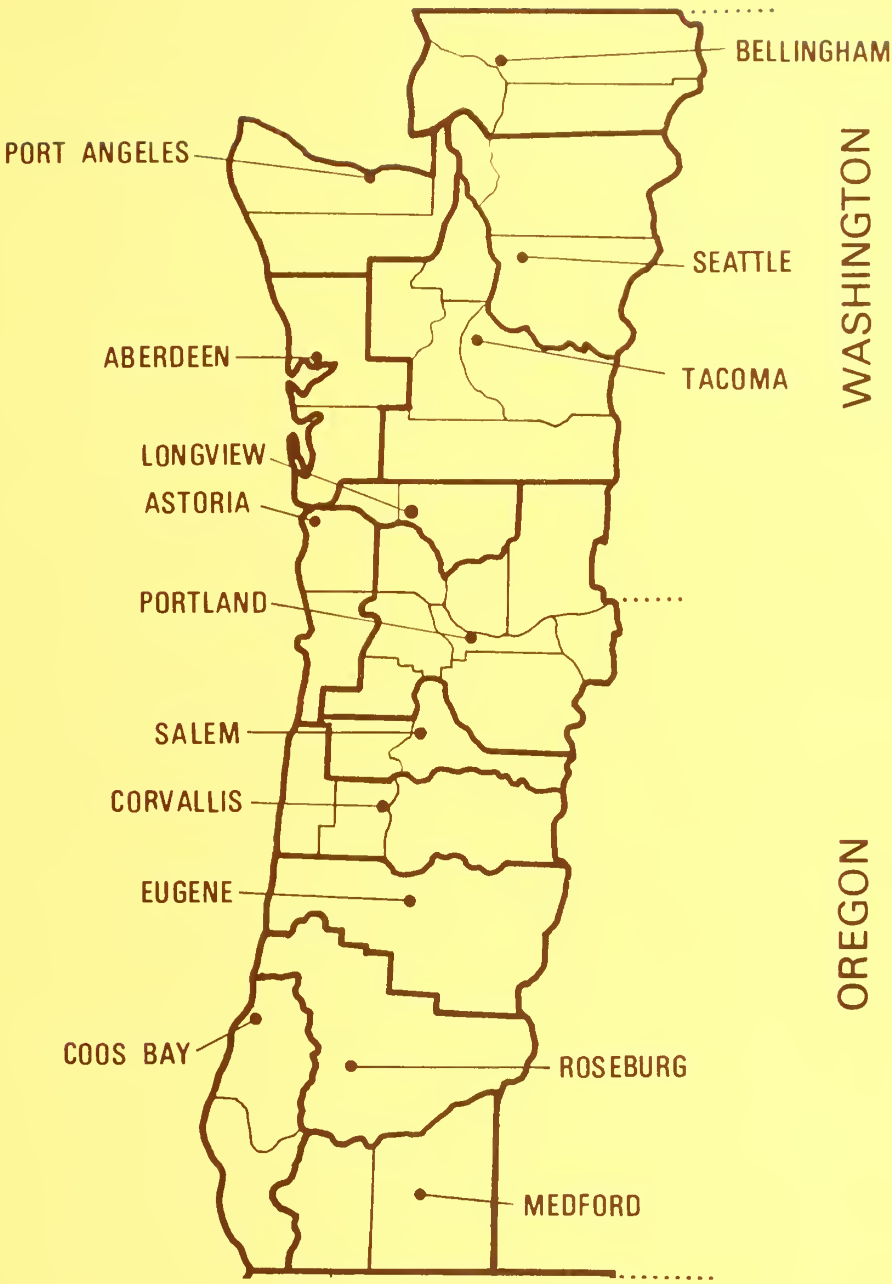

Figure 2.--*Economic areas and growth centers in Douglas-fir region of Oregon and Washington.*

TABLE 1.--*Estimated total changes and those due to local conditions in covered employment in the lumber and wood products industries in western Oregon and Washington, 1959-71*

Economic area	Total covered employment		Percent actual change in employment					Percent change in employment due to local conditions 1/				
	1959	1971	1959-62	1962-65	1965-68	1968-71	12-year period	1959-62	1962-65	1965-68	1968-71	12-year period
Oregon areas:												
Astoria	2,997	2,233	2	-15	0	-14	-26	5	-22	-4	-12	-32
Coos Bay	7,441	6,560	-4	3	-4	-8	-12	-1	-4	-8	-6	-19
Corvallis	8,101	6,657	-4	4	-7	-11	-18	-1	-3	-11	-9	-25
Eugene	11,859	13,318	13	10	-5	-4	12	16	3	-10	-2	6
Medford	5,968	6,068	-11	10	12	-7	2	-8	2	7	-5	-5
Portland	12,125	13,253	1	11	12	-13	9	4	4	8	-11	3
Roseburg	7,315	7,709	-9	15	-7	8	5	-6	8	-12	10	-1
Salem	2,490	2,284	7	10	-8	-15	-8	10	2	-13	-13	-15
Oregon total	58,296	58,082	-2	8	0	-7	0	1	1	-5	-6	-7
Washington areas:												
Aberdeen	6,548	4,862	-8	15	-1	-30	-26	-5	7	-5	-28	-32
Bellingham	1,963	1,646	-3	3	4	-19	-16	0	-5	-1	-17	-23
Longview	5,160	5,338	-10	17	-4	2	3	-7	10	-8	4	-3
Port Angeles	1,802	2,034	0	2	23	-11	13	3	-5	19	-9	6
Seattle	9,571	8,905	-5	-2	6	-6	-7	-2	-10	1	-4	-14
Tacoma	11,035	10,570	-7	7	3	-7	-4	-4	0	-1	-5	-11
Washington total	36,079	33,355	-6	7	3	-10	-8	-3	0	-1	-9	-14
Douglas-fir region	94,375	91,437	-3	8	1	-9	-3	0	0	-3	-7	-10

1/ Calculated as the difference between actual change and change that would have just matched national employment changes in the lumber and wood products industries of:

Period	Percent change
1959-62	-3.0
1962-65	7.3
1965-68	4.5
1968-71	-1.9
12-year	6.7

national industry trends.[6] This led to a series of calculations such as the following:

1. Between 1959 and 1962, nationwide covered employment in the lumber and wood products industries declined by about 3 percent.

2. Employment in the lumber and wood products industries in the Astoria area in 1959 was 2,997. If the area had exactly mirrored national trends, 91 jobs would have been lost.

3. In fact, 50 jobs were gained in the lumber and wood products industries in the Astoria area between 1959 and 1962. This was about 2-percent gain in employment.

4. The difference between the projected loss of 91 jobs and the actual gain of 50 jobs must have been due to local conditions. This difference of 141 jobs, expressed as a percentage [5 percent = 2 percent - (-3 percent)] in table 1, is defined as the change in employment due to local conditions.

DECREASES IN LOCAL EMPLOYMENT NOT EXPLAINED BY NATIONAL TRENDS

National employment in the lumber and wood products industries went down from 1959 to 1962, up from 1962 through 1968, and down again from 1968 to 1971. For the 12-year period there was a 7-percent net increase.

Local influences on employment for the most part were negative. Only in the Portland, Eugene, and Port Angeles areas did local conditions lead to exceptional increases in employment. None of the other areas increased to the extent that would be expected on the basis of national trends; half the areas suffered substantial losses.

For the most part, area employment factors are closely associated with the local conditions of sustained timber utilization and employment in each of the 14 areas. Included in these local considerations is the relative competitive position of the particular area for the lumber and wood products industries group.

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[6] This kind of bookkeeping breakdown is known as a shift-share analysis. The reader is referred to L. D. Ashby, The geographical redistribution of employment: an examination of the elements of change, Surv. Curr. Bus. 44: 13-20, 1964. An application to the southern forest industry is given by George F. Dutrow, Shift-share analysis of southern forest industry, 1958-1967, Forest Prod. J. 22:10-14, 1972.

RELATIVE IMPORTANCE OF WOOD PRODUCTS INDUSTRIES TO LOCAL ECONOMIES DECLINING

We know that total employment in the Douglas-fir region increased substantially from 1959 to 1971. And we know that during the same period there was a slight decrease in employment in the timber-dependent industries. This suggests that these industries have become less important, at least with reference to total covered employment.

Further analysis shows that the timber-dependent industries are less important, also, in terms of the region's economic base. In 1959, these industries accounted for 46 percent of the economic base; by 1971, the percentage had declined to 40. Thus, the timber dependency of the regional economy had declined measurably during the 1959-71 period.

IMPORTANCE OF INDUSTRIES MEASURED BY CONTRIBUTION TO ECONOMIC BASE

Our measurement of the importance of timber-based employment starts with an identification of those industries which produce goods and services for markets outside their local areas. Most commodity-producing employment, such as in the lumber and wood products industries, is classified as part of this economic base. In contrast, most service employment, such as in barber shops, schools, and local governments, is geared to local needs. Dollar inflows from nonlocal sales of the products of economic base industries are used in buying locally-produced goods and services. Generally, the economic vitality of a community depends on the success of its economic base.[7/]

To evaluate the contribution of a particular industry to the economic vitality of an area, we estimate its relative importance in the area's economic base. We accept the national percentage distribution of employment among industries as a norm. For any sector of an area's economy, an industry with employment in excess of this norm is considered to be producing for export markets and, therefore, is part of the area's economic base.

Consider the Roseburg economic area. In 1970, 26.2 percent of all employees, including those not under unemployment insurance, worked for

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[7/] Charles M. Tiebout. The community economic base study. Suppl. Pap. No. 16. New York, Comm. Econ. Dev., 1962. See also, Edward L. Ullman, Michael F. Dacey, and Harold Brodsky. The economic base of American cities. Monogr. No. 1. Seattle, Cent. Urban & Reg. Res., Univ. Wash., 1969.

the timber-dependent industries. In the United States as a whole, 1.5 percent of all workers were in this group. Therefore, based on just these industries, 24.7 percent of all the Roseburg area employees were in excess employment. Those 5,967 employees were producing for sales outside the economic area; they were part of the area's economic base. All other industries together contributed another 975 workers in excess employment. Thus, about 86 percent of the Roseburg area excess base of 6,942 workers were in the wood products industries. We label this percentage the timber-dependency ratio. We use the corresponding ratio based only on covered employment data, which is available on an annual basis, as the timber-dependency indicator.[8/]

TWELVE-YEAR TREND SHOWS DECREASING TIMBER DEPENDENCY

Figure 3 shows that most of the economies that were highly dependent upon timber in 1959 were still highly dependent 12 years later. But in nearly every instance, the timber-dependent industries made up a declining share of the economic bases.

The relative importance of timber-based employment decreased substantially in a number of economic areas (table 2). However, if we define as highly timber-dependent those areas with a timber-dependency indicator of 70 percent or greater, half the economic areas were still highly timber-dependent in 1971. The region as a whole still relies heavily on timber-based employment to bring in money from outside the individual economic areas. Thus, the economies of at least half of the economic areas in the Douglas-fir region are extremely vulnerable to the ups and downs of the timber-dependent industries.

8/ Our analysis overestimates the degree of timber dependency of those areas with significant excess employment in industries not included in the covered employment series. However, the timber-dependency indicators are useful as measures of the direction of changes in timber dependency for given economic areas.

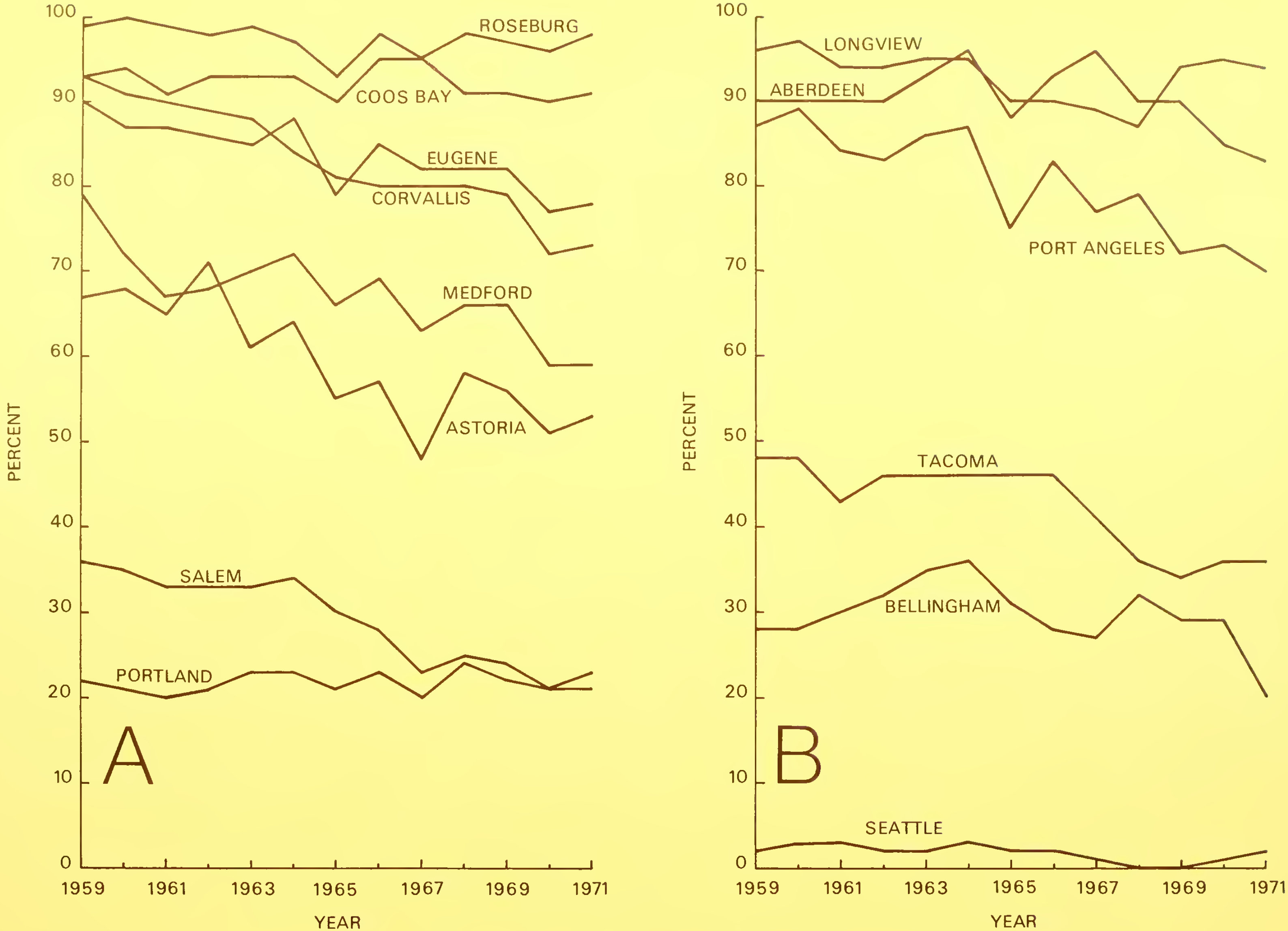

Figure 3.--*Excess employment indicators of timber dependency of economic areas from 1959 to 1971: A, Western Oregon; B, western Washington.*

TABLE 2.--*Classification of economic areas by degrees of dependency upon timber-based employment, 1959 and 1971*

Degree of dependency	Economic area	Percentage of excess employment in wood products industries	
		1959	1971
Slight	Seattle	2	2
	Portland	22	21
	Salem	36	23
	Bellingham	28	20
Moderate	Tacoma	48	36
	Astoria	67	53
	Medford	79	59
High	Port Angeles	87	70
	Corvallis	93	73
	Eugene	90	78
	Aberdeen	90	83
	Coos Bay	93	91
	Longview	93	94
	Roseburg	99	98
	Douglas-fir region	46	40

GPO 988-499

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-197 March 1973

ESTIMATING DUNNING'S SITE INDEX FROM PLANT INDICATORS

by

Colin D. MacLean

and

Charles L. Bolsinger

ABSTRACT

In California, selective cutting often removes most or all trees suitable for measuring site index. For such areas, an alternative method is described whereby site index is related, through multiple regression analysis, to the occurrence of indicator plants and certain physical variables.

Four equations are presented for estimating Dunning's site index: one for each of four geographic areas covering about 70 percent of California's forest land. The equations account for 55 to 64 percent of the total variation in site index. Independent tests indicate that they predict site index with a standard error of estimate averaging about 20 feet at the base age of 300 years.

Keywords: Site index, classification, indicator plants.

INTRODUCTION

Dunning's site class[1] is a widely accepted measure of timber productivity throughout the mixed conifer forests of California. It is intended for use in the mixed-age, mixed-species stands that typify much of that State's forests. Although not associated with yield tables, these site classes are widely used to rank lands by their capacity to grow timber.

Estimates of Dunning's site class are derived from a family of six site-curves harmonized to intercept 25-foot intervals at the reference age of 300 years. Although Dunning intended that they be expressed in discrete classes, the use of the continuous variable form--site index--is often more convenient.

Site index is determined by measuring the height and age of typical dominant trees in the stand--a procedure that poses no particular problem as long as the dominant trees are present. However, many California stands have been selectively logged, leaving only the shorter codominant and intermediate trees. In other areas, the trees have been destroyed by fire, leaving a semipermanent brush field in their place. In both cases, the absence of dominant trees makes conventional site class measurements impossible or unreliable. In addition, many areas are stocked with trees too young to permit reliable estimates of site index. In short, substantial areas of forest land lack suitable site trees.

THE STUDY

We recently investigated the possibility of estimating Dunning's site index, using a multiple regression equation based on plant indicators and physical characteristics. This study is a byproduct of a larger study aimed at improving estimates of productivity.[2] In that investigation, we used multiple regression analysis of plant indicators and other likely variables such as slope, aspect, and elevation to develop equations for predicting stocking capacity. Many of these same factors have proved useful in predicting Dunning's site index. Thus, we have been able to use data collected for the productivity study to develop site index prediction equations for four geographic areas covering a large part of California.

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[1] Duncan Dunning. A site classification for the mixed conifer selection forests of the Sierra Nevada. USDA Forest Serv. Calif. Forest & Range Exp. Stn. Res. Note 28, 21 p., 1942.

[2] Colin D. MacLean and Charles L. Bolsinger. Estimating productivity on sites with a low stocking capacity. Pac. Northwest Forest & Range Exp. Stn. USDA Forest Serv. Res. Pap. PNW-152, 18 p., illus., 1973.

DEVELOPING THE EQUATIONS

Our approach was suggested by the work of James Griffin[3] who related Dunning's site class to elevation and a soil drought index developed by him for use in eastern Shasta County, California. Griffin also demonstrated that soil drought index could be replaced by vegetative drought index--a soil moisture rating determined by the species of plants that occur on a site. However, rather than use vegetative drought index, we elected to relate the plant species growing on a site directly to the site class.

Dunning's site index was measured for the productivity study on 81 to 177 well-distributed locations in each of four separate geographic areas (fig. 1) chosen on the basis of climate, geology, and, to some extent, Forest Survey work plans. Area 3 bounds area 4 on the Sierra Divide. Otherwise, the boundaries conform either to county lines or the lower limits of commercial forest. Sampling covered the range of natural conditions but was restricted to relatively undisturbed locations. We visited each location once during the growing season and identified all recognizable plant species. We also recorded latitude and such topographic features as slope, aspect, elevation, soil depth, and physiographic class.

Plots were located in stands with uniform site characteristics. At each location, we measured the height and age of several dominant trees and searched an area of about an acre to insure finding all species of plants. The only plant species not recorded were those growing on microsites with obviously different site characteristics--i.e., rock outcrops and abandoned roadbeds.

For each unit, the species list was reduced to about 60 by screening out plants that were either hard to identify or apparently unrelated to site index. The list was further reduced by grouping plants that often grow together. The remaining plants and plant groupings plus the various topographic variables were entered in a stepwise multiple regression program with each species or species group treated as a dummy variable with a value of 1 if present and 0 if absent. Dunning's site index--the dependent variable--was entered as precisely as it could be read from Dunning's site curves.

From this analysis, we developed four equations--one for predicting Dunning's site index in each of the four geographic areas. The variation accounted for ranged from 55 to 64 percent (table 1), and the standard errors of estimate averaged about 20 feet when measured against the basic study data.

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[3] James R. Griffin. Soil moisture and vegetation patterns in northern California forests. Pac. Southwest Forest & Range Exp. Stn. USDA Forest Serv. Res. Pap. PSW-46, 22 p., 1967.

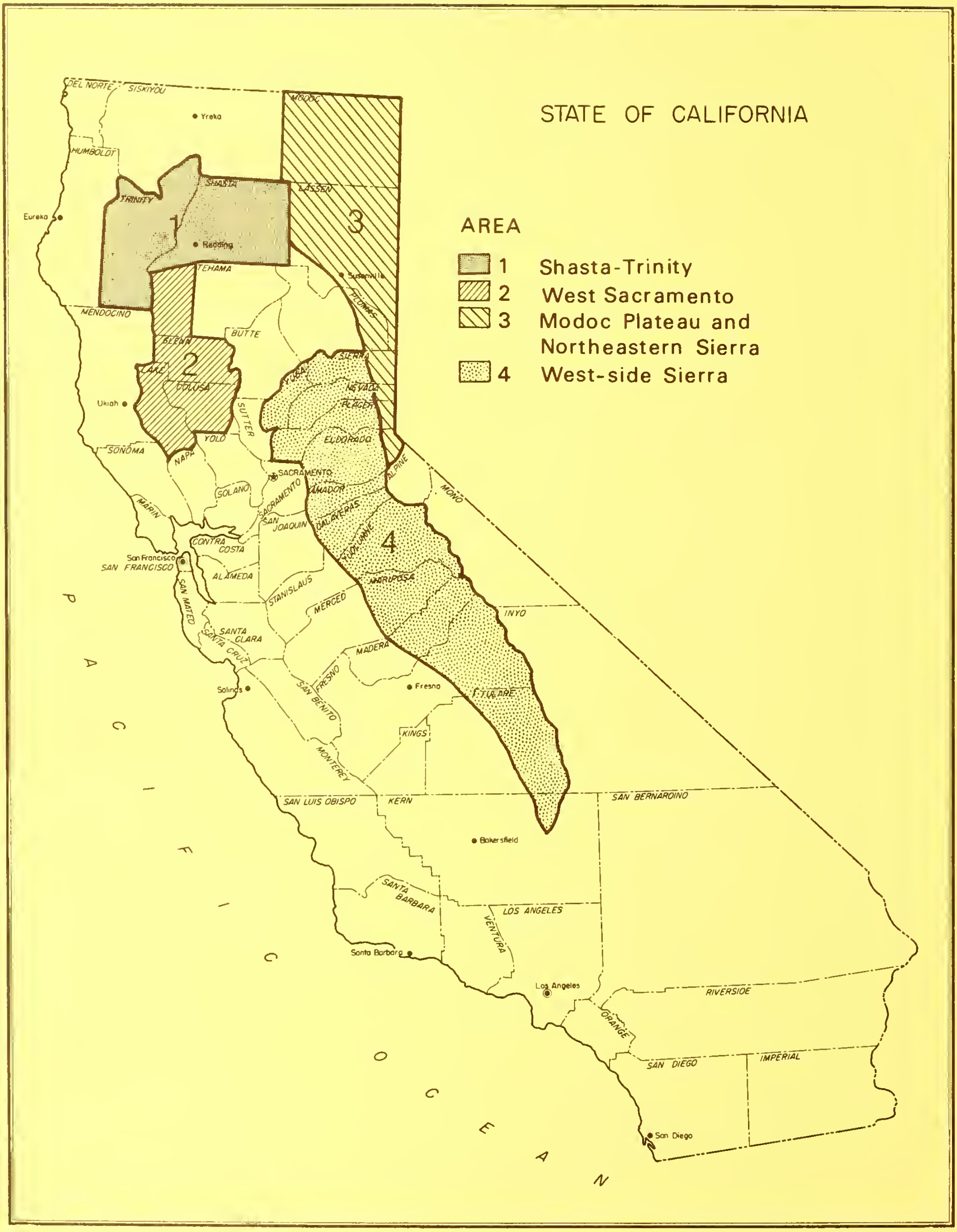

Figure 1.--State of California showing the four geographic areas sampled for this study.

Table 1.--*Reliability of equations for predicting Dunning's site index for four geographic areas in California*

Reliability indicators	Shasta and Trinity	West Sacramento	Modoc Plateau and Northeastern Sierra	West-side Sierra
Number of plots to develop equation	97	81	95	177
R^2	0.64	0.55	0.55	0.60
Standard error of estimate (feet)	19.4	21.8	14.3	18.6
Number of plots in independent test	162	22	89	55
Standard error of estimate for independent test (feet)	20.3	21.4	14.6	19.8
Equation bias in independent test (feet)[1/]	+0.2	+5.5	-0.4	-0.2

[1/] Average amount by which equation estimates exceeded or fell short of field measured site index.

We also tested each of the equations against field data not used in the regression analysis. The test plots sampled disturbed conditions, particularly partial cuts, much more heavily than the original sample. In other respects, the test plots generally represented the same range of conditions sampled for the regression analysis in all areas except the west Sacramento area. There, the few test plots available to us sampled a narrow range of site indices. Further testing of this equation would be desirable.

We anticipated that the test results might show the equations to be less reliable than the multiple regression analysis would indicate. This proved true, but the drop in precision was small (see table 1). Equation results were neither significantly higher nor lower than field measured site index. The small amount of bias that did occur--5.5 feet in the west Sacramento area--was probably an accident of sampling.

Although many of the test plots had been heavily logged, the equations appeared to work here as well as on undisturbed areas. This finding agrees with Griffin's (see footnote 3) observation that "most of the 'usable' indicator plants can be found in most habitats even after drastic disturbance." Of necessity, the test plots were restricted to sites where suitable site trees were available. We, therefore, lack data on the reliability of the equations under conditions of extreme disturbance--for example, severe burns or clearcuts. Dyrness,[4/] however, working in western Oregon, found plant species to be remarkably persistent, even after clearcutting and burning. Small, unburned remnants of the original ground vegetation proved particularly helpful.

We suspect that the equations may work less well in areas where the tree overstory has been replaced by a semipermanent brush cover. Still, we are not aware of any better means to objectively estimate site index on such areas.

THE EQUATIONS

The four equations follow. All independent variables are "dummy variables" with a value of 1 if present and 0 if absent, except for elevation which is recorded to the nearest 100 feet and latitude which is recorded to the nearest degree. Plant groupings are recorded as present if any of the species in the group is found.

Area 1 (Shasta and Trinity Counties)

$$\text{Dunning's site index} = 138 - 28X_1 - 16X_2 - 10X_3 + 18X_4 + 25X_5 + 15X_6 + 8X_7 + 20X_8 - 9X_9 - 20X_{10} - 24X_{11} - 20X_{12} + 18X_{13}$$

Where:

X_1 = *Pinus monticola* (western white pine)[5/]

[4/] C. T. Dyrness. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology 54(1): 57-69, illus., 1973.

[5/] Scientific names of grasses, herbs, and shrubs follow Philip A. Munz and David D. Keck, A California flora. Univ. Calif. Press, Berkeley, Calif., 1,681 p., illus., 1970. Names of trees follow E. L. Little, Jr., Check list of native and naturalized trees of the United States (including Alaska), U.S. Dep. Agric. Agric. Handb. 41, 472 p., illus., 1953.

X_2 = *Ceanothus cuneatus* (wedgeleaf ceanothus), *Cercocarpus betuloides* (birchleaf mountain-mahogany) or *C. ledifolius* (curlleaf mountain-mahogany)
X_3 = *Rhamnus californica* ssp. *tomentella* (coffeeberry) or *Prunus subcordata* (Sierra plum)
X_4 = *Abies concolor* (white fir)
X_5 = *Castanopsis sempervirens* (bush chinkapin) or *Prunus emarginata* (bitter cherry)
X_6 = *Pteridium aquilinum* (bracken fern)
X_7 = *Quercus kelloggii* (California black oak)
X_8 = *Adenocaulon bicolor* (trail plant), *Disporum* spp. (fairy bells), or *Osmorhiza chilensis* (sweet cicely)
X_9 = *Pterospora andromedea* (pine drops), *Chimaphila umbellata* var. *occidentalis* (prince's pine), or *Smilacina* spp. (false solomon seal)
X_{10} = *Campanula prenanthoides* (California harebell)
X_{11} = *Arctostaphylos patula* (greenleaf manzanita)
X_{12} = *Castilleja applegatei* (paint brush), *Clarkia rhomboidea* (forest clarkia), *Delphinium nuttallianum* (Nuttall larkspur), or *Juniperus occidentalis* (western juniper)
X_{13} = *Wyethia mollis* (woolly mule's ears) or *Balsamorhiza* spp. (balsam root)

Area 2 (Colusa, Glenn, Lake, and western Tehama Counties)

Dunning's site index = $149 + 13X_1 - 15X_2 - 28X_3 - 11X_4 + 24X_5 - 10X_6 + 16X_7 + 23X_8 - 10X_9 - 17X_{10} - 11X_{11}$

Where:

X_1 = *Rhus diversiloba* (poison oak)
X_2 = *Arctostaphylos canescens* (hoary manzanita)
X_3 = *Arctostaphylos manzanita* (common manzanita) or *A. viscida* (whiteleaf manzanita)
X_4 = *Ceanothus cordulatus* (mountain whitethorn) or *C. integerrimus* (deer brush)
X_5 = *Rosa gymnocarpa* (wood rose)
X_6 = *Phlox speciosa* ssp. *occidentalis* (low shrubby phlox)
X_7 = *Pyrola picta* (white-veined shin-leaf)
X_8 = *Montia perfoliata* (miners' lettuce), *Sanicula bipinnatifida* (purple sanicle), or *Stipa californica* (California stipa)
X_9 = *Carex multicaulis* (many stem sedge)

X_{10} = *Pinus sabiniana* (digger pine), *Quercus garryana* (Oregon white oak), *Q. garryana* var. *breweri* (Brewer oak), or *Q. dumosa* (California scrub oak)

X_{11} = shallow soil (soil depth of 1-1/2 feet or less)

Area 3 (Modoc, Lassen, eastern Plumas, eastern Sierra, eastern Nevada, eastern Placer, eastern Eldorado Counties)

Dunning's site index = $155 - 5X_1 - 6X_2 - 15X_3 + 11X_4 - 6X_5 + 7X_6$

$- 13X_7 + 16X_8 + 4X_9 - 19X_{10} - 12X_{11} - 0.008X_{12}$

Where:

X_1 = shallow soil (soil depth of 1-1/2 feet or less)

X_2 = *Montia perfoliata* (miners' lettuce) or *Geum ciliatum* (prairie smoke)

X_3 = *Cercocarpus ledifolius* (curlleaf mountain-mahogany) or *C. betuloides* (birchleaf mountain-mahogany)

X_4 = *Achillea lanulosa* (western yarrow)

X_5 = *Clarkia rhomboidea* (forest clarkia) or *Eriophyllum lanatum* (woolly sunflower)

X_6 = *Osmorhiza chilensis* (sweet cicely), *Smilacina* spp. (false solomon seal), *Chimaphila umbellata* var. *occidentalis* (prince's pine), *Pterospora andromedea* (pine drops), *Pyrola picta* (white-veined shin-leaf), or *P. picta forma aphylla* (leafless pyrola)

X_7 = *Bromus tectorum* (cheat grass) or *Stipa comata* (needle and thread grass)

X_8 = *Abies magnifica* (California red fir)

X_9 = *Ribes* spp. (gooseberry or currant)

X_{10} = *Linanthus ciliatus* or *L. nuttallii* (linanthus)

X_{11} = *Pinus monticola* (western white pine)

X_{12} = $(\text{elevation})^2$

Area 4 (Yuba, western Sierra, western Nevada, western Placer, western Eldorado, Amador, Calaveras, Tuolumne, Mariposa, Madera, Fresno, Tulare, and Kern Counties)

Dunning's site index = $247 - 0.53X_1 - 2.33X_2 - 22X_3 - 14X_4 + 10X_5$

$- 8X_6 - 15X_7 + 13X_8 - 10X_9 + 17X_{10} + 12X_{11}$

$- 10X_{12} - 21X_{13} + 11X_{14} + 7X_{15} - 10X_{16} + 0.0188X_{2,2}$

Where:

X_1 = elevation
X_2 = latitude
X_3 = shallow soil (less than 2 feet deep)
X_4 = *Pinus jeffreyi* (Jeffrey pine)
X_5 = *Ceanothus integerrimus* (deer brush), *C. cordulatus* (mountain whitethorn), or *Ribes roezlii* (Sierra gooseberry)
X_6 = *Stipa californica*, *S. occidentalis*, *S. elmeri* (needlegrass), *Sitanion hystrix* (bottlebrush squirreltail), or *Festuca* spp. (annual fescue)
X_7 = *Corylus californica* (California hazel), *Rubus leucodermis* (western raspberry), or *R. parviflorus* (thimbleberry)
X_8 = *Adenocaulon bicolor* (trail plant), *Disporum* spp. (fairy bells), *Goodyera oblongifolia* (rattlesnake plantain), *Viola lobata* (pine violet), *Pyrola picta* (white-veined shin-leaf), or *P. picta forma aphylla* (leafless pyrola)
X_9 = *Eriogonum latifolium* spp. *nudum*, *E. marifolium*, *E. umbellatum* or *E. virgatum* (wild buckwheat), or *Pedicularis semibarbata* (lousewort)
X_{10} = *Clarkia rhomboidea* (forest clarkia)
X_{11} = *Osmorhiza* spp. (sweet cicely) or *Asarum* spp. (wild ginger)
X_{12} = *Wyethia mollis* (woolly mule's ears) or *Balsamorhiza* spp. (balsam root)
X_{13} = area falls in Kern County (an area where the indicators are associated with a somewhat lower site than the rest of the Sierra)
X_{14} = *Pteridium aquilinum* (bracken fern)
X_{15} = *Abies concolor* (white fir)
X_{16} = *Pinus ponderosa* (ponderosa pine)
$X_{2,2}$ = $(\text{latitude})^2$

USING THE EQUATIONS

The equations are easy to apply. All that is needed is a search of the general area to ascertain which of the plants and other variables are present. The search should be careful enough to find those plants whose occurrence is typically scattered--pine drops, for example. Plants growing on microsites such as springs, rock outcrops, or skid roads should be ignored--all others should be counted even if scarce. Tree species that have been removed through disturbance should also be counted as indicators.

Although learning to identify a dozen or more shrubs, herbs, and grasses may seem a formidable task to some foresters, it really is not. Forest Survey fieldmen--many of them college students from eastern schools--quickly learned to do a satisfactory job of plant identification. Although some of the names may be strange, the plants themselves are familiar to anyone with experience in California forests. Preliminary identification may require the use of one of the many available plant keys or a visit to an herbarium. Others may then be trained quickly by using fresh or pressed specimens.

Substantial areas of northern California were outside the study area. Application of these equations to such areas involves considerable risk of errors and should not be attempted without preliminary testing.

GPO 987-859

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-198 March 1973

TOTAL SOIL NITROGEN ANALYSIS USING MICRO-KJELDAHL DIGESTION AND PORTABLE DISTILLATION EQUIPMENT[1]

by

J. Michael Geist, *Soil Scientist*

ABSTRACT

Equipment modifications and methodology alternatives for determining total nitrogen in soils using a micro-Kjeldahl digestion apparatus were investigated. Results showed that using an air shield over the flask bulbs and a standard copper catalyst-salt mixture should give satisfactory recovery in routine analyses with a running time and sample size similar to that used with macro-Kjeldahl racks. Recovery of several standards was high (96-99 percent), but for recovery of highly refractory compounds, methodology adjustments will be required.

Keywords: Soil analysis, nitrogen, methodology.

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[1] Use of trade, firm, or corporation names is for the information and convenience of the reader and does not constitute an official endorsement or approval by the U.S. Department of Agriculture.

INTRODUCTION

The surge of research in recent decades has created crowded working conditions in many laboratories. Space shortages have encouraged the researcher to use laboratory space more efficiently by employing newer automated instrument methods or smaller versions of larger equipment models when they will do the job required. The latter was my approach to soil nitrogen determinations.

Micro-Kjeldahl equipment is commonly used for plant analyses, and satisfactory results have been obtained with small soil samples (0.2-1.0 g.) ground finer than 80 mesh (Bremner 1960). However, it seemed more desirable to attempt analyses of soil samples similar in size to macro-Kjeldahl samples in order to avoid the grinding, which is required for small sample size, and yet retain reproducibility. In an effort to meet these objectives, micro-Kjeldahl digestion apparatus (Labconco) and portable dual-place distillation equipment (Precision Scientific) were purchased. Both kinds of equipment can be used on the laboratory bench or in hoods without plumbing or electrical modifications.

For methodology consistent with analysis objectives, a number of possible alternatives were considered. Hundreds of variations of the Kjeldahl procedure have been used for N analyses (Kirk 1950). Certainly with the many modifications of digestion time, salts, salt/acid ratios, presoaking, and catalysts, a little experience can lead to considerable frustration in deciding what the proper set of alternatives should be. The best discussions on these topics appear to be those by Kirk (1950) and Bremner (1965b).

The author's early experience resulted in excessive digestion times with slow clearing conditions using the micro-Kjeldahl units; inadequate heating rate for comparatively large samples may have been a reason. The manufacturer's standard heaters (200-watt) were being used with 100-milliliter semi-micro-Kjeldahl flasks, and the digestion units were being subjected to a considerable draft in the hood where they were placed (hood rating 950 cubic feet per minute). An "air shield" was fashioned from galvanized sheet metal to reduce cooling from drafts and surrounding air and to improve heating efficiency. The shield covered the bulb portions but not the necks of the digestion flasks, thus affording lower neck temperatures and refluxing of the sulfuric acid fumes during digestion (fig. 1).

With this equipment modification, an experiment was performed to compare the use of the air shield with other digestion alternatives in an effort to develop a satisfactory method of determining total nitrogen in macro soil samples with the micro-Kjeldahl digestors and portable distillation units.

Figure 1.--*End oblique view of micro-Kjeldahl digestion unit with air shield attached by piano hinge which affords raising and lowering during digestion without interference with controls. The shield can be easily pivoted to check charring, clearing progress, etc.*

METHODS AND MATERIALS

Four alternatives of the digestion phase were considered in conjunction with the same distillation and titration phases of the analyses in a four-treatment randomized block design (a 2 by 2 factorial could have been used but different orthogonal comparisons were desired). Digestion was performed with and without the air shield both in the presence and in the absence of selenium catalyst. A total of 24 soil samples were analyzed in duplicate by each of the four alternative digestion procedures. Samples were reference collections made from upland forest and grassland soils occurring on the Starkey Experimental Forest and Range, 30 miles south of La Grande in Union County, Oregon (Geist and Strickler 1970).

Much of the general procedure which applied to all samples was derived from Bremner (1965b) and Jackson (1958) as follows:

Duplicate 5-gram samples of soil (less than 2-mm.) were placed in 100-milliliter semi-micro-Kjeldahl flasks, and 10 grams of a salt-catalyst mixture called Kel Pac 2 (10 g K_2SO_4:0.3 g $CuSO_4 . 5H_2O$) were added, followed by 30-milliliters concentrated sulfuric acid added so as to wash down the flask neck. The flask was swirled to mix the contents and then placed on the digestion unit. Medium heat was applied for 15-20 minutes and then raised to maximum heat for the duration of digestion. Flasks were rotated occasionally, and a refluxing action of the fumes was maintained one-third of the way up the flask neck. After clearing (greenish-white), digestion was continued for 1.5 hours to complete the digestion phase. Flasks were allowed to cool, and the contents were then transferred to 800-milliliter Kjeldahl flasks using several portions of distilled water totalling about 250 milliliters. Transfer is necessary to achieve adequate volume of distillate. Flasks were then further cooled, after which a few pieces of mossy zinc and 100 milliliters of 50-percent (weight/volume) sodium hydroxide were added and the solution swirled to mix. The flasks were then quickly attached to the distillation unit, heat applied, and about 150 milliliters of distillate collected in boric acid containing brom cresol green and methyl red indicators. Titration with standard hydrochloric acid was taken to a light pink end point. In the cases where the air shield was employed, it was raised into position over the digestion flasks after frothing subsided (15-20 minutes after heat was raised to maximum) and remained there until completion of digestion. In cases where selenium catalyst was included, 25 milligrams of selenium powder was added with the aforementioned salt-catalyst mixture.

Determinations were also made of the soil organic matter content by a modified Walkley-Black procedure (Jackson 1958) and soil texture by hydrometer technique.

Because of concern for heat supply and digestion temperatures discussed by Bremner (1965b), Jackson (1958), and Lake et al. (1951), temperatures of several digestion mixtures were taken at the end of the digestion period using a thermocouple as described by Lake et al.

RESULTS

General note was made of digestion time because of the expected effects from the treatments involved. In the case where neither the shield nor a selenium catalyst was used, the time for clearing varied from 1.5 to 2.5 hours. The color of the samples changed more gradually during digestion and thus made diagnosis of clearing point difficult. The time for clearing was 1 hour or less and was less variable when either the shield or selenium catalyst, or both, were used during digestion. In no case was there a problem with excess volumes, frothing over, or improper refluxing action using 100-milliliter flasks and 5-gram soil samples.

Results of the various analyses are presented in Table 1 which shows the diversity of soils involved. Mean values for total nitrogen indicated increased recovery over the check for all treatments. Orthogonal comparisons verified these differences statistically (F = 59.5 at 0.05 level). There was also a difference in recovery (F = 5.5) between shield or selenium treatments used independently as opposed to both together. Mean values indicated a possible interaction between shield and selenium treatments together; however, this was apparently due to the limited quantity of nitrogen which was reached or approached closely when the treatments were applied together or independently.

Table 1.--*Mean values of duplicate analyses performed on experimental soils*

Soil	Organic matter	Clay content	Soil texture[1/]	Total N			
				No shield or selenium	Shield only	Selenium only	Shield and selenium
	Percent	*Percent*		*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*
1	3.37	23	l	1,568	1,620	1,626	1,633
2	1.78	25	l	1,006	1,059	1,048	1,064
3	1.49	27	l	858	895	894	908
4	6.52	48	c	2,088	2,117	2,120	2,162
5	6.61	41	c	2,181	2,216	2,267	2,315
6	1.82	49	c	807	818	797	796
7	.94	57	c	419	445	431	430
8	.40	35	cl	206	227	219	215
9	1.73	34	cl	712	745	726	743
10	9.08	40	c	3,112	3,157	3,122	3,181
11	4.66	45	c	1,948	2,026	1,980	2,040
12	1.74	39	cl	868	908	894	932
13	6.01	18	l	1,580	1,793	1,791	1,801
14	3.07	22	l	953	1,107	1,038	1,080
15	1.47	29	cl	592	633	654	638
16	3.75	29	cl	1,799	1,878	1,855	1,927
17	2.70	11	sil	765	805	777	782
18	1.29	9	sil	463	473	483	481
19	2.12	10	l	679	666	695	695
20	1.07	9	l	394	410	411	412
21	4.02	27	cl	1,812	1,896	1,951	1,982
22	2.39	31	cl	1,217	1,306	1,280	1,323
23	1.04	43	c	777	789	805	816
24	.56	65	c	338	379	351	369
Mean				1,131	1,182	1,176	1,197

[1/] l = loam, c = clay, cl = clay-loam, sil = silt-loam.

Temperatures of various boiling mixtures at the end of digestion under various combinations of shield, selenium, and soil use are reported in table 2. Flasks covered by the air shield had somewhat higher digestion temperatures than those not covered by the shield. When flasks were placed on a 750-watt heater, all temperatures read the same (358° C.).

Recovery of standard compounds (10-mg. N) indicated sufficient digestion conditions for breakdown and recovery of less resistant materials but insufficient conditions for hydrolysis of refractory compounds such as pyridine (table 3).

Table 2.-- *Temperature of various Kjeldahl digestion mixtures under different digestion conditions 1.5 hours after clearing at 680 mm. Hg. (soil 19)*

Soil content	Salt-catalyst mixture	Sulfuric acid	Selenium powder	Air shield	Temperature
---------*Grams*	----------	*Milliliters*	*Milligrams*		*° C.*
0	10	30	0	No	343
5	10	30	0	No	343
0	10	30	0	Yes	358
5	10	30	0	Yes	353
0	10	30	25	No	340
5	10	30	25	No	343
0	10	30	25	Yes	358
5	10	30	25	Yes	350

Table 3.-- *Standard recovery data under digestion conditions using air shield only*

Compound	Recovery
	Percent
Na_2-EDTA[1/]	96
Glutamic acid	97
Alanine	97
Arginine·HCl	99
Pyridine	61

1/ Disodium (ethylenedinitrilo) tetraacetate dihydrate.

DISCUSSION AND CONCLUSIONS

Use of the air shield or selenium or both shows several advantages over the use of neither in the digestion procedure described. Higher final digestion temperatures, color of the digest, and differences in clearing time all indicated possible higher recovery (verified in table 1). The time saved during digestion is clearly meaningful and results in a digestion time similar to macro-Kjeldahl racks; however, an increase of 45-66 p.p.m. (parts per million) in total N may be inconsequential to those interested only in comparative N content, even though the increases were statistically significant. No time advantage and very little recovery advantage (15-21 p.p.m. N) were gained using both shield and selenium compared with either alone. The need for recovery of these small amounts will depend partly on the intended use of the analysis and one's ability to duplicate the field sample.

In the author's laboratory, routine duplicate analyses for total nitrogen are considered acceptable if they are within a maximum difference of 25 p.p.m. Although the digestion time and recovery levels were about the same for both selenium and the shield, attaching and using the shield is a one-time expense whereas selenium requires measurement and handling in every set of samples. It is emphasized that there were no physical problems involved with using 5-gram soil samples in any of the determinations.

The general effect of selenium found here and by other researchers in the past was a shorter digestion period. There have been reports of losses of nitrogen with selenium; however, it has been recommended that use of low quantities over short digestion periods should avoid such losses (Kirk 1950). If one were to employ higher wattage heaters with a similar shield and selenium, it would be well to check for possible nitrogen losses.

The lower temperatures which existed in unshielded flasks lacking selenium were probably accompanied by slower digestion rates. The net effect was a somewhat lower recovery and a considerably longer clearing time. Addition of selenium apparently counteracted the lower temperature effects on clearing time.

The conditions of digestion proposed by Lake et al. (1951) were designed to accomplish recovery of pyridine and other refractory compounds expected to be present in shale oil or petroleum products. Soils apparently contain very low levels of refractory compounds. Various Kjeldahl methods, modified for recovery of such materials, as well as conventional methods have been shown to give similar analytical recoveries in a variety of soils (Bremner 1960). The organic nitrogen in surface soils exists mainly as bound amino acids and combined hexosamines, and purine and pyrimidine derivatives make up 1 percent or less of the total soil nitrogen. The chemical nature of the remainder is still principally unknown, and the recoverability of fixed-N remains in doubt (Bremner 1965a). Bremner (1965b) recommends a 5-hour digestion after clearing for high accuracy. However, he adds that rarely is recovery less than 98 percent of these values with a 2-hour digestion (for most soils there is no difference), and he suggests that a 1-hour digestion is adequate for routine soil analyses.

Considering the above discussion and standard recoveries reported, I concluded that the method using the air shield with the copper catalyst-salt mixture should yield satisfactory recovery of total N in most soils for routine conditions with a minimum of labor involved. Reasonably large sample sizes should be easily accommodated. In materials where refractory compounds are likely to be present in significant concentration, the proposed method would not be satisfactory without attaining higher final digestion temperatures through increasing the salt/acid ratio or using a longer digestion period, or some combination of both (Lake et al. 1951).

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ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

· USDA FOREST SERVICE RESEARCH NOTE

PNW-199 *April 1973*

MISSION RIDGE - A CASE HISTORY OF SOIL DISTURBANCE AND REVEGETATION OF A WINTER SPORTS AREA DEVELOPMENT [1/]

by

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ABSTRACT

Areas of soil disturbance caused by construction of a winter sports area are identified, and the private operator's use of forest research findings to reduce the effect of these disturbances are reviewed.

Keywords: Environment, skiing, soil management.

1/ *This paper was presented at the National Winter Sports Symposium, Denver, Colo., February 26 to March 2, 1973.*

First, I must acknowledge that I am both a winter sports enthusiast and a U.S. Forest Service research soil scientist interested in conserving nature's delicate balance in the near alpine forest environment. As a skier, I enjoy safe, well-groomed slopes. As a soil scientist, I see the need for minimal environmental impact, particularly with respect to soil disturbance. Recognizing that some compromise must be reached between these two desires, this presentation will attempt to identify the necessity of some soil disturbance at winter sports area developments and provide some of the technical knowledge needed to reduce the effect of these disturbances. In conclusion, an example of one positive relationship between required soil management and winter sports area development, the history of Mission Ridge, a recent ski area development near Wenatchee, Washington, is reviewed.

SOIL DISTURBANCE AND PROTECTION

Three reasons for soil disturbance in a winter sports development such as a ski area can be identified:

(1) construction of buildings and parking facilities,
(2) construction of roads,
(3) construction of trails and summer slope grooming.

Construction of the necessary buildings (lodges, lift towers, maintenance shops, sewage treatment facilities, etc.) and parking area normally involves areas of limited size. The possibility of condominiums or other service facilities increases the size of these areas. Thus, besides having very severe soil disturbance from construction, this area gets very heavy traffic during the operation of the facilities. Many opportunities exist for using landscape techniques for stabilizing disturbed soil areas, including planting of trees, shrubs, and lawns. Methods of providing acceptable minimum soil protection will be discussed later. Particularly in the area of structures and parking, plans must be made for water dispersal because of the reduction in land area available for infiltration and potential overland flow. Much of the soil disturbance and difficulty in establishing vegetative cover in these areas can be minimized by using good preconstruction planning.

Access roads to a development may cause major disturbance to the soils and can develop a high erosion potential. Since good engineering can reduce the impact of access roads, we will limit our discussion of this point. The most important feature to remember is that winter sports developments are normally on north and east slopes where we are most likely to find unstable soils.

Limited engineering is the usual case for the lower level of installation and maintenance roads associated with winter recreation developments. The area and number of these roads should be kept at a minimum. It may be possible to include these roads effectively into a ski trail system. Wherever such roads are needed, they should be constructed with minimum impact on the hydrology of the area and should avoid unstable soil. Fords, culverts, waterbars, etc. should be used wherever necessary. Revegetation and other soil protection techniques needed would be similar to those used on graded trails.

On steeper slopes or where the soils are highly unstable, lift towers should be installed with a skyline or helicopter system. Hand construction should be used in building footings to keep equipment off these slopes.

Because of U.S. Forest Service and public concern about the ecology of subalpine areas used for winter recreation development, it appears unlikely that any large continuous areas will be cleared of trees and brush for skiing in the future. Thus, we might expect many future developments to provide trail-type skiing. Trails provide a rather narrow area with high use where snow management can be intensified. To provide the conditions necessary for good snow management at less expense as well as provide a more desirable and safer area for the skier, proper trail construction appears imperative.

In areas where the slopes are too steep for equipment (usually about 30- to 50-percent grade), clearing and summer slope grooming must be done by hand and soil disturbance kept at a minimum. For less critical slopes, equipment may be used and some soil disturbance might be permissible.

Ski trails and slopes may require some grading. Winter sports area developers should recognize that as development approaches the alpine zone, revegetation becomes increasingly difficult to accomplish. Any soil disturbance activity including grading of trails in this zone should be well planned. On the east slopes of the Cascade Mountains, revegetation becomes increasingly difficult to accomplish at over 5,000-foot elevation.

Thus, from our identification of possible areas of soil disturbance, it appears ski trails will most likely have the most extensive area where revegetation is necessary for erosion control and good general grooming appearance. A number of management alternatives are available to insure satisfactory revegetation on ski trail and road system areas as well as around construction areas. They include:

(1) topsoil conservation. In the initial construction activity or trail grading, topsoil, if available, should be stockpiled and redistributed over exposed subsoil in the final grading.

(2) proper selection of plant species to be seeded. Species adaptability may be critical. Native species should be favored over introduced species, and this may require a seed collection program ahead of construction. Consideration might be given to annuals as well as perennials. Proper species information should be available from the U.S. Forest Service, Soil Conservation Service, or State university. If this information is not available for the local area, some plant screening trials may be required.

(3) soil fertility testing. County agents in connection with State universities normally provide this service for a small fee. Major nutrients of concern are nitrogen, phosphorus, potassium, and sulfur. Although there appears to be no general agreement on nitrogen fertilizer requirements for soil test data, we use a "rule of thumb" for a general guide in the establishment of vegetation on disturbed areas. We find that if the total nitrogen is 0.2 percent and above on upland slopes, nitrogen fertilization is not necessary. Nitrogen fertilization is generally advisable for plantings on disturbed upland soils when the total nitrogen is below 0.2 percent. If the total nitrogen is below 0.1 percent, nitrogen fertilization is usually necessary for satisfactory plant development. In some areas of the West, upland soils require sulfur fertilization for effective utilization of nitrogen fertilizers. In many cases, a starter fertilizer with about 50 pounds per acre total nitrogen applied at planting enhances the emergence and development of new grass seedlings on upland slopes.

(4) correct time of seeding. Winter sports areas usually have a relatively short summer season; thus, it would be difficult to separate differences between spring and fall plantings. Experience has shown that the most successful plantings are those made immediately after soil disturbance and where germination and emergence have occurred before permanent winter snow cover. Plantings should not be delayed until after precipitation and wind have caused "crusting" of the soil surface. If the summer months are quite dry, irrigation may be helpful to hasten plant establishment.

(5) seed and fertilizer covering. A shallow cover of soil over the newly planted seed and fertilizer enhances planting success. In areas of recent soil disturbance, natural soil compaction will normally sufficiently cover the seed and fertilizer. On areas where surface "crusting" has occurred, covering the seed and fertilizer can be accomplished by seeding with a rangeland drill or light harrowing after broadcast seeding. Covering the fertilizer, especially during warm, dry weather, with a shallow layer of soil will reduce possible nitrogen volatilization loss and increase the fertilizer's effectiveness.

(6) mulching. Mulches may be useful to provide more desirable soil moisture conditions for new seedlings. Many materials and methods are available. In windy areas, grass hay with an asphalt binder may be the most effective mulch. Chipping and distributing material from trail clearing may help and may reduce the need for burning.

(7) control of number of reoccurring soil disturbances. If at all possible, soil disturbing activities such as grading should involve careful planning so the job is done correctly the first time. Continuous soil redisturbance delays effective erosion control over an undesirable length of time.

(8) judging planting success after two growing seasons. Under most alpine or subalpine environments, planting of perennials will require at least 2 years before effective erosion control cover can be expected. Thus, judgment of success or failure of a planting cannot be made for most plantings in the first growing season. As an interim planting in high erosion potential areas, the use of a seed mix including annuals may be desirable. Cereal rye has been one of our most successful annuals planted on disturbed soils in the near alpine environment of north central Washington.

(9) use of maintenance fertilizer. To maintain healthy vegetation cover, particularly in high-use areas, a periodic maintenance nitrogen fertilization (perhaps every 2 to 3 years) may be necessary.

The above recommendations should assist the winter recreation manager to develop a good erosion control program as well as provide an attractive summer ground cover around his facilities.

AN EXAMPLE - MISSION RIDGE

Although a number of winter sports developments may have a good summer slope management program and Mission Ridge cannot be considered unique in this respect, we are more familiar with its summer slope management history. Thus, we will use Mission Ridge as an example to show its choice of management alternatives to provide soil resource protection.

Mission Ridge, located 13 miles southwest of Wenatchee, Washington, opened in 1966 and is now in its seventh season of operation. The 2,500-acre area from 4,600-foot elevation at the base to nearly 6,800 feet at the top is on Wenatchee National Forest and Washington State Department of Game lands. This northeast-facing, bowl-shaped basin includes the Squilchuck watershed providing domestic and irrigation water to residents of the lower valley.

Four chair lifts with a total length of 17,600 feet can carry 3,700 skiers per hour. Skiers have a choice of more than 20 major runs or trails. Buildings include a large day lodge, a ski patrol center and attendant dormitory, a shop, and a sewage treatment plant. Parking is provided for 750 cars next to the day lodge. A two-lane blacktop county road provides access to the area.

The geology of the basin is characterized by a cap of extrusive Columbia River basalts and consequent talus slopes overlying sandstones. The soils, whose parent material is generally basalt, are quite thin, making topsoil conservation nearly impossible for any soil disturbance activities. Overstory vegetation is predominantly western larch, lodgepole pine, subalpine fir, and Engelmann spruce. Understory vegetation is mostly needle grasses, lupine, and sedges. Numerous natural clearings in this vegetation are caused by the absence of soil on the talus slopes.

Before construction of the recreation development, the locations of buildings, lifts, and trails were outlined in an agreement between the operator and the U.S. Forest Service. A rather unique cooperation developed, as the construction engineer hired by Mission Ridge is Magnus Bakke, a retired local Forest Service engineer and an internationally known ski activity participant. Thus, the developing organization was fortunate to have an individual knowledgeable in U.S. Forest Service construction requirements and soils and vegetation characteristics of the area, as well as having an understanding of ski slope requirements.

The most extensive severe soil disturbance involved construction of the day lodge and the parking lot. An example of the construction engineer's concern about structures and soil disturbance is the use of a wooden off-loading ramp at the top of one of the lifts. Use of a fill, as advocated by some of the staff, would have been less expensive but would have left an extensive disturbed area visible from the Wenatchee valley. Besides reducing the possible hazard of overloading the slope and initiating mass soil movement, the present structure blends nicely into the surrounding vegetation. An example of the operator's concern is a lift visible from the lodge--acknowledging that a straight line through forest vegetation is esthetically unpleasant; only the large trees were felled beneath the lift line and the smaller trees and understory vegetation remain undisturbed. Lift towers were moved into position with a skyline system.

The road to the recreational area was constructed by Chelan County. The route used was along a proposed Forest Service access road, and Forest Service and county funds were used in the project. Almost all the land along the 4 miles of road construction is in private ownership. This road was built at a minimum construction cost. No funding was provided for erosion control and the cutbanks are oversteepened. Thus, the roadbanks are a serious source of erosion by runoff, slumping, and dry ravel.

One installation and summer maintenance road designed for minimum impact was constructed to the top of the development. It was particularly necessary to keep disturbance by this road to a minimum because of the numerous springs supplying summer water to valley residents. The road is kept closed to all but essential maintenance traffic. The road is integrated into the trail system to provide an easy "run" from the scenic viewpoint on top to the base area. The presence of talus made road surface material available locally when needed and possibly reduced an erosion hazard.

Trails on steep slopes were hand-cleared and the slash burned. Stumps and fallen logs were removed. On the lesser slope, about 100 acres of trail area were graded. Also, grading was used to remove adverse trail conditions such as "waterfalls" (areas of very steep descent) and to control water runoff. Because of the soils in the area, surface conditions after grading tended to be "armored" by exposure of rock. But the soils of the area are quite permeable, and the reduction in soil surface area available for water infiltration did not appear to increase the erosion potential. The operator's use of curved and contoured trails limits the unpleasant straight-line view as well as provides better snow management and ski traffic control.

Underground power and communication cables to a communication station on top of the ridge follow a cleared trail slope near the top of the development. In the early spring of 1968, a cable needing repair was excavated from the apparently highly erodible soil in which it was trenched. Later in the spring melt period, considerable local erosion did occur. This was emergency work in which the recreation area management and the Forest Service appeared to have limited opportunity to provide erosion protection.

In the Forest Service area use permit, the operator was required to revegetate the exposed slopes. In the late fall of 1967, the disturbed areas were seeded with a mixture of orchard grass, timothy, and hard fescue. The seed was broadcast on top of a blanket of snow. In the summer of 1968, the only evidence of the previous fall planting was on undisturbed topsoil and near ski lifts where chemicals had been used to condition the snow. The moisture and temperature conditions did not appear responsible for the absence of new seedlings in the disturbed areas.

At this point, scientists at the Pacific Northwest Forest and Range Experiment Station Forest Hydrology Laboratory in Wenatchee became involved in the problem of revegetation. Involvement in this problem on ski slopes was also related to possible future problems on nearby National Forest land that may be disturbed by wildfire and fireline construction.

Initially, soil samples collected from the disturbed areas on the ski slopes were chemically analyzed for a possible cause for the limited success of the first planting. All plant nutrients were found to be low with the nitrogen measured at 0.02 percent. A greenhouse study was initiated to confirm that the soil nutrient supply was one of the major limiting factors in revegetating the ski slopes. Crested wheatgrass seeds planted in unfertilized containers grew only until their endosperm energy was exhausted and then slowly died. Containers of fertilized soil grew an abundant quantity of healthy grass.

In late August, a field trial was established in the middle of one of the major ski runs. Crested wheatgrass, common ryegrass, and a mixture of orchard grass, timothy, and hard fescue was broadcast in plots 15 by 40 feet. One half of each plot received a starter fertilizer at planting. Nitrogen in the form of urea was applied at the rate of 100 pounds per acre, phosphorus (P205) as single superphosphate at 100 pounds per acre, and potassium (K20) as muriate of potash at 100 pounds per acre. The surface soil was lightly harrowed to cover the seed and to minimize fertilizer loss due to volatilization.

Seventeen days after planting, a high percentage of seedlings had emerged on the half of the plot receiving starter fertilizer, but the low percentage of seedlings on the unfertilized section of the plot was conspicuous. This difference after planting and subsequent winter survival was very evident when the snowpack melted off the plots in May 1969. At this time, all fall unfertilized plantings were fertilized with 100 pounds of nitrogen per acre in the form of urea. The vegetative growth of the half of each plot receiving a starter fertilizer[2/] was spectacular. This excellent growth was in contrast to the low productivity on the plots not receiving a starter fertilizer.

One section of the test area was broadcast planted on top of snow in late fall to duplicate previous planting attempts. Although a generous quantity of orchard grass, timothy, and hard fescue was planted, very few seedlings emerged the following spring. This test demonstrated that broadcast planting on snow is not a recommended practice in this area.

The results of these field tests[3/] demonstrate that the method of planting at this location is perhaps as important as the choice of seed mixture. Here, it was important to use a starter fertilizer with a thin layer of soil over the seed. Spring planting would most likely be successful with this practice, but wet soil conditions along with late snowmelt runoff makes such plantings impractical.

Using the planting and fertilizing techniques practiced in this study, the operators of Mission Ridge have made successful plantings. The successful planting procedures developed here would be adaptable to revegetating areas disturbed by winter sports developments in many places along the upper slopes of the West.

In summary, it appears that a reasonable land use plan by the U.S. Forest Service and the Mission Ridge management provides an excellent recreation area with a minimum impact on the soil resource. The best test for those concerned about the development's effect on the environment would be its effect on the domestic water supply in the lower valley. No change in water quality has been measured although the county access road poses a potential threat of sedimentation.

2/ G. O. Klock. *Use of a starter fertilizer for vegetation establishment. Northwest Sci. 43(1): 38, 1969.*

3/ G. O. Klock and W. A. Hampton. *Skiing--'and on a grass base.' Wash. Farmer-Stockman 97(2): 34, 1972.*

For the operator, summer grading and grooming of trails has been financially rewarding. The early snowpack in the 1972-73 season has been unusually low. Without summer grooming which provided slope conditions necessary for proper winter grooming, operation of the ski area in December and early January would have been doubtful. In 1 week during December, Mission Ridge lift receipts were large enough to pay for the total investment in trail clearing and summer grooming, including seeding and fertilizing for erosion protection.

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GPO 988-175

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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INITIAL RELEASES OF *CHRYSOCHARIS LARICINELLAE* AND *DICLADOCERUS WESTWOODII*[1/] FOR BIOLOGICAL CONTROL OF THE LARCH CASEBEARER IN THE WESTERN UNITED STATES

by

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ABSTRACT

A total of 240 Chrysocharis laricinellae *and 513* Dicladocerus westwoodii *(Hymenoptera: Eulophidae) from Austria and England were released in Washington and Idaho in 1972. This is the first attempted establishment of these parasites in western North America for biological control of the larch casebearer.*

Keywords: *Biological control (pests), larch casebearer,* Coleophora laricella.

1/ Hymenoptera: Eulophidae.

The larch casebearer, *Coleophora laricella* (Hbn.) (Lepidoptera: Coleophoridae), discovered in western North America in 1957 near St. Maries, Idaho (Denton 1958), has spread over much of the range of western larch, *Larix occidentalis* Nutt., in Idaho, Montana, Washington, Oregon, and British Columbia. Larch stands on the eastern slopes of the Cascade Range in Oregon and Washington are apparently still uninfested.

Population levels are commonly high in infested stands, with counts of overwintering casebearers reaching 200 or more per 100 buds in the older areas of infestation. Repeated moderate to severe defoliation has resulted in severely reduced radial increment, branch mortality, and some tree mortality (Tunnock et al. 1969).

A biological control program was initiated in 1960 with the introduction of *Agathis pumila* (Ratz.) (Hymenoptera: Braconidae) (Denton 1972) from colonies previously established in the northeastern United States (Dowden 1962). In 1972 two other parasitoids were introduced, *Chrysocharis laricinellae* (Ratz.) and *Dicladocerus westwoodii* Westw. (Hymenoptera: Eulophidae).[2/] [3/] The objective of this report is to document those liberations.

Collections of parasitized larch casebearer larvae and pupae were made at several locations in Austria and near Cinderford, Gloucestershire, England, through arrangements with H. Pschorn-Walcher of the European Station, Commonwealth Institute of Biological Control, Delemont, Switzerland. Material was shipped to the Research Institute, Canadian Department of Agriculture, Belleville, Ontario, where adult parasites emerged and were forwarded to Corvallis, Oregon, by J. S. Kelleher and G. D. Williamson.

A total of 513 *D. westwoodii* and 240 *C. laricinellae* was released in Washington and Idaho (table 1). Parasite releases were made on predesignated study plots to facilitate subsequent evaluation of parasite effectiveness. Unfortunately, by June 7, when the first shipment of *D. westwoodii* arrived, the bulk of the casebearer population on most plots had pupated and passed the stage where they were susceptible to parasitism. However, larvae were still present in the Charley Creek plot, and *D. westwoodii* was released. *C. laricinellae* was first available for release on June 17. Because

[2/] Identification of European parasites made by Dr. C. Yoshimoto, Canadian Forestry Service, Department of the Environment, Ottawa. Voucher specimens have been deposited at the U.S. National Museum, Washington, D.C.

[3/] The *Dicladocerus westwoodii* released is believed to be distinct from the *Dicladocerus* sp. which is already present. According to Dr. B. D. Burks, U.S. National Museum, Washington, D.C., specific distinction can be found in the longer branches on the male antennae in *D. westwoodii* than in *Dicladocerus* sp. No distinctive characters have been found to separate the females.

synchronization with the susceptible casebearing larvae was poor, adults were held in the laboratory until this stage was again available in September. Meanwhile, separate colonies of *C. laricinellae* from Austria and England were established on the larch casebearer in the laboratory. The Austrian colony furnished the individuals for the September 26 release. A third colony of *C. laricinellae* was started from individuals collected from the casebearer in Wisconsin by H. C. Coppel and J. W. Mertins. The numbers of parasites in the English and Wisconsin colonies were too low for release in 1972 and are being maintained for subsequent release. Collection and rearing efforts will continue to provide additional individuals and other parasite species for release in these and other areas in Washington and Montana.

Table 1.--Releases of *Dicladocerus westwoodii* and *Chrysocharis laricinellae* against larch casebearer in Washington and Idaho, 1972

Liberation site	Source	Date of release	Number released		
			Male	Female	Total
D. westwoodii:					
Charley Creek, 15 miles S. Pomeroy, Washington 46°15'N, 117°30'W	Austria	June 7	116	57	173
	England	June 7	44	26	70
U.S. Hwy. 95, 25 miles N. Moscow, Idaho 47°02'N, 116°52'W	Austria	June 27	132	79	211
		July 6	31	28	59
C. laricinellae:					
U.S. Hwy. 95, 25 miles N. Moscow, Idaho 47°02'N, 116°52'W	Austria	September 13	10	90	100
	lab reared (Austrian stock)	September 26	53	87	140

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· USDA FOREST SERVICE RESEARCH NOTE

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SUMMARY OF CLIMATIC DATA FOR THE BONANZA CREEK EXPERIMENTAL FOREST, INTERIOR ALASKA

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ABSTRACT

A summary of climatic data during the 1968-71 growing seasons is presented for the subarctic Bonanza Creek Experimental Forest located near Fairbanks, Alaska. Data were obtained from three weather station sites at elevations of 1,650, 1,150, and 550 feet from May until September each year. Data are for relative humidity, rainfall, and maximum, minimum, and mean temperatures. Analyses indicate that Fairbanks mean monthly temperatures were higher than those at Nenana or at the Bonanza Creek Experimental Forest.

Keywords: Climate, temperature, Alaska, humidity, rainfall.

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

INTRODUCTION

Climatic summaries are often considered to be routine academic collection of data without practical application. This may be a valid criticism in areas of high station density, but it is not true for such areas as subarctic Alaska, where weather stations are few and scattered. By evaluating relatively short-term records, an idea of the locality's climate can be ascertained.

There have been numerous studies of fire, silviculture, entomology, wildlife, and plant ecology in interior Alaska. Many of these studies required climatic characterization. This report provides a summary of summertime Bonanza Creek Experimental Forest climatic information.

STUDY AREA LOCATION

The Bonanza Creek Experimental Forest is a 13,800-acre (5,585-hectare) State-owned area located 14 air miles (22.5 kilometers) west-southwest of the first order National Weather Service station at the Fairbanks International Airport and 28 miles (45 kilometers) east of the second order station at Nenana (fig. 1). It lies from 64°43'18" to 64°46'19" N. latitude and 148°6'38" to 148°20'22" W. longitude on a generally east-west oriented ridge. This ridge delineates the northern boundary of the Tanana River valley. Over 90 percent of the Experimental Forest is on the south side of the ridge, while the remainder has a northerly aspect (fig. 2).

The Fairbanks and Nenana weather stations are on the Tanana River flood plain at elevations of 436 and 353 feet (133 and 108 meters) above mean sea level. Experimental Forest elevations range from 550 feet (168 meters) at site 3 to 1,650 feet (503 meters) at site 1 (fig. 1).

DESCRIPTION OF SITES AND INSTRUMENTATION

The three weather station sites were in stands of upland paper birch, *Betula papyrifera* Marsh. (elevation 1,650 feet), upland black spruce, *Picea mariana* (Mill.) B.S.P. (elevation 1,150 feet), and lowland black spruce (elevation 550 feet) (table 1, fig. 2). Because of microclimatic differences among cover types,[2] the data reflect the confounding effect of site and elevation.

Stand openings for instrumentation were 100 feet (30.5 meters) in diameter. Standard National Weather Service field shelters or thermoscreens (Cotton Region type) and instrumentation were used at each site. Instrumentation included a hygrothermograph, a maximum-minimum thermometer to verify the hygrothermograph thermal sensor, and a tipping-bucket rain gage along with an 8-inch Forest Service

[2] Rudolf Geiger. The climate near the ground. Cambridge: Harvard Univ. Press, 611 p., 1965.

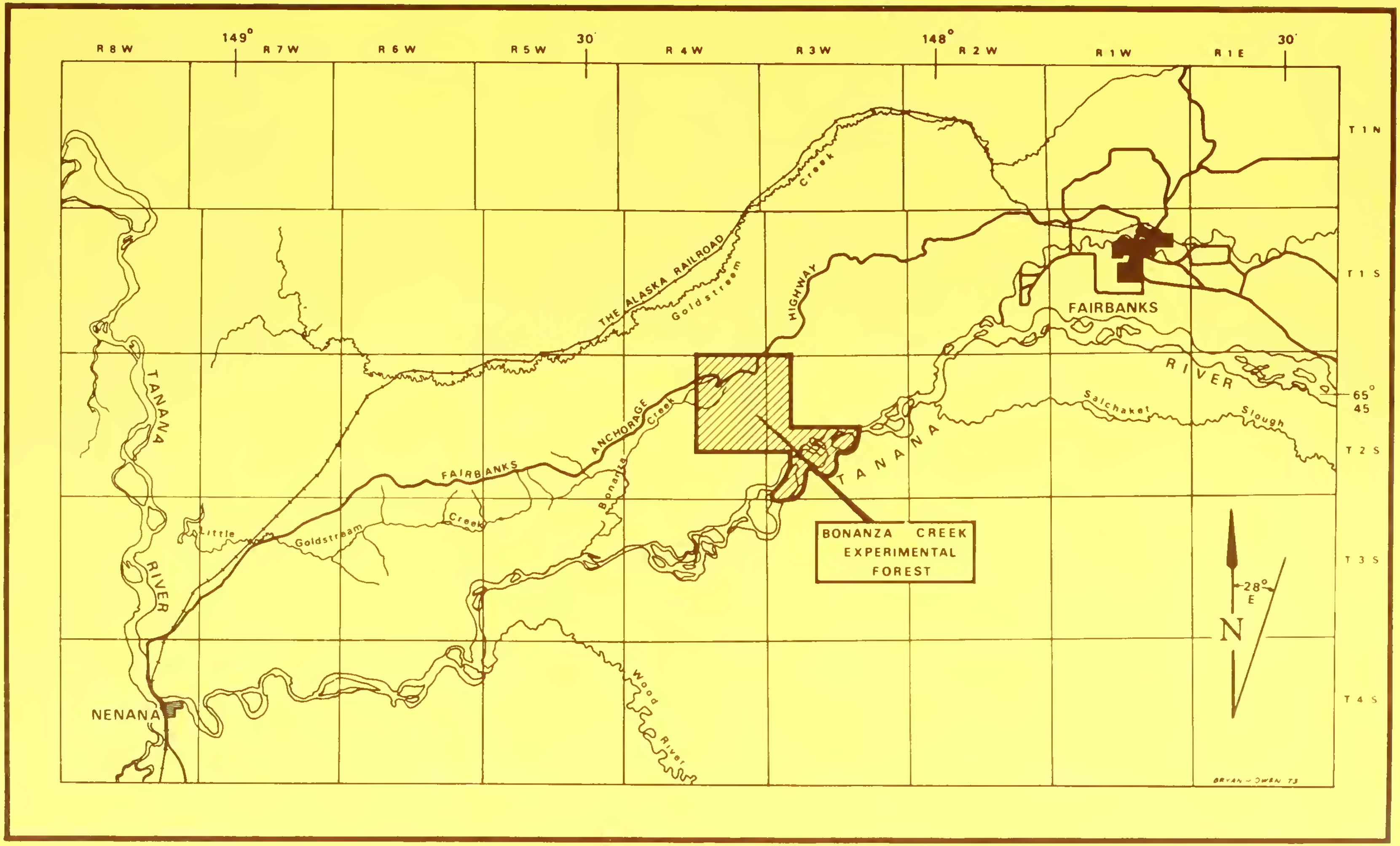

Figure 1.--*Bonanza Creek Experimental Forest location in relation to Fairbanks and Nenana, Alaska, where first and second order National Weather Service stations are located.*

BONANZA CREEK EXPERIMENTAL FOREST

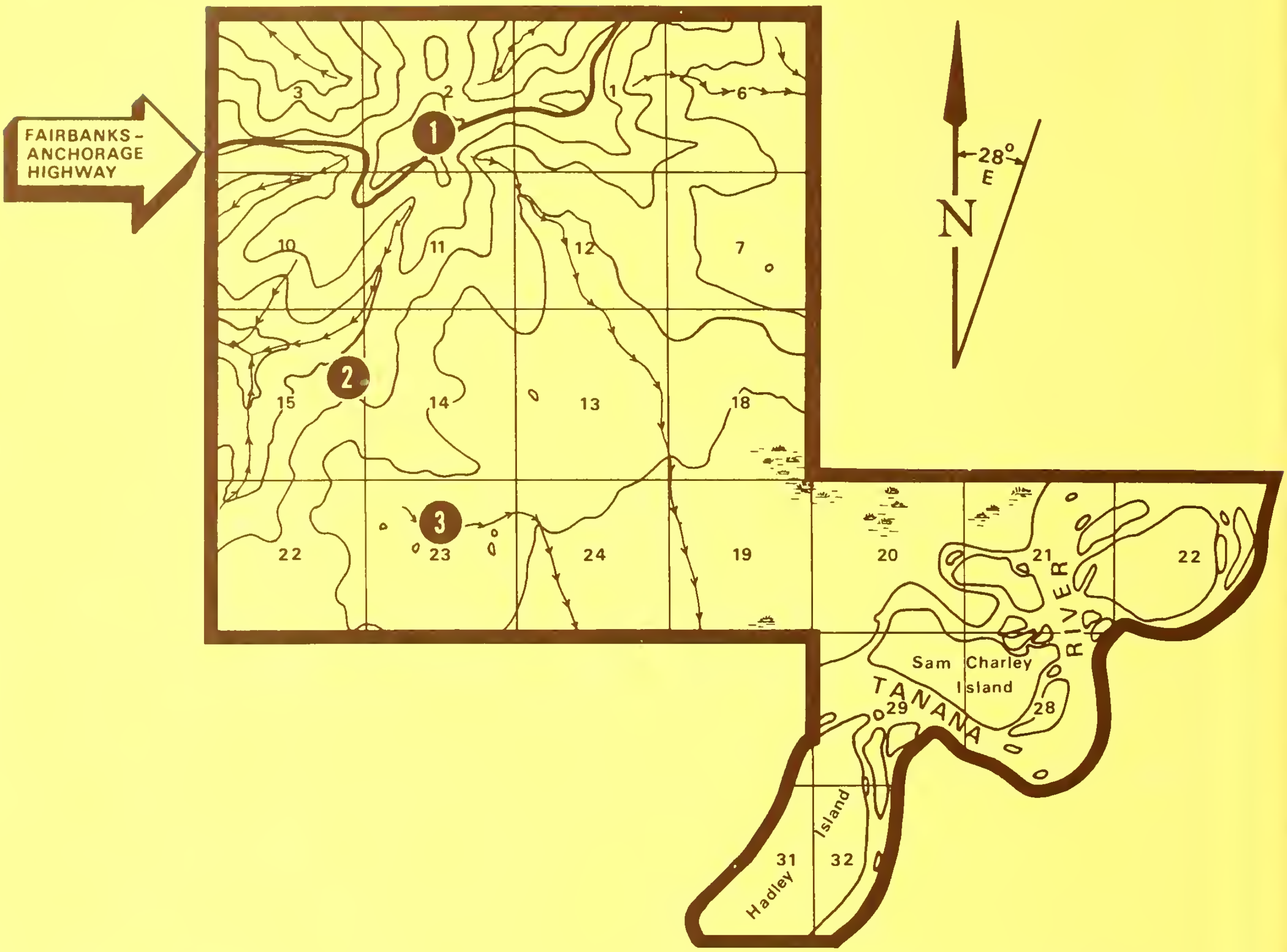

Figure 2.--*Weather station site locations and elevations on the Bonanza Creek Experimental Forest, Alaska, upland paper birch (site 1), upland black spruce (site 2), and lowland black spruce (site 3).*

nonrecording rain gage. Humidity sensor calibrations were made throughout each season with a fan-aspirated psychrometer. The nonrecording rain gage was used for comparing with the tipping-bucket gage's weekly catch.

DESCRIPTION AND ANALYSIS OF DATA

The data consist of maximum, minimum, and mean temperatures, relative humidity, and daily precipitation. Daily data were summarized by 5-day and monthly intervals.

Table 1.--*Site descriptions on the Bonanza Creek Experimental Forest near Fairbanks, Alaska*

Characteristic	Weather station location					
	Upland paper birch, site 1		Upland black spruce, site 2		Lowland black spruce, site 3	
Elevation (feet, meters)	1,650	502.9	1,150	350.5	550	167.6
Average dominant height (feet, meters)	55	16.8	33	10.1	9.4	2.9
Average age (years)	120[1]		101[1]		51[2]	
Average diameter (inches, centimeters)	8	20.3	3.73	9.46	1.05	2.7
Basal area (square feet per acre, square meters per hectare)	110	25.3	149	34.2	82	18.8
Density (stems per acre, stems per hectare)	303	749	2,000	4,942	11,067	27,374

1/ At breast height (4.5 feet above mean ground level).

2/ At ground level.

Data observational periods for each site during the 4-year period from 1968 through 1971 are recorded in table 2. "Daily" observations were those recorded during the defined day of 1400 Alaska Standard Time (0000 G.m.t.) one day to 1400 A.s.t. the following day. Missing data were not a significant problem. Occasional missing observations were estimated from the adjacent stations and the data preceding and following the missing day.

A comparison of the lowland black spruce (site 3) mean monthly temperature and monthly rainfall was made with corresponding data from Nenana and Fairbanks weather stations (table 3). The analysis of variance for temperature revealed no significant difference between temperatures at the lowland black spruce and the Nenana stations, but the temperature at Fairbanks station was significantly greater at the 1-percent level. This may be attributed to the pocketlike location of Fairbanks and the possible influence on air movement (fig. 1).

Table 2.--*Data observational periods for three weather stations, 1968-71, on the Bonanza Creek Experimental Forest, Alaska*

Site	Type	Year	Starting date	Ending date
1	Upland paper birch	1968	May 28	Sept. 29
		1969	May 26	Sept. 14
		1970	May 20	Sept. 13
		1971	May 27	Sept. 5
2	Upland black spruce	1968	June 11	Sept. 29
		1969	May 26	Sept. 14
		1970	May 20	Sept. 13
		1971	May 26	Sept. 5
3	Lowland black spruce	1968	June 5	Sept. 29
		1969	May 26	Sept. 14
		1970	May 20	Sept. 13
		1971	May 26	Sept. 5

Table 3.--*Comparison of the mean monthly temperature and total monthly rainfall for the lowland black spruce stand (site 3, elevation 550 feet), Nenana FAA Municipal Airport (elevation 353 feet), and Fairbanks International Airport (elevation 436 feet), Alaska, 1968-71*

Year and month	Temperature				Rainfall			
	Lowland black spruce (site 3)	Nenana	Fairbanks	Fairbanks departure from normal	Lowland black spruce (site 3)	Nenana	Fairbanks	Fairbanks departure from normal
	Degrees Fahrenheit				*Inches*			
1968:								
June	58.1	57.8	60.4		1.36	0.90	1.07	
July	63.9	62.8	65.8	+6.1	.57	1.62	.84	+1.62
August	58.8	56.7	58.5	+4.2	1.54	1.26	.96	+1.26
September	43.3	40.2	43.4		.05	.06	.15	
1969:								
May	47.1	47.8	50.6		0	.08	(1/)	
June	59.9	59.4	64.9	+6.5	.22	.66	.39	-1.00
July	57.2	57.9	59.4	-.3	2.41	2.96	1.33	-.51
August	47.9	48.7	49.8	-4.5	2.54	1.53	2.04	-.16
September	49.1	48.6	51.4		.28	.35	.28	
1970:								
May	53.4	53.1	56.0		.61	.41	.32	
June	55.0	55.0	58.0	-.4	2.78	3.29	2.57	+1.18
July	59.2	58.4	62.4	+2.7	1.59	1.39	1.81	-.03
August	54.4	53.8	56.9	+2.6	2.04	1.37	1.98	-.22
September	45.2	44.4	47.4		.48	.36	.24	
1971:								
May	52.0	50.9	54.1		0	0	.01	
June	58.4	60.5	63.4	+5.0	.20	.30	.31	-1.08
July	57.0	58.5	61.0	+1.3	2.82	3.84	2.08	+.24
August	52.8	54.1	56.1	+1.8	2.80	4.14	2.32	+.12
September	43.7	42.1	45.2		1.22	1.07	1.05	

1/ Trace.

Monthly rainfall for the lowland black spruce, Nenana, and Fairbanks weather stations was not significantly different.

From the 4-year monthly means summarized per site in table 4, the only apparent difference between sites was the lower minimum temperatures for the lowland black spruce (site 3). The confounding of site and elevation did not permit separating cover type and elevation influences on observed data.

CONCLUSIONS

The data reemphasize the need for at least general climatic information at any study site. There was a significant difference in growing season temperatures between the three weather stations, lowland black spruce, Fairbanks, and Nenana, although data were from similar station locations. It is not sufficient to rely on data from distant but similar weather station sites. Local measurements should be made to insure proper and adequate interpretation.

Table 4.--*Monthly means for maximum and minimum temperature, maximum and minimum relative humidity, and rainfall for four observational periods (1968-71), Bonanza Creek Experimental Forest, Alaska*

Characteristic	Site[1]	May	June	July	August	September
Maximum temperature (°F.)	1	64.4	72.4	69.7	63.1	52.2
	2	66.1	73.3	72.4	64.3	52.8
	3	65.9	72.8	72.5	65.8	56.5
Minimum temperature (°F.)	1	41.9	49.0	50.0	45.1	37.0
	2	41.9	50.2	51.3	46.1	37.8
	3	35.8	42.9	46.2	41.2	34.2
Maximum relative humidity (percent)	1	71.2	75.6	87.0	90.0	92.9
	2	62.8	76.9	90.9	92.2	91.6
	3	84.6	89.2	95.1	96.8	95.7
Minimum relative humidity (percent)	1	29.9	31.2	37.4	44.8	55.0
	2	22.2	31.0	41.9	48.2	55.3
	3	23.7	28.5	37.6	44.0	48.4
Rainfall (inches)	1	.23	1.32	2.15	2.35	.64
	2	.33	1.31	1.88	2.41	.54
	3	.20	1.14	1.85	2.23	.51

[1] Site 1 = upland paper birch, site 2 = upland black spruce, and site 3 = lowland black spruce.

CLIMATIC SUMMARY

BONANZA CREEK EXPERIMENTAL FOREST, ALASKA

SITE 1 MAY 1968

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
28	68.0	42.0	55.0	100.0	34.0	67.0	0.0
29	64.0	46.0	55.0	100.0	44.0	72.0	0.10
30	64.0	44.0	54.0	100.0	32.0	66.0	0.01
31	58.0	38.0	48.0	100.0	46.0	73.0	0.0
MEAN	63.5	42.5	53.0	100.0	39.0	69.5	0.11
MONTHLY MEAN	63.5	42.5	53.0	100.0	39.0	69.5	0.11

SITE 1 JUNE 1968

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	58.0	42.0	50.0	100.0	40.0	70.0	0.01
2	68.0	46.0	57.0	100.0	44.0	72.0	0.03
3	70.0	48.0	59.0	100.0	38.0	69.0	0.09
4	58.0	46.0	52.0	100.0	58.0	79.0	0.10
5	65.0	49.0	57.0	100.0	46.0	73.0	0.11
MEAN	63.8	46.2	55.0	100.0	45.2	72.6	0.34
6	64.0	48.0	56.0	100.0	34.0	67.0	0.0
7	56.0	45.0	50.5	100.0	68.0	84.0	0.01
8	54.0	45.0	49.5	100.0	22.0	61.0	0.01
9	74.0	48.0	61.0	92.0	26.0	59.0	0.0
10	75.0	53.0	64.0	72.0	28.0	50.0	0.0
MEAN	64.6	47.8	56.2	92.8	35.6	64.2	0.02
11	76.0	52.0	64.0	66.0	26.0	46.0	0.0
12	76.0	52.0	64.0	66.0	30.0	48.0	0.0
13	77.0	53.0	65.0	54.0	30.0	42.0	0.0
14	77.0	50.0	63.5	100.0	32.0	66.0	0.13
15	71.0	48.0	59.5	100.0	42.0	71.0	0.38
MEAN	75.4	51.0	63.2	77.2	32.0	54.6	0.51
16	64.0	45.0	54.5	100.0	56.0	78.0	0.38
17	70.0	49.0	59.5	96.0	36.0	66.0	0.0
18	69.0	50.0	59.5	94.0	34.0	64.0	0.0
19	72.0	49.0	60.5	100.0	44.0	72.0	0.05
20	65.0	48.0	56.5	100.0	50.0	75.0	0.15
MEAN	68.0	48.2	58.1	98.0	44.0	71.0	0.58
21	62.0	44.0	53.0	100.0	50.0	75.0	0.05
22	52.0	42.0	47.0	100.0	70.0	85.0	0.08
23	65.0	40.0	52.5	100.0	30.0	65.0	0.0
24	64.0	46.0	55.0	74.0	30.0	52.0	0.0
25	68.0	48.0	58.0	95.0	42.0	68.5	0.0
MEAN	62.2	44.0	53.1	93.8	44.4	69.1	0.13
26	66.0	44.0	55.0	100.0	52.0	76.0	0.0
27	72.0	47.0	59.5	100.0	28.0	64.0	0.0
28	73.0	48.0	60.5	74.0	26.0	50.0	0.0
29	64.0	47.0	55.5	84.0	46.0	65.0	0.0
30	62.0	45.0	53.5	100.0	50.0	75.0	0.0
MEAN	67.4	46.2	56.8	91.6	40.4	66.0	0.0
MONTHLY MEAN	66.9	47.2	57.1	92.2	40.3	66.3	1.58

UPLAND PAPER BIRCH

SITE 1 JULY 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	63.0	45.0	54.0	100.0	50.0	75.0	0.01
2	62.0	45.0	53.5	100.0	48.0	74.0	0.05
3	64.0	47.0	55.5	100.0	50.0	75.0	0.0
4	71.0	48.0	59.5	100.0	40.0	70.0	0.06
5	74.0	52.0	63.0	81.0	38.0	59.5	0.0
MEAN	66.8	47.4	57.1	96.2	45.2	70.7	0.12
6	76.0	56.0	66.0	68.0	38.0	53.0	0.0
7	80.0	60.0	70.0	60.0	32.0	46.0	0.0
8	82.0	60.0	71.0	46.0	20.0	33.0	0.0
9	82.0	56.0	69.0	72.0	20.0	46.0	0.0
10	76.0	50.0	63.0	89.0	20.0	54.5	0.0
MEAN	79.2	56.4	67.8	67.0	26.0	46.5	0.0
11	72.0	47.0	59.5	44.0	18.0	31.0	0.0
12	70.0	49.0	59.5	72.0	24.0	48.0	0.0
13	72.0	47.0	59.5	88.0	30.0	59.0	0.0
14	73.0	52.0	62.5	90.0	30.0	60.0	0.0
15	64.0	50.0	57.0	91.0	39.0	65.0	0.02
MEAN	70.2	49.0	59.6	77.0	28.2	52.6	0.02
16	68.0	46.0	57.0	84.0	30.0	57.0	0.0
17	70.0	46.0	58.0	78.0	26.0	52.0	0.0
18	72.0	50.0	61.0	59.0	24.0	41.5	0.0
19	78.0	53.0	65.5	66.0	22.0	44.0	0.0
20	78.0	51.0	64.5	86.0	20.0	53.0	0.0
MEAN	73.2	49.2	61.2	74.6	24.4	49.5	0.0
21	82.0	57.0	69.5	64.0	20.0	42.0	0.0
22	84.0	57.0	70.5	60.0	24.0	42.0	0.0
23	84.0	60.0	72.0	58.0	24.0	41.0	0.0
24	83.0	60.0	71.5	68.0	24.0	46.0	0.0
25	80.0	60.0	70.0	66.0	30.0	48.0	0.02
MEAN	82.6	58.8	70.7	63.2	24.4	43.8	0.02
26	78.0	54.0	66.0	50.0	30.0	40.0	0.0
27	74.0	52.0	63.0	92.0	30.0	61.0	0.0
28	64.0	48.0	56.0	100.0	46.0	73.0	0.11
29	70.0	50.0	60.0	88.0	36.0	62.0	0.0
30	73.0	50.0	61.5	76.0	30.0	53.0	0.0
31	71.0	49.0	60.0	100.0	38.0	69.0	0.40
MEAN	71.7	50.5	61.1	84.3	35.0	59.7	0.51
MONTHLY MEAN	73.9	51.8	62.9	77.3	30.7	54.0	0.67

UPLAND PAPER BIRCH

SITE 1 AUGUST 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	64.0	50.0	57.0	98.0	58.0	78.0	0.25
2	65.0	49.0	57.0	100.0	50.0	75.0	0.02
3	66.0	48.0	57.0	92.0	44.0	68.0	0.0
4	70.0	48.0	59.0	80.0	38.0	59.0	0.0
5	71.0	51.0	61.0	100.0	34.0	67.0	0.17
MEAN	67.2	49.2	58.2	94.0	44.8	69.4	0.44
6	80.0	58.0	69.0	97.0	40.0	68.5	0.0
7	80.0	62.0	71.0	76.0	36.0	56.0	0.0
8	78.0	55.0	66.5	60.0	36.0	48.0	0.0
9	77.0	56.0	66.5	67.0	33.0	50.0	0.0
10	76.0	54.0	65.0	62.0	30.0	46.0	0.0
MEAN	78.2	57.0	67.6	72.4	35.0	53.7	0.0
11	79.0	52.0	65.5	66.0	30.0	48.0	0.0
12	78.0	51.0	64.5	86.0	32.0	59.0	0.0
13	80.0	56.0	68.0	69.0	30.0	49.5	0.0
14	80.0	54.0	67.0	68.0	26.0	47.0	0.0
15	70.0	48.0	59.0	100.0	37.0	68.5	0.0
MEAN	77.4	52.2	64.8	77.8	31.0	54.4	0.0
16	71.0	46.0	58.5	98.0	26.0	62.0	0.0
17	70.0	51.0	60.5	100.0	40.0	70.0	0.08
18	66.0	47.0	56.5	98.0	44.0	71.0	0.0
19	66.0	48.0	57.0	98.0	42.0	70.0	0.0
20	72.0	50.0	61.0	93.0	36.0	64.5	0.0
MEAN	69.0	48.4	58.7	97.4	37.6	67.5	0.08
21	70.0	47.0	58.5	100.0	38.0	69.0	0.07
22	64.0	48.0	56.0	100.0	60.0	80.0	0.04
23	64.0	48.0	56.0	100.0	60.0	80.0	0.54
24	60.0	46.0	53.0	100.0	56.0	78.0	0.0
25	65.0	46.0	55.5	100.0	44.0	72.0	0.0
MEAN	64.6	47.0	55.8	100.0	51.6	75.8	0.65
26	64.0	45.0	54.5	100.0	46.0	73.0	0.0
27	64.0	44.0	54.0	100.0	50.0	75.0	0.0
28	62.0	46.0	54.0	100.0	48.0	74.0	0.05
29	52.0	40.0	46.0	100.0	58.0	79.0	0.03
30	57.0	38.0	47.5	100.0	49.0	74.5	0.0
31	58.0	37.0	47.5	100.0	44.0	72.0	0.0
MEAN	59.5	41.7	50.6	100.0	49.2	74.6	0.08
MONTHLY MEAN	69.0	49.0	59.0	90.6	41.8	66.2	1.25

SITE 1 SEPTEMBER 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	57.0	39.0	48.0	86.0	41.0	63.5	0.0
2	58.0	39.0	48.5	80.0	30.0	55.0	0.0
3	59.0	36.0	47.5	66.0	28.0	47.0	0.0
4	60.0	42.0	51.0	50.0	30.0	40.0	0.0
5	60.0	42.0	51.0	77.0	30.0	53.5	0.0
MEAN	58.8	39.6	49.2	71.8	31.8	51.8	0.0
6	62.0	41.0	51.5	80.0	30.0	55.0	0.0
7	62.0	38.0	50.0	64.0	30.0	47.0	0.0
8	62.0	40.0	51.0	70.0	32.0	51.0	0.0
9	64.0	44.0	54.0	78.0	32.0	55.0	0.0
10	64.0	45.0	54.5	64.0	32.0	48.0	0.0
MEAN	62.8	41.6	52.2	71.2	31.2	51.2	0.0
11	58.0	42.0	50.0	94.0	46.0	70.0	0.0
12	54.0	40.0	47.0	94.0	46.0	70.0	0.02
13	60.0	38.0	49.0	86.0	40.0	63.0	0.0
14	60.0	37.0	48.5	86.0	40.0	63.0	0.42
15	56.0	37.0	46.5	100.0	40.0	70.0	0.0
MEAN	57.6	38.8	48.2	92.0	42.4	67.2	0.44
16	54.0	35.0	44.5	100.0	56.0	78.0	0.0
17	42.0	30.0	36.0	100.0	62.0	81.0	0.01
18	39.0	30.0	34.5	96.0	62.0	79.0	0.0
19	39.0	29.0	34.0	100.0	64.0	82.0	0.03
20	40.0	29.0	34.5	100.0	56.0	78.0	0.0
MEAN	42.8	30.6	36.7	99.2	60.0	79.6	0.04
21	38.0	24.0	31.0	90.0	46.0	68.0	0.0
22	38.0	23.0	30.5	98.0	46.0	72.0	0.0
23	37.0	23.0	30.0	100.0	54.0	77.0	0.0
24	33.0	16.0	24.5	90.0	40.0	65.0	0.0
25	32.0	22.0	27.0	100.0	50.0	75.0	0.0
MEAN	35.6	21.6	28.6	95.6	47.2	71.4	0.0
26	42.0	29.0	35.5	80.0	50.0	65.0	0.0
27	48.0	30.0	39.0	80.0	44.0	62.0	0.0
28	48.0	33.0	40.5	100.0	46.0	73.0	0.0
29	42.0	22.0	32.0	100.0	64.0	82.0	0.0
MEAN	45.0	28.5	36.8	90.0	51.0	70.5	0.0
MONTHLY MEAN	50.6	33.6	42.1	86.5	43.7	65.1	0.48

SITE 1 MAY 1969

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
26	66.0	40.0	53.0	50.0	16.0	33.0	0.0
27	50.0	25.0	37.5	74.0	20.0	47.0	0.0
28	56.0	32.0	44.0	38.0	23.0	30.5	0.0
29	66.0	40.0	53.0	40.0	17.0	28.5	0.0
30	66.0	48.0	57.0	42.0	18.0	30.0	0.0
31	77.0	45.0	61.0	44.0	20.0	32.0	0.0
MEAN	63.5	38.3	50.9	48.0	19.0	33.5	0.0
MONTHLY MEAN	63.5	38.3	50.9	48.0	19.0	33.5	0.0

SITE 1 JUNE 1969

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	59.0	38.0	48.5	71.0	22.0	46.5	0.02
2	67.0	41.0	54.0	62.0	14.0	38.0	0.04
3	68.0	46.0	57.0	28.0	10.0	19.0	0.0
4	69.0	45.0	57.0	70.0	14.0	42.0	0.0
5	61.0	47.0	54.0	68.0	26.0	47.0	0.20
MEAN	64.8	43.4	54.1	59.8	17.2	38.5	0.26
6	70.0	46.0	58.0	40.0	20.0	30.0	0.0
7	70.0	51.0	60.5	57.0	30.0	43.5	0.0
8	74.0	54.0	64.0	50.0	30.0	40.0	0.0
9	70.0	56.0	63.0	50.0	32.0	41.0	0.0
10	73.0	47.0	60.0	60.0	28.0	44.0	0.0
MEAN	71.4	50.8	61.1	51.4	28.0	39.7	0.0
11	72.0	52.0	62.0	54.0	26.0	40.0	0.0
12	78.0	51.0	64.5	63.0	30.0	46.5	0.0
13	78.0	53.0	65.5	65.0	28.0	46.5	0.0
14	86.0	60.0	73.0	50.0	26.0	38.0	0.0
15	92.0	67.0	79.5	44.0	20.0	32.0	0.0
MEAN	81.2	56.6	68.9	55.2	26.0	40.6	0.0
16	93.0	67.0	80.0	39.0	16.0	27.5	0.0
17	75.0	55.0	65.0	72.0	24.0	48.0	0.0
18	74.0	53.0	63.5	72.0	24.0	48.0	0.0
19	80.0	53.0	66.5	49.0	22.0	35.5	0.0
20	88.0	60.0	74.0	40.0	20.0	30.0	0.0
MEAN	82.0	57.6	69.8	54.4	21.2	37.8	0.0
21	88.0	54.0	71.0	85.0	21.0	53.0	0.0
22	84.0	66.0	75.0	42.0	24.0	33.0	0.0
23	84.0	58.0	71.0	41.0	12.0	26.5	0.0
24	80.0	54.0	67.0	44.0	14.0	29.0	0.0
25	76.0	52.0	64.0	66.0	26.0	46.0	0.0
MEAN	82.4	56.8	69.6	55.6	19.4	37.5	0.0
26	80.0	53.0	66.5	73.0	25.0	49.0	0.0
27	84.0	63.0	73.5	43.0	16.0	29.5	0.0
28	84.0	62.0	73.0	51.0	18.0	34.5	0.0
29	78.0	56.0	67.0	100.0	38.0	69.0	0.06
30	68.0	53.0	60.5	94.0	36.0	65.0	0.0
MEAN	78.8	57.4	68.1	72.2	26.6	49.4	0.06
MONTHLY MEAN	76.8	53.8	65.3	58.1	23.1	40.6	0.32

UPLAND PAPER BIRCH

SITE 1 JULY 1969

	TEMPERATURE			RELATIVE HUMIDITY			
DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	PRECIP
1	69.0	51.0	60.0	90.0	31.0	60.5	0.0
2	70.0	54.0	62.0	98.0	36.0	67.0	0.03
3	70.0	52.0	61.0	100.0	26.0	63.0	0.09
4	72.0	51.0	61.5	92.0	30.0	61.0	0.0
5	75.0	53.0	64.0	78.0	28.0	53.0	0.0
MEAN	71.2	52.2	61.7	91.6	30.2	60.9	0.12
6	74.0	59.0	66.5	60.0	28.0	44.0	0.0
7	76.0	58.0	67.0	84.0	32.0	58.0	0.0
8	70.0	54.0	62.0	97.0	54.0	75.5	0.0
9	70.0	53.0	61.5	100.0	53.0	76.5	0.0
10	66.0	53.0	59.5	99.0	56.0	77.5	0.01
MEAN	71.2	55.4	63.3	88.0	44.6	66.3	0.01
11	68.0	54.0	61.0	100.0	50.0	75.0	0.08
12	74.0	50.0	62.0	76.0	33.0	54.5	0.0
13	75.0	54.0	64.5	100.0	33.0	66.5	0.01
14	75.0	56.0	65.5	100.0	37.0	68.5	0.0
15	74.0	52.0	63.0	100.0	45.0	72.5	0.02
MEAN	73.2	53.2	63.2	95.2	39.6	67.4	0.11
16	67.0	51.0	59.0	100.0	48.0	74.0	0.15
17	70.0	51.0	60.5	98.0	40.0	69.0	0.01
18	71.0	51.0	61.0	86.0	40.0	63.0	0.0
19	69.0	49.0	59.0	100.0	48.0	74.0	0.0
20	68.0	49.0	58.5	100.0	47.0	73.5	0.23
MEAN	69.0	50.2	59.6	96.8	44.6	70.7	0.39
21	64.0	49.0	56.5	100.0	50.0	75.0	0.04
22	66.0	50.0	58.0	90.0	44.0	67.0	0.02
23	62.0	43.0	52.5	100.0	52.0	76.0	0.04
24	48.0	44.0	46.0	100.0	96.0	98.0	0.47
25	52.0	41.0	46.5	100.0	66.0	83.0	0.17
MEAN	58.4	45.4	51.9	98.0	61.6	79.8	0.74
26	51.0	41.0	46.0	100.0	55.0	77.5	0.11
27	54.0	44.0	49.0	100.0	60.0	80.0	0.02
28	56.0	46.0	51.0	100.0	66.0	83.0	0.15
29	57.0	47.0	52.0	100.0	62.0	81.0	0.39
30	50.0	40.0	45.0	100.0	70.0	85.0	0.15
31	59.0	40.0	49.5	100.0	45.0	72.5	0.02
MEAN	54.5	43.0	48.8	100.0	59.7	79.8	0.84
MONTHLY MEAN	65.9	49.7	57.8	95.1	47.1	71.1	2.21

UPLAND PAPER BIRCH

SITE 1 AUGUST 1969

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	60.0	48.0	54.0	100.0	42.0	71.0	0.0
2	60.0	52.0	56.0	100.0	70.0	85.0	0.17
3	54.0	53.0	53.5	100.0	100.0	100.0	0.35
4	66.0	52.0	59.0	100.0	64.0	82.0	0.64
5	64.0	40.0	52.0	100.0	44.0	72.0	0.60
MEAN	60.8	49.0	54.9	100.0	64.0	82.0	1.76
6	53.0	37.0	45.0	79.0	44.0	61.5	0.0
7	51.0	31.0	41.0	100.0	50.0	75.0	0.12
8	40.0	32.0	36.0	100.0	62.0	81.0	0.07
9	49.0	40.0	44.5	100.0	82.0	91.0	0.61
10	46.0	26.0	36.0	92.0	40.0	66.0	0.0
MEAN	47.8	33.2	40.5	94.2	55.6	74.9	0.80
11	49.0	28.0	38.5	85.0	29.0	57.0	0.01
12	49.0	30.0	39.5	75.0	29.0	52.0	0.0
13	51.0	29.0	40.0	80.0	34.0	57.0	0.0
14	54.0	31.0	42.5	75.0	30.0	52.5	0.0
15	60.0	38.0	49.0	58.0	30.0	44.0	0.0
MEAN	52.6	31.2	41.9	74.6	30.4	52.5	0.01
16	63.0	42.0	52.5	60.0	32.0	46.0	0.0
17	59.0	41.0	50.0	92.0	32.0	62.0	0.02
18	60.0	38.0	49.0	59.0	30.0	44.5	0.0
19	58.0	36.0	47.0	74.0	30.0	52.0	0.0
20	48.0	37.0	42.5	100.0	50.0	75.0	0.0
MEAN	57.6	38.8	48.2	77.0	34.8	55.9	0.02
21	48.0	35.0	41.5	100.0	46.0	73.0	0.0
22	57.0	34.0	45.5	92.0	38.0	65.0	0.0
23	62.0	40.0	51.0	91.0	32.0	61.5	0.0
24	64.0	40.0	52.0	82.0	30.0	56.0	0.0
25	56.0	34.0	45.0	100.0	42.0	71.0	0.0
MEAN	57.4	36.6	47.0	93.0	37.6	65.3	0.0
26	54.0	36.0	45.0	90.0	37.0	63.5	0.0
27	58.0	36.0	47.0	88.0	30.0	59.0	0.0
28	65.0	44.0	54.5	50.0	26.0	38.0	0.0
29	66.0	48.0	57.0	59.0	28.0	43.5	0.0
30	67.0	46.0	56.5	64.0	29.0	46.5	0.0
31	62.0	47.0	52.0	98.0	34.0	66.0	0.0
MEAN	62.0	47.0	52.0	74.8	30.7	52.8	0.0
MONTHLY MEAN	56.5	38.6	47.6	85.3	41.8	63.5	2.59

SITE 1 SEPTEMBER 1969

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	64.0	41.0	52.5	98.0	36.0	67.0	0.0
2	66.0	44.0	55.0	87.0	31.0	59.0	0.0
3	66.0	44.0	55.0	90.0	28.0	59.0	0.0
4	52.0	36.0	44.0	100.0	52.0	76.0	0.0
5	55.0	40.0	47.5	100.0	46.0	73.0	0.22
MEAN	60.6	41.0	50.8	95.0	38.6	66.8	0.22
6	57.0	38.0	47.5	98.0	42.0	70.0	0.0
7	56.0	37.0	46.5	98.0	38.0	68.0	0.0
8	60.0	40.0	50.0	100.0	34.0	67.0	0.0
9	60.0	41.0	50.5	80.0	32.0	56.0	0.0
10	57.0	37.0	47.0	100.0	40.0	70.0	0.0
MEAN	58.0	38.6	48.3	95.2	37.2	66.2	0.0
11	60.0	42.0	51.0	99.0	36.0	67.5	0.0
12	58.0	39.0	48.5	99.0	36.0	67.5	0.0
13	56.0	41.0	48.5	82.0	40.0	61.0	0.0
14	60.0	42.0	51.0	76.0	38.0	57.0	0.0
MEAN	58.5	41.0	49.8	89.0	37.5	63.3	0.0
MONTHLY MEAN	59.1	40.1	49.6	93.4	37.8	65.6	0.22

UPLAND PAPER BIRCH

SITE 1 MAY 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
20	66.0	44.0	55.0	68.0	32.0	50.0	0.0
MEAN	66.0	44.0	55.0	68.0	32.0	50.0	0.0
21	67.0	45.0	56.0	59.0	31.0	45.0	0.0
22	69.0	46.0	57.5	72.0	30.0	51.0	0.0
23	69.0	45.0	57.0	86.0	36.0	61.0	0.08
24	66.0	44.0	55.0	80.0	30.0	55.0	0.01
25	68.0	44.0	56.0	74.0	23.0	48.5	0.44
MEAN	67.8	44.8	56.3	74.2	30.0	52.1	0.53
26	67.0	43.0	55.0	82.0	26.0	54.0	0.0
27	68.0	45.0	56.5	45.0	24.0	34.5	0.0
28	68.0	42.0	55.0	45.0	22.0	33.5	0.0
29	65.0	47.0	56.0	78.0	32.0	55.0	0.04
30	62.0	47.0	54.5	82.0	42.0	62.0	0.19
31	66.0	48.0	57.0	76.0	40.0	58.0	0.01
MEAN	66.0	45.3	55.7	68.0	31.0	49.5	0.24
MONTHLY MEAN	66.8	45.0	55.9	70.6	30.7	50.6	0.77

SITE 1 JUNE 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	68.0	45.0	56.5	98.0	34.0	66.0	0.10
2	59.0	41.0	50.0	97.0	48.0	72.5	0.15
3	61.0	39.0	50.0	97.0	43.0	70.0	0.0
4	69.0	43.0	56.0	68.0	44.0	56.0	0.0
5	70.0	45.0	57.5	96.0	31.0	63.5	0.01
MEAN	65.4	42.6	54.0	91.2	40.0	65.6	0.26
6	72.0	47.0	59.5	77.0	34.0	55.5	0.0
7	74.0	50.0	62.0	64.0	30.0	47.0	0.02
8	63.0	33.0	48.0	92.0	32.0	62.0	0.0
9	56.0	30.0	43.0	82.0	40.0	61.0	0.0
10	54.0	40.0	47.0	100.0	39.0	69.5	0.21
MEAN	63.8	40.0	51.9	83.0	35.0	59.0	0.23
11	60.0	41.0	50.5	96.0	48.0	72.0	0.04
12	62.0	44.0	53.0	92.0	38.0	65.0	0.0
13	69.0	45.0	57.0	70.0	32.0	51.0	0.01
14	69.0	47.0	58.0	88.0	26.0	57.0	0.50
15	60.0	46.0	53.0	90.0	48.0	69.0	0.0
MEAN	64.0	44.6	54.3	87.2	38.4	62.8	0.55
16	60.0	36.0	48.0	100.0	48.0	74.0	0.08
17	64.0	42.0	53.0	100.0	46.0	73.0	0.02
18	64.0	46.0	55.0	57.0	32.0	44.5	0.0
19	65.0	46.0	55.5	64.0	28.0	46.0	0.0
20	66.0	44.0	55.0	90.0	28.0	59.0	0.0
MEAN	63.8	42.8	53.3	82.2	36.4	59.3	0.10
21	70.0	45.0	57.5	92.0	30.0	61.0	0.12
22	60.0	46.0	53.0	100.0	44.0	72.0	0.54
23	70.0	47.0	58.5	100.0	32.0	66.0	0.0
24	72.0	49.0	60.5	100.0	30.0	65.0	0.03
25	74.0	48.0	61.0	100.0	30.0	65.0	0.11
MEAN	69.2	47.0	58.1	98.4	33.2	65.8	0.80
26	74.0	48.0	61.0	100.0	32.0	66.0	0.02
27	68.0	48.0	58.0	100.0	44.0	72.0	0.24
28	68.0	49.0	58.5	100.0	38.0	69.0	0.39
29	66.0	47.0	56.5	100.0	40.0	70.0	0.41
30	58.0	47.0	52.5	100.0	86.0	93.0	0.09
MEAN	66.8	47.8	57.3	100.0	48.0	74.0	1.15
MONTHLY MEAN	65.5	44.1	54.8	90.3	38.5	64.4	3.09

SITE 1 JULY 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	72.0	49.0	60.5	100.0	44.0	72.0	0.0
2	74.0	55.0	64.5	100.0	38.0	69.0	0.0
3	78.0	53.0	65.5	100.0	34.0	67.0	0.44
4	66.0	53.0	59.5	100.0	50.0	75.0	0.33
5	69.0	48.0	58.5	100.0	32.0	66.0	0.0
MEAN	71.8	51.6	61.7	100.0	39.6	69.8	0.77
6	69.0	45.0	57.0	92.0	34.0	63.0	0.0
7	69.0	46.0	57.5	100.0	33.0	66.5	0.03
8	59.0	48.0	53.5	100.0	50.0	75.0	0.22
9	75.0	49.0	62.0	100.0	40.0	70.0	0.0
10	65.0	46.0	55.5	100.0	47.0	73.5	0.0
MEAN	67.4	46.8	57.1	98.4	40.8	69.6	0.25
11	67.0	46.0	56.5	100.0	30.0	65.0	0.0
12	68.0	49.0	58.5	75.0	31.0	53.0	0.0
13	70.0	50.0	60.0	76.0	30.0	53.0	0.0
14	70.0	48.0	59.0	98.0	30.0	64.0	0.03
15	64.0	50.0	57.0	100.0	48.0	74.0	0.01
MEAN	67.8	48.6	58.2	89.8	33.8	61.8	0.04
16	63.0	50.0	56.5	100.0	48.0	74.0	0.18
17	69.0	50.0	59.5	100.0	36.0	68.0	0.0
18	69.0	48.0	58.5	100.0	31.0	65.5	0.25
19	50.0	45.0	47.5	100.0	74.0	87.0	0.08
20	68.0	47.0	57.5	100.0	38.0	69.0	0.11
MEAN	63.8	48.0	55.9	100.0	45.4	72.7	0.62
21	74.0	48.0	61.0	84.0	30.0	57.0	0.0
22	74.0	50.0	62.0	96.0	30.0	63.0	0.0
23	69.0	47.0	58.0	100.0	30.0	65.0	0.0
24	74.0	51.0	62.5	86.0	36.0	61.0	0.0
25	74.0	52.0	63.0	80.0	38.0	59.0	0.0
MEAN	73.0	49.6	61.3	89.2	32.8	61.0	0.0
26	74.0	50.0	62.0	94.0	32.0	63.0	0.0
27	82.0	57.0	69.5	66.0	26.0	46.0	0.0
28	83.0	53.0	68.0	100.0	25.0	62.5	0.07
29	63.0	45.0	54.0	100.0	60.0	80.0	0.0
30	62.0	48.0	55.0	100.0	46.0	73.0	0.16
31	60.0	45.0	52.5	100.0	50.0	75.0	0.28
MEAN	70.7	49.7	60.2	93.3	39.8	66.6	0.51
MONTHLY MEAN	69.1	49.1	59.1	95.1	38.7	66.9	2.19

UPLAND PAPER BIRCH

SITE 1 AUGUST 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	63.0	47.0	55.0	100.0	44.0	72.0	0.11
2	67.0	48.0	57.5	100.0	36.0	68.0	0.02
3	64.0	45.0	54.5	100.0	44.0	72.0	0.19
4	62.0	46.0	54.0	100.0	58.0	79.0	0.01
5	56.0	47.0	51.5	100.0	70.0	85.0	0.48
MEAN	62.4	46.6	54.5	100.0	50.4	75.2	0.81
6	60.0	42.0	51.0	100.0	50.0	75.0	0.01
7	62.0	48.0	55.0	94.0	50.0	72.0	0.24
8	60.0	43.0	51.5	100.0	52.0	76.0	0.0
9	64.0	42.0	53.0	100.0	42.0	71.0	0.0
10	65.0	44.0	54.5	100.0	42.0	71.0	0.0
MEAN	62.2	43.8	53.0	98.8	47.2	73.0	0.25
11	67.0	52.0	59.5	100.0	44.0	72.0	0.06
12	65.0	48.0	56.5	100.0	59.0	79.5	0.01
13	72.0	52.0	62.0	82.0	30.0	56.0	0.0
14	73.0	50.0	61.5	84.0	30.0	57.0	0.0
15	73.0	51.0	62.0	90.0	35.0	62.5	0.0
MEAN	70.0	50.6	60.3	91.2	39.6	65.4	0.07
16	66.0	48.0	57.0	100.0	50.0	75.0	0.0
17	67.0	48.0	57.5	100.0	42.0	71.0	0.0
18	66.0	50.0	58.0	64.0	38.0	51.0	0.0
19	68.0	48.0	58.0	84.0	36.0	60.0	0.0
20	66.0	46.0	56.0	78.0	33.0	55.5	0.0
MEAN	66.6	48.0	57.3	85.2	39.8	62.5	0.0
21	60.0	44.0	52.0	100.0	52.0	76.0	0.07
22	67.0	41.0	54.0	100.0	50.0	75.0	0.09
23	56.0	40.0	48.0	100.0	50.0	75.0	0.0
24	55.0	43.0	49.0	100.0	56.0	78.0	0.51
25	54.0	41.0	47.5	100.0	66.0	83.0	0.0
MEAN	58.4	41.8	50.1	100.0	54.8	77.4	0.67
26	63.0	45.0	54.0	100.0	48.0	74.0	0.0
27	68.0	46.0	57.0	100.0	48.0	74.0	0.0
28	69.0	50.0	59.5	60.0	34.0	47.0	0.0
29	65.0	49.0	57.0	80.0	38.0	59.0	0.02
30	57.0	47.0	52.0	100.0	58.0	79.0	0.27
31	55.0	48.0	51.5	100.0	85.0	92.5	0.05
MEAN	62.8	47.5	55.2	90.0	51.8	70.9	0.34
MONTHLY MEAN	63.7	46.4	55.1	94.1	47.4	70.7	2.14

SITE 1 SEPTEMBER 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	60.0	46.0	53.0	100.0	54.0	77.0	0.04
2	59.0	43.0	51.0	100.0	54.0	77.0	0.02
3	56.0	38.0	47.0	100.0	42.0	71.0	0.0
4	56.0	45.0	50.5	90.0	44.0	67.0	0.0
5	54.0	38.0	46.0	100.0	62.0	81.0	0.0
MEAN	57.0	42.0	49.5	98.0	51.2	74.6	0.06
6	49.0	34.0	41.5	84.0	34.0	59.0	0.0
7	46.0	28.0	37.0	100.0	33.0	66.5	0.0
8	41.0	20.0	30.5	96.0	46.0	71.0	0.0
9	46.0	26.0	36.0	100.0	38.0	69.0	0.0
10	54.0	31.0	42.5	72.0	33.0	52.5	0.0
MEAN	47.2	27.8	37.5	90.4	36.8	63.6	0.0
11	58.0	40.0	49.0	52.0	28.0	40.0	0.0
12	56.0	44.0	50.0	100.0	32.0	66.0	0.07
13	52.0	48.0	50.0	100.0	94.0	97.0	0.35
MEAN	55.3	44.0	49.7	84.0	51.3	67.7	0.42
MONTHLY MEAN	52.8	37.0	44.9	91.3	45.7	68.8	0.48

SITE 1 MAY 1971

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
27	59.0	36.0	47.5	92.0	34.0	63.0	0.0
28	66.0	48.0	57.0	46.0	32.0	39.0	0.02
29	64.0	43.0	53.5	80.0	29.0	54.5	0.0
30	64.0	38.0	51.0	58.0	28.0	43.0	0.0
31	65.0	44.0	54.5	55.0	32.0	43.5	0.0
MEAN	63.6	41.8	52.7	66.2	31.0	48.6	0.02
MONTHLY MEAN	63.6	41.8	52.7	66.2	31.0	48.6	0.02

SITE 1 JUNE 1971

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	64.0	46.0	55.0	70.0	25.0	47.5	0.0
2	56.0	39.0	47.5	60.0	34.0	47.0	0.0
3	60.0	40.0	50.0	63.0	36.0	49.5	0.0
4	69.0	43.0	56.0	58.0	29.0	43.5	0.0
5	78.0	53.0	65.5	45.0	23.0	34.0	0.0
MEAN	65.4	44.2	54.8	59.2	29.4	44.3	0.0
6	80.0	56.0	68.0	40.0	22.0	31.0	0.0
7	80.0	56.0	68.0	47.0	19.0	33.0	0.0
8	76.0	52.0	64.0	48.0	18.0	33.0	0.0
9	82.0	55.0	68.5	40.0	18.0	29.0	0.0
10	82.0	61.0	71.5	50.0	18.0	34.0	0.01
MEAN	80.0	56.0	68.0	45.0	19.0	32.0	0.01
11	77.0	51.0	64.0	50.0	27.0	38.5	0.0
12	70.0	45.0	57.5	66.0	28.0	47.0	0.0
13	67.0	44.0	55.5	98.0	24.0	61.0	0.05
14	58.0	41.0	49.5	94.0	20.0	57.0	0.03
15	66.0	47.0	56.5	74.0	22.0	48.0	0.01
MEAN	67.6	45.6	56.6	76.4	24.2	50.3	0.09
16	69.0	46.0	57.5	54.0	22.0	38.0	0.0
17	70.0	46.0	58.0	52.0	20.0	36.0	0.0
18	70.0	48.0	59.0	66.0	18.0	42.0	0.0
19	75.0	49.0	62.0	76.0	28.0	52.0	0.0
20	75.0	54.0	64.5	89.0	36.0	62.5	0.05
MEAN	71.8	48.6	60.2	67.4	24.8	46.1	0.05
21	83.0	56.0	69.5	92.0	30.0	61.0	0.0
22	78.0	51.0	64.5	92.0	24.0	58.0	0.0
23	87.0	64.0	75.5	52.0	20.0	36.0	0.0
24	86.0	62.0	74.0	34.0	12.0	23.0	0.0
25	86.0	62.0	74.0	36.0	10.0	23.0	0.0
MEAN	84.0	59.0	71.5	61.2	19.2	40.2	0.0
26	84.0	62.0	73.0	32.0	13.0	22.5	0.0
27	83.0	58.0	70.5	53.0	18.0	35.5	0.0
28	80.0	53.0	66.5	36.0	20.0	28.0	0.0
29	76.0	46.0	61.0	94.0	20.0	57.0	0.14
30	59.0	36.0	47.5	94.0	34.0	64.0	0.0
MEAN	76.4	51.0	63.7	61.8	21.0	41.4	0.14
MONTHLY MEAN	74.2	50.7	62.5	61.8	22.9	42.4	0.29

UPLAND PAPER BIRCH

SITE 1 JULY 1971

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	58.0	38.0	43.0	98.0	30.0	64.0	0.03
2	68.0	42.0	55.0	94.0	32.0	63.0	0.40
3	73.0	50.0	61.5	76.0	26.0	51.0	0.0
4	76.0	51.0	63.5	78.0	25.0	51.5	0.0
5	76.0	49.0	62.5	93.0	24.0	58.5	0.0
MEAN	70.2	46.0	58.1	87.8	27.4	57.6	0.43
6	78.0	54.0	66.0	81.0	18.0	49.5	0.10
7	79.0	56.0	67.5	60.0	16.0	38.0	0.0
8	74.0	51.0	62.5	92.0	28.0	60.0	0.01
9	77.0	53.0	65.0	78.0	26.0	52.0	0.0
10	78.0	56.0	67.0	75.0	24.0	49.5	0.0
MEAN	77.2	54.0	65.6	77.2	22.4	49.8	0.11
11	78.0	54.0	66.0	90.0	34.0	62.0	0.33
12	62.0	56.0	59.0	92.0	60.0	76.0	0.79
13	60.0	55.0	57.5	92.0	87.0	89.5	0.38
14	58.0	43.0	50.5	93.0	76.0	84.5	0.70
15	58.0	40.0	49.0	93.0	40.0	66.5	0.03
MEAN	63.2	49.6	56.4	92.0	59.4	75.7	2.23
16	67.0	44.0	55.5	73.0	30.0	51.5	0.0
17	70.0	49.0	59.5	80.0	32.0	56.0	0.0
18	80.0	54.0	67.0	62.0	24.0	43.0	0.0
19	78.0	54.0	66.0	79.0	24.0	51.5	0.03
20	76.0	58.0	67.0	63.0	26.0	44.5	0.0
MEAN	74.2	51.8	63.0	71.4	27.2	49.3	0.03
21	69.0	47.0	58.0	93.0	24.0	58.5	0.05
22	67.0	46.0	56.5	56.0	26.0	41.0	0.0
23	70.0	49.0	59.5	60.0	24.0	42.0	0.0
24	72.0	51.0	61.5	59.0	26.0	42.5	0.0
25	71.0	47.0	59.0	86.0	30.0	58.0	0.01
MEAN	69.8	48.0	58.9	70.8	26.0	48.4	0.06
26	73.0	52.0	62.5	73.0	22.0	47.5	0.0
27	70.0	48.0	59.0	79.0	20.0	49.5	0.0
28	62.0	42.0	52.0	92.0	34.0	63.0	0.25
29	62.0	42.0	52.0	92.0	32.0	62.0	0.30
30	63.0	48.0	55.5	74.0	33.0	53.5	0.0
31	60.0	48.0	54.0	94.0	66.0	80.0	0.11
MEAN	65.0	46.7	55.8	84.0	34.5	59.3	0.66
MONTHLY MEAN	69.8	49.3	59.5	80.6	32.9	56.8	3.52

UPLAND PAPER BIRCH

SITE 1 AUGUST 1971

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	61.0	51.0	56.0	90.0	67.0	78.5	0.20
2	63.0	50.0	56.5	92.0	44.0	68.0	0.06
3	60.0	40.0	50.0	88.0	34.0	61.0	0.0
4	57.0	44.0	50.5	94.0	38.0	66.0	0.17
5	59.0	46.0	52.5	92.0	41.0	66.5	0.0
MEAN	60.0	46.2	53.1	91.2	44.8	68.0	0.43
6	58.0	49.0	53.5	92.0	60.0	76.0	0.0
7	57.0	50.0	53.5	92.0	73.0	82.5	0.16
8	56.0	49.0	52.5	92.0	83.0	87.5	0.15
9	57.0	54.0	55.5	94.0	90.0	92.0	0.43
10	58.0	52.0	55.0	94.0	94.0	94.0	0.46
MEAN	57.2	50.8	54.0	92.8	80.0	86.4	1.20
11	67.0	49.0	58.0	93.0	30.0	61.5	0.02
12	67.0	50.0	58.5	82.0	38.0	60.0	0.0
13	68.0	48.0	58.0	84.0	32.0	58.0	0.0
14	66.0	40.0	53.0	78.0	32.0	55.0	0.0
15	64.0	39.0	51.5	80.0	32.0	56.0	0.0
MEAN	66.4	45.2	55.8	83.4	32.8	58.1	0.02
16	68.0	44.0	56.0	66.0	30.0	48.0	0.0
17	70.0	49.0	59.5	66.0	27.0	46.5	0.0
18	72.0	52.0	62.0	66.0	28.0	47.0	0.0
19	72.0	52.0	62.0	80.0	27.0	53.5	0.0
20	64.0	42.0	53.0	100.0	56.0	78.0	0.97
MEAN	69.2	47.8	58.5	75.6	33.6	54.6	0.97
21	46.0	39.0	42.5	100.0	92.0	96.0	0.38
22	66.0	44.0	55.0	88.0	50.0	69.0	0.0
23	67.0	48.0	57.5	82.0	50.0	66.0	0.01
24	64.0	46.0	55.0	100.0	54.0	77.0	0.0
25	60.0	47.0	53.5	100.0	56.0	78.0	0.08
MEAN	60.6	44.8	52.7	94.0	60.4	77.2	0.47
26	63.0	46.0	54.5	100.0	60.0	80.0	0.0
27	64.0	44.0	54.0	100.0	44.0	72.0	0.0
28	65.0	43.0	54.0	100.0	31.0	65.5	0.0
29	71.0	44.0	57.5	100.0	30.0	65.0	0.0
30	70.0	44.0	57.0	100.0	26.0	63.0	0.0
31	63.0	47.0	55.0	100.0	48.0	74.0	0.33
MEAN	66.0	44.7	55.3	100.0	39.8	69.9	0.33
MONTHLY MEAN	63.3	46.5	54.9	89.8	48.3	69.1	3.42

SITE 1 SEPTEMBER 1971

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	54.0	41.0	47.5	100.0	72.0	86.0	0.15
2	46.0	40.0	43.0	100.0	96.0	98.0	0.60
3	43.0	34.0	38.5	100.0	98.0	99.0	0.09
4	44.0	37.0	40.5	100.0	98.0	99.0	0.53
5	45.0	35.0	40.0	100.0	100.0	100.0	0.0
MEAN	46.4	37.4	41.9	100.0	92.8	96.4	1.37
MONTHLY MEAN	46.4	37.4	41.9	100.0	92.8	96.4	1.37

SITE 2 JUNE 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
11	82.0	57.0	69.5	60.0	28.0	44.0	0.0
12	82.0	55.0	68.5	65.0	28.0	46.5	0.0
13	82.0	57.0	69.5	56.0	28.0	42.0	0.0
14	80.0	54.0	67.0	94.0	32.0	63.0	0.0
15	74.0	51.0	62.5	94.0	46.0	70.0	0.26
MEAN	80.0	54.8	67.4	73.8	32.4	53.1	0.26
16	63.0	49.0	56.0	94.0	56.0	75.0	0.15
17	75.0	52.0	63.5	92.0	34.0	63.0	0.02
18	70.0	53.0	61.5	85.0	38.0	61.5	0.0
19	72.0	53.0	62.5	92.0	46.0	69.0	0.0
20	69.0	51.0	60.0	94.0	48.0	71.0	0.02
MEAN	69.8	51.6	60.7	91.4	44.4	67.9	0.19
21	64.0	48.0	56.0	94.0	46.0	70.0	0.11
22	56.0	46.0	51.0	94.0	60.0	77.0	0.16
23	68.0	44.0	56.0	94.0	36.0	65.0	0.0
24	72.0	48.0	60.0	78.0	30.0	54.0	0.0
25	74.0	51.0	62.5	94.0	36.0	65.0	0.02
MEAN	66.8	47.4	57.1	90.8	41.6	66.2	0.29
26	72.0	49.0	60.5	94.0	38.0	66.0	0.0
27	76.0	52.0	64.0	94.0	24.0	59.0	0.0
28	77.0	51.0	64.0	75.0	24.0	49.5	0.0
29	69.0	50.0	59.5	82.0	40.0	61.0	0.0
30	67.0	50.0	58.5	94.0	42.0	68.0	0.0
MEAN	72.2	50.4	61.3	87.8	33.6	60.7	0.0
MONTHLY MEAN	72.2	51.0	61.6	85.9	38.0	62.0	0.74

SITE 2 JULY 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	68.0	49.0	58.5	94.0	40.0	67.0	0.0
2	68.0	48.0	58.0	94.0	40.0	67.0	0.02
3	72.0	52.0	62.0	94.0	37.0	65.5	0.0
4	76.0	51.0	63.5	92.0	36.0	64.0	0.12
5	81.0	57.0	69.0	68.0	32.0	50.0	0.0
MEAN	73.0	51.4	62.2	88.4	37.0	62.7	0.14
6	86.0	61.0	73.5	62.0	30.0	46.0	0.0
7	88.0	62.0	75.0	64.0	28.0	46.0	0.0
8	90.0	66.0	78.0	42.0	24.0	33.0	0.0
9	90.0	62.0	76.0	72.0	24.0	48.0	0.0
10	82.0	55.0	68.5	94.0	24.0	59.0	0.0
MEAN	87.2	61.2	74.2	66.8	26.0	46.4	0.0
11	80.0	52.0	66.0	57.0	22.0	39.5	0.0
12	76.0	53.0	64.5	76.0	28.0	52.0	0.0
13	76.0	52.0	64.0	90.0	40.0	65.0	0.0
14	76.0	57.0	66.5	92.0	38.0	65.0	0.0
15	71.0	58.0	64.5	94.0	44.0	69.0	0.0
MEAN	75.8	54.4	65.1	81.8	34.4	58.1	0.0
16	72.0	48.0	60.0	94.0	40.0	67.0	0.0
17	74.0	52.0	63.0	88.0	32.0	60.0	0.0
18	80.0	55.0	67.5	72.0	31.0	51.5	0.0
19	82.0	56.0	69.0	76.0	30.0	53.0	0.0
20	86.0	53.0	69.5	94.0	30.0	62.0	0.0
MEAN	78.8	52.8	65.8	84.8	32.6	58.7	0.0
21	88.0	58.0	73.0	84.0	22.0	53.0	0.0
22	90.0	60.0	75.0	81.0	26.0	53.5	0.0
23	90.0	63.0	76.5	64.0	26.0	45.0	0.0
24	90.0	61.0	75.5	80.0	26.0	53.0	0.0
25	86.0	62.0	74.0	68.0	24.0	46.0	0.0
MEAN	88.8	60.8	74.8	75.4	24.8	50.1	0.0
26	86.0	60.0	73.0	46.0	30.0	38.0	0.0
27	82.0	57.0	69.5	79.0	30.0	54.5	0.0
28	68.0	53.0	60.5	94.0	48.0	71.0	0.14
29	74.0	53.0	63.5	85.0	40.0	62.5	0.0
30	77.0	55.0	66.0	85.0	30.0	57.5	0.0
31	74.0	51.0	62.5	92.0	34.0	63.0	0.25
MEAN	76.8	54.8	65.8	80.2	35.3	57.8	0.39
MONTHLY MEAN	80.0	55.9	67.9	79.6	31.8	55.7	0.53

SITE 2 AUGUST 1968

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	64.0	52.0	58.0	90.0	52.0	71.0	0.22
2	66.0	50.0	58.0	90.0	50.0	70.0	0.01
3	66.0	49.0	57.5	86.0	46.0	66.0	0.0
4	74.0	47.0	60.5	86.0	34.0	60.0	0.0
5	70.0	54.0	62.0	94.0	38.0	66.0	0.17
MEAN	68.0	50.4	59.2	89.2	44.0	66.6	0.40
6	81.0	56.0	68.5	95.0	40.0	67.5	0.0
7	82.0	59.0	70.5	90.0	38.0	64.0	0.0
8	80.0	57.0	68.5	58.0	36.0	47.0	0.0
9	80.0	56.0	68.0	72.0	34.0	53.0	0.0
10	80.0	56.0	68.0	64.0	34.0	49.0	0.0
MEAN	80.6	56.8	68.7	75.8	36.4	56.1	0.0
11	81.0	53.0	67.0	68.0	32.0	50.0	0.0
12	81.0	51.0	66.0	90.0	32.0	61.0	0.0
13	83.0	53.0	68.0	82.0	38.0	60.0	0.0
14	83.0	54.0	68.5	88.0	31.0	59.5	0.0
15	74.0	49.0	61.5	94.0	38.0	66.0	0.0
MEAN	80.4	52.0	66.2	84.4	34.2	59.3	0.0
16	73.0	47.0	60.0	94.0	28.0	61.0	0.0
17	68.0	53.0	60.5	94.0	48.0	71.0	0.09
18	66.0	47.0	56.5	92.0	44.0	68.0	0.0
19	68.0	46.0	57.0	96.0	48.0	72.0	0.0
20	75.0	50.0	62.5	96.0	40.0	68.0	0.0
MEAN	70.0	48.6	59.3	94.4	41.6	68.0	0.09
21	72.0	49.0	60.5	96.0	42.0	69.0	0.08
22	62.0	50.0	56.0	96.0	70.0	83.0	0.04
23	63.0	49.0	56.0	96.0	66.0	81.0	1.05
24	58.0	47.0	52.5	96.0	60.0	78.0	0.0
25	66.0	46.0	56.0	96.0	50.0	73.0	0.0
MEAN	64.2	48.2	56.2	96.0	57.6	76.8	1.17
26	64.0	42.0	53.0	96.0	48.0	72.0	0.0
27	64.0	42.0	53.0	96.0	50.0	73.0	0.0
28	61.0	46.0	53.5	96.0	52.0	74.0	0.05
29	52.0	42.0	47.0	96.0	66.0	81.0	0.10
30	58.0	35.0	46.5	96.0	48.0	72.0	0.0
31	54.0	37.0	45.5	96.0	50.0	73.0	0.0
MEAN	58.8	40.7	49.8	96.0	52.3	74.2	0.15
MONTHLY MEAN	70.0	49.2	59.6	89.5	44.6	67.1	1.81

SITE 2 SEPTEMBER 1968

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	59.0	40.0	49.5	90.0	42.0	66.0	0.0
2	60.0	39.0	49.5	83.0	30.0	56.5	0.0
3	60.0	35.0	47.5	73.0	32.0	52.5	0.0
4	62.0	41.0	51.5	52.0	30.0	41.0	0.0
5	60.0	44.0	52.0	74.0	32.0	53.0	0.0
MEAN	60.2	39.8	50.0	74.4	33.2	53.8	0.0
6	63.0	43.0	53.0	76.0	32.0	54.0	0.0
7	63.0	40.0	51.5	56.0	34.0	45.0	0.0
8	62.0	40.0	51.0	70.0	38.0	54.0	0.0
9	64.0	42.0	53.0	83.0	38.0	60.5	0.0
10	62.0	46.0	54.0	66.0	38.0	52.0	0.0
MEAN	62.8	42.2	52.5	70.2	36.0	53.1	0.0
11	60.0	44.0	52.0	92.0	44.0	68.0	0.01
12	54.0	41.0	47.5	95.0	50.0	72.5	0.01
13	56.0	36.0	46.0	92.0	40.0	66.0	0.0
14	55.0	35.0	45.0	90.0	36.0	63.0	0.0
15	54.0	36.0	45.0	94.0	36.0	65.0	0.01
MEAN	55.8	38.4	47.1	92.6	41.2	66.9	0.03
16	49.0	35.0	42.0	94.0	52.0	73.0	0.0
17	43.0	33.0	38.0	94.0	54.0	74.0	0.0
18	42.0	33.0	37.5	82.0	54.0	68.0	0.06
19	42.0	32.0	37.0	94.0	58.0	76.0	0.0
20	39.0	31.0	35.0	94.0	60.0	77.0	0.0
MEAN	43.0	32.8	37.9	91.6	55.6	73.6	0.06
21	39.0	25.0	32.0	93.0	50.0	71.5	0.0
22	36.0	22.0	29.0	95.0	54.0	74.5	0.0
23	37.0	24.0	30.5	92.0	58.0	75.0	0.0
24	35.0	20.0	27.5	95.0	55.0	75.0	0.0
25	36.0	24.0	30.0	95.0	66.0	80.5	0.0
MEAN	36.6	23.0	29.8	94.0	56.6	75.3	0.0
26	42.0	31.0	36.5	94.0	66.0	80.0	0.0
27	50.0	33.0	41.5	90.0	56.0	73.0	0.0
28	50.0	33.0	41.5	95.0	60.0	77.5	0.0
29	42.0	26.0	34.0	94.0	84.0	89.0	0.0
MEAN	46.0	30.8	38.4	93.3	66.5	79.9	0.0
MONTHLY MEAN	50.9	34.6	42.8	85.8	47.6	66.7	0.09

SITE 2 MAY 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
26	68.0	41.0	54.5	38.0	17.0	27.5	0.0
27	56.0	27.0	41.5	86.0	20.0	53.0	0.0
28	62.0	36.0	49.0	36.0	22.0	29.0	0.01
29	65.0	40.0	52.5	48.0	18.0	33.0	0.0
30	66.0	47.0	56.5	53.0	20.0	36.5	0.0
31	68.0	46.0	57.0	46.0	21.0	33.5	0.03
MEAN	64.2	39.5	51.8	51.2	19.7	35.4	0.04
MONTHLY MEAN	64.2	39.5	51.8	51.2	19.7	35.4	0.04

SITE 2 JUNE 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	62.0	40.0	51.0	84.0	26.0	55.0	0.0
2	68.0	40.0	54.0	74.0	18.0	46.0	0.29
3	69.0	46.0	57.5	42.0	13.0	27.5	0.0
4	69.0	46.0	57.5	84.0	16.0	50.0	0.0
5	63.0	46.0	54.5	86.0	28.0	57.0	0.08
MEAN	66.2	43.6	54.9	74.0	20.2	47.1	0.37
6	72.0	47.0	59.5	50.0	20.0	35.0	0.16
7	73.0	53.0	63.0	48.0	20.0	34.0	0.0
8	78.0	55.0	66.5	42.0	20.0	31.0	0.0
9	78.0	58.0	68.0	42.0	19.0	30.5	0.0
10	76.0	48.0	62.0	68.0	28.0	48.0	0.0
MEAN	75.4	52.2	63.8	50.0	21.4	35.7	0.16
11	75.0	52.0	63.5	54.0	24.0	39.0	0.0
12	84.0	52.0	68.0	68.0	16.0	42.0	0.0
13	84.0	54.0	69.0	72.0	16.0	44.0	0.0
14	90.0	60.0	75.0	54.0	16.0	35.0	0.0
15	94.0	68.0	81.0	44.0	12.0	28.0	0.0
MEAN	85.4	57.2	71.3	58.4	16.8	37.6	0.0
16	97.0	70.0	83.5	34.0	2.0	18.0	0.0
17	80.0	54.0	67.0	80.0	15.0	47.5	0.0
18	80.0	53.0	66.5	80.0	16.0	48.0	0.0
19	82.0	55.0	68.5	56.0	12.0	34.0	0.0
20	90.0	62.0	76.0	44.0	8.0	26.0	0.0
MEAN	85.8	58.8	72.3	58.8	10.6	34.7	0.0
21	89.0	53.0	71.0	79.0	12.0	45.5	0.0
22	86.0	64.0	75.0	34.0	10.0	22.0	0.0
23	86.0	57.0	71.5	38.0	10.0	24.0	0.0
24	81.0	53.0	67.0	61.0	12.0	36.5	0.0
25	75.0	50.0	62.5	80.0	31.0	55.5	0.0
MEAN	83.4	55.4	69.4	58.4	15.0	36.7	0.0
26	81.0	51.0	66.0	80.0	24.0	52.0	0.0
27	85.0	61.0	73.0	55.0	16.0	35.5	0.0
28	85.0	59.0	72.0	69.0	15.0	42.0	0.0
29	77.0	54.0	65.5	96.0	37.0	66.5	0.04
30	67.0	50.0	58.5	88.0	34.0	61.0	0.0
MEAN	79.0	55.0	67.0	77.6	25.2	51.4	0.04
MONTHLY MEAN	79.2	53.7	66.4	62.9	18.2	40.5	0.57

UPLAND BLACK SPRUCE

SITE 2 JULY 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	68.0	49.0	58.5	80.0	36.0	58.0	0.0
2	68.0	51.0	59.5	80.0	36.0	58.0	0.04
3	66.0	52.0	59.0	80.0	36.0	58.0	0.06
4	74.0	49.0	61.5	80.0	32.0	56.0	0.02
5	88.0	51.0	69.5	80.0	30.0	55.0	0.0
MEAN	72.8	50.4	61.6	80.0	34.0	57.0	0.12
6	78.0	55.0	66.5	80.0	30.0	55.0	0.0
7	76.0	55.0	65.5	80.0	30.0	55.0	0.0
8	70.0	54.0	62.0	80.0	56.0	68.0	0.0
9	72.0	53.0	62.5	80.0	56.0	68.0	0.13
10	60.0	48.0	54.0	100.0	60.0	80.0	0.01
MEAN	71.2	53.0	62.1	84.0	46.4	65.2	0.14
11	68.0	53.0	60.5	96.0	54.0	75.0	0.13
12	76.0	49.0	62.5	89.0	44.0	66.5	0.04
13	76.0	54.0	65.0	98.0	44.0	71.0	0.02
14	74.0	54.0	64.0	98.0	46.0	72.0	0.0
15	74.0	53.0	63.5	100.0	50.0	75.0	0.01
MEAN	73.6	52.6	63.1	96.2	47.6	71.9	0.20
16	69.0	51.0	60.0	100.0	52.0	76.0	0.16
17	71.0	52.0	61.5	94.0	46.0	70.0	0.02
18	70.0	54.0	62.0	80.0	46.0	63.0	0.01
19	70.0	50.0	60.0	94.0	54.0	74.0	0.0
20	68.0	49.0	58.5	100.0	54.0	77.0	0.05
MEAN	69.6	51.2	60.4	93.6	50.4	72.0	0.24
21	67.0	50.0	58.5	100.0	54.0	77.0	0.07
22	67.0	48.0	57.5	94.0	52.0	73.0	0.01
23	64.0	45.0	54.5	100.0	56.0	78.0	0.02
24	51.0	46.0	48.5	100.0	84.0	92.0	0.43
25	54.0	42.0	48.0	100.0	64.0	82.0	0.14
MEAN	60.6	46.2	53.4	98.8	62.0	80.4	0.67
26	54.0	42.0	48.0	100.0	56.0	78.0	0.11
27	57.0	47.0	52.0	94.0	60.0	77.0	0.02
28	56.0	47.0	51.5	100.0	72.0	86.0	0.12
29	59.0	48.0	53.5	100.0	68.0	84.0	0.35
30	54.0	40.0	47.0	100.0	74.0	87.0	0.13
31	64.0	42.0	53.0	100.0	50.0	75.0	0.02
MEAN	57.3	44.3	50.8	99.0	63.3	81.2	0.75
MONTHLY MEAN	67.2	49.5	58.3	92.2	51.0	71.6	2.12

SITE 2 AUGUST 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	62.0	54.0	58.0	100.0	52.0	76.0	0.0
2	62.0	54.0	58.0	100.0	74.0	87.0	0.27
3	58.0	55.0	56.5	100.0	94.0	97.0	0.38
4	68.0	54.0	61.0	100.0	74.0	87.0	0.61
5	66.0	42.0	54.0	100.0	52.0	76.0	0.51
MEAN	63.2	51.8	57.5	100.0	69.2	84.6	1.77
6	56.0	37.0	46.5	90.0	54.0	72.0	0.01
7	53.0	34.0	43.5	100.0	60.0	80.0	0.13
8	44.0	34.0	39.0	100.0	68.0	84.0	0.05
9	52.0	41.0	46.5	100.0	70.0	85.0	0.61
10	48.0	28.0	38.0	96.0	44.0	70.0	0.02
MEAN	50.6	34.8	42.7	97.2	59.2	78.2	0.82
11	50.0	30.0	40.0	88.0	36.0	62.0	0.0
12	50.0	32.0	41.0	72.0	36.0	54.0	0.0
13	53.0	31.0	42.0	78.0	40.0	59.0	0.0
14	58.0	36.0	47.0	68.0	38.0	53.0	0.0
15	63.0	38.0	50.5	66.0	38.0	52.0	0.0
MEAN	54.8	33.4	44.1	74.4	37.6	56.0	0.0
16	66.0	44.0	55.0	70.0	38.0	54.0	0.0
17	65.0	42.0	53.5	80.0	40.0	60.0	0.0
18	62.0	40.0	51.0	64.0	38.0	51.0	0.0
19	58.0	38.0	48.0	78.0	40.0	59.0	0.0
20	50.0	39.0	44.5	94.0	54.0	74.0	0.0
MEAN	60.2	40.6	50.4	77.2	42.0	59.6	0.0
21	50.0	37.0	43.5	94.0	50.0	72.0	0.0
22	60.0	36.0	48.0	86.0	42.0	64.0	0.0
23	66.0	42.0	54.0	84.0	38.0	61.0	0.0
24	64.0	38.0	51.0	90.0	40.0	65.0	0.0
25	60.0	37.0	48.5	94.0	44.0	69.0	0.0
MEAN	60.0	38.0	49.0	89.6	42.8	66.2	0.0
26	54.0	38.0	46.0	86.0	44.0	65.0	0.0
27	62.0	36.0	49.0	88.0	38.0	63.0	0.0
28	68.0	42.0	55.0	68.0	36.0	52.0	0.0
29	71.0	49.0	60.0	62.0	36.0	49.0	0.0
30	68.0	46.0	57.0	68.0	36.0	52.0	0.0
31	64.0	45.0	54.5	86.0	40.0	63.0	0.0
MEAN	64.5	42.7	53.6	76.3	38.3	57.3	0.0
MONTHLY MEAN	59.1	40.3	49.7	85.5	47.9	66.7	2.59

SITE 2 SEPTEMBER 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	68.0	44.0	56.0	88.0	40.0	64.0	0.0
2	70.0	44.0	57.0	82.0	36.0	59.0	0.0
3	66.0	48.0	57.0	78.0	38.0	58.0	0.0
4	58.0	38.0	48.0	90.0	50.0	70.0	0.0
5	56.0	44.0	50.0	94.0	48.0	71.0	0.23
MEAN	63.6	43.6	53.6	86.4	42.4	64.4	0.23
6	59.0	40.0	49.5	90.0	44.0	67.0	0.0
7	58.0	38.0	48.0	92.0	48.0	70.0	0.0
8	62.0	41.0	51.5	94.0	42.0	68.0	0.0
9	62.0	48.0	55.0	64.0	42.0	53.0	0.0
10	60.0	42.0	51.0	92.0	46.0	69.0	0.03
MEAN	60.2	41.8	51.0	86.4	44.4	65.4	0.03
11	62.0	41.0	51.5	94.0	42.0	68.0	0.0
12	60.0	38.0	49.0	94.0	42.0	68.0	0.0
13	58.0	40.0	49.0	78.0	46.0	62.0	0.0
14	62.0	41.0	51.5	72.0	44.0	58.0	0.0
MEAN	60.5	40.0	50.3	84.5	43.5	64.0	0.0
MONTHLY MEAN	61.5	41.9	51.7	85.9	43.4	64.6	0.26

SITE 2 MAY 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
20	68.0	44.0	56.0	76.0	29.0	52.5	0.0
MEAN	68.0	44.0	56.0	76.0	29.0	52.5	0.0
21	70.0	44.0	57.0	62.0	24.0	43.0	0.0
22	69.0	46.0	57.5	76.0	26.0	51.0	0.0
23	70.0	45.0	57.5	89.0	30.0	59.5	0.01
24	67.0	44.0	55.5	86.0	20.0	53.0	0.0
25	68.0	44.0	56.0	72.0	17.0	44.5	0.49
MEAN	68.8	44.6	56.7	77.0	23.4	50.2	0.50
26	76.0	42.0	59.0	87.0	20.0	53.5	0.0
27	67.0	44.0	55.5	51.0	18.0	34.5	0.0
28	66.0	43.0	54.5	48.0	16.0	32.0	0.0
29	65.0	46.0	55.5	76.0	28.0	52.0	0.03
30	65.0	46.0	55.5	84.0	36.0	60.0	0.06
31	65.0	44.0	54.5	85.0	32.0	58.5	0.02
MEAN	67.3	44.2	55.8	71.8	25.0	48.4	0.11
MONTHLY MEAN	68.0	44.3	56.2	74.3	24.7	49.5	0.61

SITE 2 JUNE 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	68.0	46.0	57.0	96.0	27.0	61.5	0.07
2	58.0	41.0	49.5	98.0	44.0	71.0	0.03
3	65.0	41.0	53.0	88.0	36.0	62.0	0.0
4	71.0	47.0	59.0	62.0	22.0	42.0	0.0
5	72.0	48.0	60.0	94.0	20.0	57.0	0.04
MEAN	66.8	44.6	55.7	87.6	29.8	58.7	0.14
6	76.0	47.0	61.5	80.0	34.0	57.0	0.0
7	76.0	51.0	63.5	82.0	24.0	53.0	0.0
8	66.0	38.0	52.0	80.0	25.0	52.5	0.0
9	58.0	33.0	45.5	74.0	30.0	52.0	0.0
10	59.0	43.0	51.0	90.0	29.0	59.5	0.18
MEAN	67.0	42.4	54.7	81.2	28.4	54.8	0.18
11	61.0	43.0	52.0	90.0	36.0	63.0	0.06
12	66.0	45.0	55.5	87.0	25.0	56.0	0.0
13	70.0	48.0	59.0	68.0	22.0	45.0	0.01
14	69.0	47.0	58.0	88.0	26.0	57.0	0.25
15	60.0	46.0	53.0	90.0	48.0	69.0	0.19
MEAN	65.2	45.8	55.5	84.6	31.4	58.0	0.51
16	60.0	41.0	50.5	100.0	48.0	74.0	0.03
17	65.0	43.0	54.0	100.0	46.0	73.0	0.04
18	66.0	47.0	56.5	64.0	30.0	47.0	0.0
19	66.0	50.0	58.0	64.0	30.0	47.0	0.0
20	68.0	45.0	56.5	79.0	30.0	54.5	0.0
MEAN	65.0	45.2	55.1	81.4	36.8	59.1	0.07
21	72.0	47.0	59.5	82.0	30.0	56.0	0.07
22	63.0	49.0	56.0	100.0	58.0	79.0	0.52
23	69.0	49.0	59.0	100.0	36.0	68.0	0.0
24	72.0	50.0	61.0	100.0	34.0	67.0	0.67
25	75.0	48.0	61.5	98.0	40.0	69.0	0.03
MEAN	70.2	48.6	59.4	96.0	39.6	67.8	1.29
26	74.0	50.0	62.0	100.0	44.0	72.0	0.05
27	69.0	50.0	59.5	100.0	56.0	78.0	0.20
28	69.0	51.0	60.0	100.0	50.0	75.0	0.83
29	68.0	49.0	58.5	100.0	52.0	76.0	0.33
30	57.0	50.0	53.5	100.0	74.0	87.0	0.06
MEAN	67.4	50.0	58.7	100.0	55.2	77.6	1.47
MONTHLY MEAN	66.9	46.1	56.5	88.5	36.9	62.7	3.66

UPLAND BLACK SPRUCE

SITE 2 JULY 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	72.0	51.0	61.5	100.0	44.0	72.0	0.0
2	77.0	56.0	66.5	100.0	36.0	68.0	0.0
3	77.0	54.0	65.5	100.0	38.0	69.0	0.36
4	67.0	55.0	61.0	100.0	50.0	75.0	0.33
5	70.0	49.0	59.5	100.0	34.0	67.0	0.0
MEAN	72.6	53.0	62.8	100.0	40.4	70.2	0.69
6	70.0	46.0	58.0	100.0	36.0	68.0	0.0
7	71.0	47.0	59.0	96.0	36.0	66.0	0.02
8	66.0	50.0	58.0	100.0	50.0	75.0	0.23
9	67.0	50.0	58.5	98.0	42.0	70.0	0.0
10	64.0	48.0	56.0	98.0	52.0	75.0	0.0
MEAN	67.6	48.2	57.9	98.4	43.2	70.8	0.25
11	70.0	49.0	59.5	93.0	30.0	61.5	0.0
12	70.0	50.0	60.0	72.0	30.0	51.0	0.0
13	71.0	51.0	61.0	88.0	34.0	61.0	0.01
14	71.0	50.0	60.5	86.0	32.0	59.0	0.01
15	64.0	52.0	58.0	93.0	50.0	71.5	0.0
MEAN	69.2	50.4	59.8	86.4	35.2	60.8	0.02
16	66.0	52.0	59.0	90.0	48.0	69.0	0.0
17	70.0	51.0	60.5	100.0	36.0	68.0	0.08
18	71.0	52.0	61.5	92.0	34.0	63.0	0.29
19	51.0	46.0	48.5	92.0	79.0	85.5	0.10
20	70.0	48.0	59.0	92.0	40.0	66.0	0.07
MEAN	65.6	49.8	57.7	93.2	47.4	70.3	0.54
21	76.0	50.0	63.0	95.0	32.0	63.5	0.0
22	77.0	52.0	64.5	100.0	36.0	68.0	0.0
23	70.0	50.0	60.0	100.0	40.0	70.0	0.0
24	75.0	53.0	64.0	94.0	40.0	67.0	0.0
25	78.0	54.0	66.0	98.0	36.0	67.0	0.0
MEAN	75.2	51.8	63.5	97.4	36.8	67.1	0.0
26	78.0	52.0	65.0	98.0	30.0	64.0	0.0
27	84.0	58.0	71.0	73.0	26.0	49.5	0.0
28	85.0	56.0	70.5	100.0	26.0	63.0	0.07
29	64.0	46.0	55.0	100.0	60.0	80.0	0.01
30	64.0	50.0	57.0	100.0	42.0	71.0	0.18
31	63.0	46.0	54.5	100.0	48.0	74.0	0.19
MEAN	73.0	51.3	62.2	95.2	38.7	66.9	0.45
MONTHLY MEAN	70.6	50.8	60.7	95.1	40.2	67.7	1.95

UPLAND BLACK SPRUCE

SITE 2 AUGUST 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	64.0	49.0	56.5	100.0	44.0	72.0	0.14
2	68.0	48.0	58.0	100.0	40.0	70.0	0.02
3	64.0	46.0	55.0	100.0	46.0	73.0	0.11
4	62.0	48.0	55.0	100.0	68.0	84.0	0.0
5	58.0	49.0	53.5	100.0	61.0	80.5	0.44
MEAN	63.2	48.0	55.6	100.0	51.8	75.9	0.71
6	62.0	44.0	53.0	100.0	48.0	74.0	0.01
7	63.0	50.0	56.5	100.0	50.0	75.0	0.27
8	62.0	45.0	53.5	100.0	48.0	74.0	0.0
9	63.0	44.0	53.5	100.0	42.0	71.0	0.0
10	69.0	46.0	57.5	100.0	38.0	69.0	0.0
MEAN	63.8	45.8	54.8	100.0	45.2	72.6	0.28
11	69.0	53.0	61.0	84.0	40.0	62.0	0.05
12	63.0	50.0	56.5	100.0	64.0	82.0	0.0
13	74.0	52.0	63.0	90.0	34.0	62.0	0.0
14	75.0	50.0	62.5	92.0	26.0	59.0	0.0
15	72.0	50.0	61.0	100.0	40.0	70.0	0.0
MEAN	70.6	51.0	60.8	93.2	40.8	67.0	0.05
16	66.0	50.0	58.0	100.0	52.0	76.0	0.0
17	68.0	49.0	58.5	100.0	34.0	67.0	0.0
18	69.0	52.0	60.5	68.0	34.0	51.0	0.0
19	68.0	49.0	58.5	84.0	34.0	59.0	0.0
20	66.0	47.0	56.5	80.0	32.0	56.0	0.0
MEAN	67.4	49.4	58.4	86.4	37.2	61.8	0.0
21	61.0	47.0	54.0	100.0	50.0	75.0	0.07
22	56.0	44.0	50.0	100.0	52.0	76.0	0.06
23	56.0	41.0	48.5	100.0	52.0	76.0	0.0
24	55.0	44.0	49.5	100.0	52.0	76.0	0.40
25	54.0	43.0	48.5	100.0	52.0	76.0	0.0
MEAN	56.4	43.8	50.1	100.0	51.6	75.8	0.53
26	63.0	45.0	54.0	92.0	40.0	66.0	0.0
27	69.0	45.0	57.0	100.0	30.0	65.0	0.0
28	68.0	49.0	58.5	74.0	30.0	52.0	0.0
29	67.0	51.0	59.0	92.0	36.0	64.0	0.0
30	59.0	48.0	53.5	100.0	58.0	79.0	0.29
31	56.0	50.0	53.0	100.0	86.0	93.0	0.08
MEAN	63.7	48.0	55.8	93.0	46.7	69.8	0.37
MONTHLY MEAN	64.2	47.7	55.9	95.4	45.6	70.5	1.94

SITE 2 SEPTEMBER 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	59.0	47.0	53.0	100.0	58.0	79.0	0.04
2	59.0	44.0	51.5	100.0	54.0	77.0	0.02
3	56.0	39.0	47.5	100.0	38.0	69.0	0.0
4	56.0	46.0	51.0	86.0	44.0	65.0	0.0
5	54.0	40.0	47.0	100.0	60.0	80.0	0.0
MEAN	56.8	43.2	50.0	97.2	50.8	74.0	0.06
6	50.0	34.0	42.0	100.0	36.0	68.0	0.0
7	48.0	31.0	39.5	100.0	34.0	67.0	0.0
8	40.0	24.0	32.0	90.0	50.0	70.0	0.0
9	46.0	26.0	36.0	100.0	40.0	70.0	0.0
10	52.0	28.0	40.0	90.0	32.0	61.0	0.0
MEAN	47.2	28.6	37.9	96.0	38.4	67.2	0.0
11	58.0	40.0	49.0	62.0	30.0	46.0	0.0
12	58.0	46.0	52.0	100.0	34.0	67.0	0.10
13	53.0	50.0	51.5	100.0	92.0	96.0	0.34
MEAN	56.3	45.3	50.8	87.3	52.0	69.7	0.44
MONTHLY MEAN	53.0	38.1	45.5	94.5	46.3	70.4	0.50

SITE 2 MAY 1971

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
26	67.0	45.0	56.0	54.0	30.0	42.0	0.0
27	64.0	37.0	50.5	97.0	32.0	64.5	0.0
28	66.0	48.0	57.0	46.0	32.0	39.0	0.0
29	64.0	43.0	53.5	80.0	29.0	54.5	0.01
30	64.0	38.0	51.0	58.0	28.0	43.0	0.0
31	65.0	44.0	54.5	55.0	32.0	43.5	0.0
MEAN	65.0	42.5	53.8	65.0	30.5	47.8	0.01
MONTHLY MEAN	65.0	42.5	53.8	65.0	30.5	47.8	0.01

SITE 2 JUNE 1971

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	60.0	44.0	52.0	66.0	28.0	47.0	0.0
2	56.0	38.0	47.0	57.0	34.0	45.5	0.0
3	62.0	37.0	49.5	63.0	35.0	49.0	0.0
4	69.0	40.0	54.5	61.0	30.0	45.5	0.0
5	79.0	50.0	64.5	50.0	26.0	38.0	0.0
MEAN	65.2	41.8	53.5	59.4	30.6	45.0	0.0
6	82.0	56.0	69.0	46.0	26.0	36.0	0.0
7	82.0	54.0	68.0	50.0	24.0	37.0	0.0
8	79.0	51.0	65.0	50.0	23.0	36.5	0.0
9	86.0	54.0	70.0	45.0	22.0	33.5	0.0
10	86.0	60.0	73.0	75.0	22.0	48.5	0.05
MEAN	83.0	55.0	69.0	53.2	23.4	38.3	0.05
11	74.0	50.0	62.0	58.0	32.0	45.0	0.0
12	67.0	45.0	56.0	60.0	30.0	45.0	0.0
13	65.0	41.0	53.0	88.0	38.0	63.0	0.02
14	59.0	40.0	49.5	91.0	26.0	58.5	0.03
15	67.0	46.0	56.5	94.0	34.0	64.0	0.02
MEAN	66.4	44.4	55.4	78.2	32.0	55.1	0.07
16	69.0	46.0	57.5	72.0	34.0	53.0	0.0
17	72.0	46.0	59.0	70.0	30.0	50.0	0.0
18	72.0	48.0	60.0	78.0	30.0	54.0	0.0
19	78.0	49.0	63.5	96.0	42.0	69.0	0.0
20	75.0	52.0	63.5	100.0	50.0	75.0	0.02
MEAN	73.2	48.2	60.7	83.2	37.2	60.2	0.02
21	83.0	56.0	69.5	100.0	38.0	69.0	0.0
22	81.0	50.0	65.5	94.0	34.0	64.0	0.0
23	88.0	61.0	74.5	74.0	32.0	53.0	0.0
24	86.0	65.0	75.5	41.0	22.0	31.5	0.0
25	85.0	63.0	74.0	45.0	20.0	32.5	0.0
MEAN	84.6	59.0	71.8	70.8	29.2	50.0	0.0
26	84.0	59.0	71.5	54.0	24.0	39.0	0.0
27	84.0	57.0	70.5	76.0	29.0	52.5	0.0
28	80.0	55.0	67.5	54.0	31.0	42.5	0.0
29	75.0	46.0	60.5	100.0	34.0	67.0	0.12
30	56.0	35.0	45.5	94.0	46.0	70.0	0.0
MEAN	75.8	50.4	63.1	75.6	32.8	54.2	0.12
MONTHLY MEAN	74.7	49.8	62.3	70.1	30.9	50.5	0.26

UPLAND BLACK SPRUCE

SITE 2 JULY 1971

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	59.0	36.0	47.5	100.0	39.0	69.5	0.0
2	68.0	41.0	54.5	100.0	42.0	71.0	0.38
3	74.0	49.0	61.5	100.0	38.0	69.0	0.04
4	74.0	48.0	61.0	100.0	36.0	68.0	0.0
5	78.0	48.0	63.0	100.0	36.0	68.0	0.0
MEAN	70.6	44.4	57.5	100.0	38.2	69.1	0.42
6	80.0	52.0	66.0	96.0	31.0	63.5	0.0
7	79.0	55.0	67.0	84.0	32.0	58.0	0.0
8	74.0	51.0	62.5	100.0	46.0	73.0	0.0
9	78.0	52.0	65.0	100.0	42.0	71.0	0.0
10	77.0	56.0	66.5	100.0	40.0	70.0	0.0
MEAN	77.6	53.2	65.4	96.0	38.2	67.1	0.0
11	80.0	56.0	68.0	100.0	46.0	73.0	0.24
12	65.0	58.0	61.5	100.0	78.0	89.0	0.60
13	62.0	56.0	59.0	100.0	100.0	100.0	0.43
14	60.0	45.0	52.5	100.0	76.0	88.0	0.44
15	60.0	39.0	49.5	100.0	44.0	72.0	0.03
MEAN	65.4	50.8	58.1	100.0	68.8	84.4	1.74
16	69.0	45.0	57.0	100.0	40.0	70.0	0.0
17	72.0	50.0	61.0	100.0	40.0	70.0	0.0
18	80.0	54.0	67.0	84.0	36.0	60.0	0.0
19	78.0	54.0	66.0	100.0	38.0	69.0	0.03
20	77.0	56.0	66.5	92.0	41.0	66.5	0.0
MEAN	75.2	51.8	63.5	95.2	39.0	67.1	0.03
21	72.0	48.0	60.0	100.0	38.0	69.0	0.06
22	78.0	43.0	60.5	86.0	38.0	62.0	0.0
23	72.0	48.0	60.0	82.0	38.0	60.0	0.0
24	74.0	50.0	62.0	82.0	39.0	60.5	0.0
25	74.0	48.0	61.0	100.0	40.0	70.0	0.01
MEAN	74.0	47.4	60.7	90.0	38.6	64.3	0.07
26	76.0	52.0	64.0	100.0	38.0	69.0	0.0
27	75.0	48.0	61.5	100.0	34.0	67.0	0.0
28	66.0	43.0	54.5	100.0	50.0	75.0	0.23
29	64.0	43.0	53.5	100.0	48.0	74.0	0.35
30	64.0	48.0	56.0	96.0	46.0	71.0	0.0
31	61.0	48.0	54.5	100.0	56.0	78.0	0.08
MEAN	67.7	47.0	57.3	99.3	45.3	72.3	0.66
MONTHLY MEAN	71.6	49.0	60.3	96.3	44.7	70.8	2.92

UPLAND BLACK SPRUCE

SITE 2 AUGUST 1971

	TEMPERATURE			RELATIVE HUMIDITY			
DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	PRECIP
1	61.0	52.0	56.5	100.0	76.0	88.0	0.16
2	63.0	52.0	57.5	100.0	60.0	80.0	0.06
3	62.0	41.0	51.5	100.0	50.0	75.0	0.0
4	58.0	46.0	52.0	100.0	52.0	76.0	0.19
5	58.0	46.0	52.0	100.0	60.0	80.0	0.0
MEAN	60.4	47.4	53.9	100.0	59.6	79.8	0.41
6	59.0	48.0	53.5	100.0	71.0	85.5	0.0
7	58.0	50.0	54.0	100.0	90.0	95.0	0.09
8	57.0	52.0	54.5	100.0	96.0	98.0	0.21
9	58.0	55.0	56.5	100.0	100.0	100.0	0.64
10	59.0	53.0	56.0	100.0	100.0	100.0	0.45
MEAN	58.2	51.6	54.9	100.0	91.4	95.7	1.39
11	69.0	50.0	59.5	100.0	50.0	75.0	0.01
12	69.0	50.0	59.5	100.0	52.0	76.0	0.0
13	68.0	50.0	59.0	100.0	48.0	74.0	0.0
14	64.0	40.0	52.0	100.0	48.0	74.0	0.02
15	66.0	41.0	53.5	88.0	46.0	67.0	0.0
MEAN	67.2	46.2	56.7	97.6	48.8	73.2	0.03
16	70.0	44.0	57.0	94.0	42.0	68.0	0.0
17	71.0	51.0	61.0	91.0	38.0	64.5	0.0
18	76.0	51.0	63.5	82.0	39.0	60.5	0.0
19	72.0	52.0	62.0	100.0	38.0	69.0	0.0
20	64.0	43.0	53.5	100.0	62.0	81.0	0.81
MEAN	70.6	48.2	59.4	93.4	43.8	68.6	0.81
21	50.0	41.0	45.5	100.0	86.0	93.0	0.30
22	62.0	46.0	54.0	100.0	58.0	79.0	0.0
23	65.0	51.0	58.0	100.0	46.0	73.0	0.01
24	62.0	44.0	53.0	100.0	48.0	74.0	0.0
25	60.0	46.0	53.0	100.0	52.0	76.0	0.07
MEAN	59.8	45.6	52.7	100.0	58.0	79.0	0.38
26	63.0	44.0	53.5	100.0	46.0	73.0	0.0
27	64.0	43.0	53.5	100.0	31.0	65.5	0.0
28	65.0	43.0	54.0	100.0	30.0	65.0	0.0
29	71.0	44.0	57.5	100.0	24.0	62.0	0.0
30	70.0	44.0	57.0	100.0	26.0	63.0	0.0
31	63.0	48.0	55.5	100.0	32.0	66.0	0.28
MEAN	66.0	44.3	55.2	100.0	31.5	65.8	0.28
MONTHLY MEAN	63.8	47.1	55.5	98.5	54.7	76.6	3.30

SITE 2 SEPTEMBER 1971

	TEMPERATURE			RELATIVE HUMIDITY			
DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	PRECIP
1	54.0	40.0	47.0	100.0	70.0	85.0	0.15
2	45.0	39.0	42.0	100.0	98.0	99.0	0.59
3	41.0	32.0	36.5	100.0	100.0	100.0	0.07
4	43.0	37.0	40.0	100.0	92.0	96.0	0.51
5	45.0	35.0	40.0	100.0	60.0	80.0	0.0
MEAN	45.6	36.6	41.1	100.0	84.0	92.0	1.32
MONTHLY MEAN	45.6	36.6	41.1	100.0	84.0	92.0	1.32

LOWLAND BLACK SPRUCE

SITE 3 JUNE 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
5	62.0	39.0	50.5	96.0	48.0	72.0	0.01
MEAN	62.0	39.0	50.5	96.0	48.0	72.0	0.01
6	66.0	38.0	52.0	96.0	37.0	66.5	0.0
7	66.0	36.0	51.0	96.0	58.0	77.0	0.11
8	64.0	31.0	47.5	96.0	26.0	61.0	0.01
9	70.0	42.0	56.0	92.0	30.0	61.0	0.0
10	78.0	41.0	59.5	93.0	26.0	59.5	0.0
MEAN	68.8	37.6	53.2	94.6	35.4	65.0	0.12
11	79.0	45.0	62.0	84.0	24.0	54.0	0.0
12	80.0	45.0	62.5	86.0	24.0	55.0	0.0
13	80.0	44.0	62.0	90.0	24.0	57.0	0.0
14	80.0	54.0	67.0	82.0	26.0	54.0	0.0
15	74.0	45.0	59.5	90.0	43.0	66.5	0.56
MEAN	78.6	46.6	62.6	86.4	28.2	57.3	0.56
16	69.0	51.0	60.0	86.0	50.0	68.0	0.32
17	75.0	46.0	60.5	90.0	34.0	62.0	0.05
18	74.0	50.0	62.0	84.0	30.0	57.0	0.0
19	71.0	48.0	59.5	88.0	40.0	64.0	0.0
20	72.0	55.0	63.5	84.0	40.0	62.0	0.06
MEAN	72.2	50.0	61.1	86.4	38.8	62.6	0.43
21	69.0	50.0	59.5	93.0	44.0	68.5	0.08
22	60.0	47.0	53.5	95.0	54.0	74.5	0.11
23	70.0	36.0	53.0	97.0	34.0	65.5	0.0
24	72.0	38.0	55.0	96.0	32.0	64.0	0.0
25	74.0	46.0	60.0	94.0	36.0	65.0	0.05
MEAN	69.0	43.4	56.2	95.0	40.0	67.5	0.24
26	72.0	42.0	57.0	96.0	36.0	66.0	0.0
27	76.0	46.0	61.0	94.0	24.0	59.0	0.0
28	77.0	45.0	61.0	90.0	24.0	57.0	0.0
29	70.0	40.0	55.0	96.0	36.0	66.0	0.0
30	68.0	54.0	61.0	78.0	38.0	58.0	0.0
MEAN	72.6	45.4	59.0	90.8	31.6	61.2	0.0
MONTHLY MEAN	71.8	44.4	58.1	90.8	35.3	63.1	1.36

SITE 3 JULY 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	66.0	45.0	55.5	96.0	44.0	70.0	0.0
2	68.0	47.0	57.5	94.0	42.0	68.0	0.01
3	70.0	46.0	58.0	94.0	40.0	67.0	0.0
4	76.0	41.0	58.5	94.0	34.0	64.0	0.0
5	81.0	44.0	62.5	94.0	30.0	62.0	0.0
MEAN	72.2	44.6	58.4	94.4	38.0	66.2	0.01
6	84.0	46.0	65.0	94.0	30.0	62.0	0.0
7	86.0	50.0	68.0	91.0	29.0	60.0	0.0
8	87.0	60.0	73.5	64.0	20.0	42.0	0.0
9	86.0	57.0	71.5	89.0	20.0	54.5	0.0
10	80.0	52.0	66.0	87.0	22.0	54.5	0.05
MEAN	84.6	53.0	68.8	85.0	24.2	54.6	0.05
11	87.0	51.0	69.0	72.0	20.0	46.0	0.0
12	75.0	43.0	59.0	86.0	24.0	55.0	0.0
13	76.0	46.0	61.0	96.0	34.0	65.0	0.0
14	76.0	55.0	65.5	84.0	34.0	59.0	0.0
15	71.0	56.0	63.5	82.0	38.0	60.0	0.0
MEAN	77.0	50.2	63.6	84.0	30.0	57.0	0.0
16	72.0	40.0	56.0	87.0	32.0	59.5	0.0
17	75.0	44.0	59.5	85.0	26.0	55.5	0.0
18	78.0	44.0	61.0	84.0	24.0	54.0	0.0
19	82.0	46.0	64.0	94.0	28.0	61.0	0.0
20	83.0	47.0	65.0	94.0	24.0	59.0	0.0
MEAN	78.0	44.2	61.1	88.8	26.8	57.8	0.0
21	87.0	47.0	67.0	94.0	18.0	56.0	0.0
22	87.0	48.0	67.5	94.0	20.0	57.0	0.0
23	88.0	50.0	69.0	93.0	24.0	58.5	0.0
24	90.0	48.0	69.0	94.0	22.0	58.0	0.0
25	87.0	50.0	68.5	94.0	24.0	59.0	0.0
MEAN	87.8	48.6	68.2	93.8	21.6	57.7	0.0
26	82.0	55.0	68.5	59.0	26.0	42.5	0.0
27	80.0	46.0	63.0	94.0	26.0	60.0	0.0
28	72.0	54.0	63.0	95.0	49.0	72.0	0.14
29	75.0	43.0	59.0	95.0	34.0	64.5	0.0
30	75.0	48.0	61.5	94.0	30.0	62.0	0.01
31	76.0	55.0	65.5	94.0	30.0	62.0	0.36
MEAN	76.7	50.2	63.4	88.5	32.5	60.5	0.51
MONTHLY MEAN	79.3	48.5	63.9	89.1	29.0	59.0	0.57

LOWLAND BLACK SPRUCE

SITE 3 AUGUST 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	69.0	56.0	62.5	94.0	62.0	78.0	0.22
2	70.0	52.0	61.0	96.0	56.0	76.0	0.0
3	70.0	50.0	60.0	94.0	50.0	72.0	0.0
4	72.0	41.0	56.5	95.0	40.0	67.5	0.0
5	74.0	56.0	65.0	94.0	38.0	66.0	0.18
MEAN	71.0	51.0	61.0	94.6	49.2	71.9	0.40
6	82.0	50.0	66.0	94.0	44.0	69.0	0.0
7	84.0	51.0	67.5	94.0	38.0	66.0	0.0
8	81.0	60.0	70.5	78.0	35.0	56.5	0.0
9	81.0	47.0	64.0	94.0	32.0	63.0	0.0
10	81.0	46.0	63.5	94.0	30.0	62.0	0.0
MEAN	81.8	50.8	66.3	90.8	35.8	63.3	0.0
11	81.0	42.0	61.5	94.0	30.0	62.0	0.0
12	82.0	42.0	62.0	94.0	28.0	61.0	0.0
13	83.0	43.0	63.0	94.0	26.0	60.0	0.0
14	84.0	47.0	65.5	94.0	24.0	59.0	0.0
15	76.0	40.0	58.0	94.0	40.0	67.0	0.0
MEAN	81.2	42.8	62.0	94.0	29.6	61.8	0.0
16	76.0	38.0	57.0	94.0	28.0	61.0	0.0
17	72.0	54.0	63.0	94.0	28.0	61.0	0.08
18	70.0	37.0	53.5	94.0	44.0	69.0	0.0
19	70.0	40.0	55.0	94.0	44.0	69.0	0.0
20	76.0	42.0	59.0	94.0	30.0	62.0	0.0
MEAN	72.8	42.2	57.5	94.0	34.8	64.4	0.08
21	75.0	52.0	63.5	94.0	32.0	63.0	0.09
22	68.0	50.0	59.0	94.0	60.0	77.0	0.10
23	68.0	52.0	60.0	94.0	58.0	76.0	0.66
24	64.0	51.0	57.5	94.0	52.0	73.0	0.0
25	68.0	37.0	52.5	94.0	44.0	69.0	0.0
MEAN	68.6	48.4	58.5	94.0	49.2	71.6	0.85
26	68.0	33.0	50.5	94.0	40.0	67.0	0.0
27	68.0	35.0	51.5	94.0	40.0	67.0	0.0
28	67.0	41.0	54.0	94.0	48.0	71.0	0.11
29	58.0	42.0	50.0	94.0	58.0	76.0	0.10
30	61.0	30.0	45.5	94.0	42.0	68.0	0.0
31	60.0	31.0	45.5	94.0	42.0	68.0	0.0
MEAN	63.7	35.3	49.5	94.0	45.0	69.5	0.21
MONTHLY MEAN	72.9	44.8	58.8	93.6	40.7	67.2	1.54

SITE 3 SEPTEMBER 1968

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	62.0	40.0	51.0	94.0	34.0	64.0	0.0
2	62.0	29.0	45.5	94.0	32.0	63.0	0.0
3	62.0	27.0	44.5	94.0	30.0	62.0	0.0
4	66.0	30.0	48.0	94.0	28.0	61.0	0.0
5	66.0	44.0	55.0	94.0	28.0	61.0	0.0
MEAN	63.6	34.0	48.8	94.0	30.4	62.2	0.0
6	66.0	35.0	50.5	95.0	32.0	63.5	0.0
7	66.0	30.0	48.0	94.0	30.0	62.0	0.0
8	66.0	31.0	48.5	94.0	32.0	63.0	0.0
9	68.0	36.0	52.0	94.0	30.0	62.0	0.0
10	68.0	33.0	50.5	94.0	30.0	62.0	0.0
MEAN	66.8	33.0	49.9	94.2	30.8	62.5	0.0
11	63.0	41.0	52.0	94.0	40.0	67.0	0.02
12	69.0	35.0	52.0	94.0	52.0	73.0	0.0
13	64.0	29.0	46.5	94.0	26.0	60.0	0.0
14	63.0	28.0	45.5	94.0	30.0	62.0	0.0
15	62.0	40.0	51.0	94.0	26.0	60.0	0.0
MEAN	64.2	34.6	49.4	94.0	34.8	64.4	0.02
16	56.0	35.0	45.5	94.0	42.0	68.0	0.0
17	48.0	32.0	40.0	94.0	55.0	74.5	0.0
18	46.0	36.0	41.0	94.0	55.0	74.5	0.0
19	46.0	34.0	40.0	94.0	58.0	76.0	0.02
20	44.0	31.0	37.5	94.0	64.0	79.0	0.0
MEAN	48.0	33.6	40.8	94.0	54.8	74.4	0.02
21	44.0	23.0	33.5	94.0	40.0	67.0	0.0
22	44.0	13.0	28.5	94.0	40.0	67.0	0.0
23	42.0	26.0	34.0	94.0	44.0	69.0	0.0
24	39.0	12.0	25.5	94.0	36.0	65.0	0.0
25	40.0	23.0	31.5	94.0	36.0	65.0	0.0
MEAN	41.8	19.4	30.6	94.0	39.2	66.6	0.0
26	47.0	28.0	37.5	94.0	48.0	71.0	0.0
27	55.0	28.0	41.5	94.0	38.0	66.0	0.0
28	55.0	26.0	40.5	94.0	38.0	66.0	0.0
29	49.0	29.0	39.0	94.0	55.0	74.5	0.01
MEAN	51.5	27.8	39.6	94.0	44.8	69.4	0.01
MONTHLY MEAN	56.1	30.5	43.3	94.0	38.9	66.5	0.05

SITE 3 MAY 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
26	67.0	29.0	48.0	79.0	17.0	48.0	0.0
27	52.0	28.0	40.0	80.0	26.0	53.0	0.0
28	58.0	34.0	46.0	42.0	25.0	33.5	0.0
29	64.0	29.0	46.5	82.0	21.0	51.5	0.0
30	68.0	36.0	52.0	80.0	20.0	50.0	0.0
31	67.0	33.0	50.0	82.0	20.0	51.0	0.0
MEAN	62.7	31.5	47.1	74.2	21.5	47.8	0.0
MONTHLY MEAN	62.7	31.5	47.1	74.2	21.5	47.8	0.0

SITE 3 JUNE 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	63.0	41.0	52.0	82.0	28.0	55.0	0.0
2	66.0	29.0	47.5	84.0	18.0	51.0	0.0
3	68.0	30.0	49.0	80.0	14.0	47.0	0.0
4	68.0	32.0	50.0	82.0	16.0	49.0	0.0
5	62.0	39.0	50.5	80.0	27.0	53.5	0.15
MEAN	65.4	34.2	49.8	81.6	20.6	51.1	0.15
6	68.0	38.0	53.0	76.0	24.0	50.0	0.04
7	70.0	44.0	57.0	76.0	22.0	49.0	0.0
8	76.0	38.0	57.0	82.0	20.0	51.0	0.0
9	76.0	54.0	65.0	68.0	20.0	44.0	0.0
10	73.0	35.0	54.0	83.0	20.0	51.5	0.0
MEAN	72.6	41.8	57.2	77.0	21.2	49.1	0.04
11	74.0	40.0	57.0	74.0	18.0	46.0	0.0
12	76.0	39.0	57.5	82.0	23.0	52.5	0.0
13	78.0	56.0	67.0	52.0	21.0	36.5	0.0
14	86.0	48.0	67.0	76.0	20.0	48.0	0.0
15	92.0	50.0	71.0	80.0	16.0	48.0	0.0
MEAN	81.2	46.6	63.9	72.8	19.6	46.2	0.0
16	94.0	48.0	71.0	76.0	10.0	43.0	0.0
17	78.0	43.0	60.5	84.0	20.0	52.0	0.0
18	78.0	42.0	60.0	82.0	20.0	51.0	0.0
19	79.0	41.0	60.0	78.0	18.0	48.0	0.0
20	86.0	42.0	64.0	79.0	14.0	46.5	0.0
MEAN	83.0	43.2	63.1	79.3	16.4	48.1	0.0
21	88.0	52.0	70.0	74.0	18.0	46.0	0.0
22	84.0	48.0	66.0	75.0	20.0	47.5	0.0
23	84.0	52.0	68.0	66.0	14.0	40.0	0.0
24	78.0	37.0	57.5	80.0	15.0	47.5	0.0
25	74.0	38.0	56.0	82.0	22.0	52.0	0.0
MEAN	81.6	45.4	63.5	75.4	17.8	46.6	0.0
26	80.0	38.0	59.0	81.0	17.0	49.0	0.0
27	82.0	43.0	62.5	76.0	14.0	45.0	0.0
28	84.0	42.0	63.0	78.0	12.0	45.0	0.0
29	78.0	55.0	66.5	78.0	24.0	51.0	0.03
30	68.0	48.0	58.0	84.0	36.0	60.0	0.0
MEAN	78.4	45.2	61.8	79.4	20.6	50.0	0.03
MONTHLY MEAN	77.0	42.7	59.9	77.7	19.4	48.5	0.22

LOWLAND BLACK SPRUCE

SITE 3 JULY 1969

	TEMPERATURE			RELATIVE HUMIDITY			
DAY	MAX	MIN	MEAN	MAX	MIN	MEAN	PRECIP
1	68.0	48.0	58.0	76.0	30.0	53.0	0.0
2	68.0	43.0	55.5	80.0	30.0	55.0	0.03
3	67.0	47.0	57.0	82.0	26.0	54.0	0.13
4	72.0	41.0	56.5	80.0	26.0	53.0	0.03
5	77.0	39.0	58.0	80.0	26.0	53.0	0.0
MEAN	70.4	43.6	57.0	79.6	27.6	53.6	0.19
6	78.0	42.0	60.0	80.0	26.0	53.0	0.0
7	78.0	42.0	60.0	81.0	24.0	52.5	0.0
8	70.0	46.0	58.0	80.0	42.0	61.0	0.0
9	71.0	49.0	60.0	80.0	43.0	61.5	0.24
10	70.0	50.0	60.0	100.0	58.0	79.0	0.16
MEAN	73.4	45.8	59.6	84.2	38.6	61.4	0.40
11	69.0	55.0	62.0	98.0	58.0	78.0	0.04
12	76.0	43.0	59.5	100.0	44.0	72.0	0.0
13	75.0	51.0	63.0	100.0	44.0	72.0	0.02
14	76.0	47.0	61.5	100.0	44.0	72.0	0.0
15	76.0	53.0	64.5	100.0	46.0	73.0	0.02
MEAN	74.4	49.8	62.1	99.6	47.2	73.4	0.08
16	70.0	51.0	60.5	100.0	46.0	73.0	0.31
17	72.0	51.0	61.5	100.0	42.0	71.0	0.01
18	73.0	46.0	59.5	100.0	44.0	72.0	0.0
19	72.0	43.0	57.5	100.0	47.0	73.5	0.0
20	70.0	42.0	56.0	100.0	48.0	74.0	0.14
MEAN	71.4	46.6	59.0	100.0	45.4	72.7	0.46
21	68.0	53.0	60.5	100.0	52.0	76.0	0.08
22	70.0	43.0	56.5	100.0	46.0	73.0	0.05
23	76.0	48.0	62.0	98.0	51.0	74.5	0.02
24	55.0	48.0	51.5	98.0	74.0	86.0	0.30
25	54.0	45.0	49.5	96.0	56.0	76.0	0.14
MEAN	64.6	47.4	56.0	98.4	55.8	77.1	0.59
26	57.0	43.0	50.0	96.0	50.0	73.0	0.12
27	60.0	45.0	52.5	96.0	54.0	75.0	0.0
28	59.0	46.0	52.5	100.0	66.0	83.0	0.09
29	61.0	50.0	55.5	98.0	59.0	78.5	0.36
30	55.0	39.0	47.0	100.0	60.0	80.0	0.12
31	63.0	32.0	47.5	100.0	42.0	71.0	0.0
MEAN	59.2	42.5	50.8	98.3	55.2	76.8	0.69
MONTHLY MEAN	68.6	45.8	57.2	93.5	45.3	69.4	2.41

SITE 3 AUGUST 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	65.0	45.0	55.0	98.0	42.0	70.0	0.01
2	65.0	56.0	60.5	98.0	60.0	79.0	0.12
3	61.0	56.0	58.5	98.0	74.0	86.0	0.48
4	70.0	56.0	63.0	100.0	74.0	87.0	0.58
5	68.0	44.0	56.0	100.0	52.0	76.0	0.46
MEAN	65.8	51.4	58.6	98.8	60.4	79.6	1.65
6	58.0	39.0	48.5	90.0	54.0	72.0	0.0
7	57.0	36.0	46.5	96.0	54.0	75.0	0.12
8	47.0	36.0	41.5	98.0	60.0	79.0	0.05
9	56.0	40.0	48.0	100.0	56.0	78.0	0.56
10	56.0	31.0	43.5	87.0	42.0	64.5	0.0
MEAN	54.8	36.4	45.6	94.2	53.2	73.7	0.73
11	50.0	28.0	39.0	97.0	36.0	66.5	0.0
12	50.0	29.0	39.5	100.0	36.0	68.0	0.0
13	52.0	26.0	39.0	98.0	38.0	68.0	0.0
14	57.0	24.0	40.5	100.0	35.0	67.5	0.0
15	62.0	27.0	44.5	100.0	34.0	67.0	0.0
MEAN	54.2	26.8	40.5	99.0	35.8	67.4	0.0
16	66.0	33.0	49.5	100.0	34.0	67.0	0.0
17	64.0	29.0	46.5	100.0	34.0	67.0	0.0
18	64.0	27.0	45.5	100.0	34.0	67.0	0.0
19	60.0	29.0	44.5	100.0	34.0	67.0	0.0
20	52.0	36.0	44.0	100.0	47.0	73.5	0.01
MEAN	61.2	30.8	46.0	100.0	36.6	68.3	0.01
21	52.0	35.0	43.5	100.0	48.0	74.0	0.0
22	59.0	29.0	44.0	100.0	43.0	71.5	0.01
23	64.0	31.0	47.5	100.0	38.0	69.0	0.0
24	66.0	27.0	46.5	100.0	36.0	68.0	0.0
25	62.0	34.0	48.0	100.0	40.0	70.0	0.14
MEAN	60.6	31.2	45.9	100.0	41.0	70.5	0.15
26	59.0	35.0	47.0	100.0	42.0	71.0	0.0
27	61.0	26.0	43.5	100.0	39.0	69.5	0.0
28	68.0	28.0	48.0	100.0	34.0	67.0	0.0
29	70.0	44.0	57.0	96.0	34.0	65.0	0.0
30	72.0	34.0	53.0	96.0	32.0	64.0	0.0
31	68.0	39.0	53.5	94.0	34.0	64.0	0.0
MEAN	66.3	34.3	50.3	97.7	35.8	66.8	0.0
MONTHLY MEAN	60.7	35.1	47.9	98.3	43.5	70.9	2.54

SITE 3 SEPTEMBER 1969

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	67.0	32.0	49.5	96.0	37.0	66.5	0.0
2	70.0	32.0	51.0	95.0	33.0	64.0	0.0
3	70.0	45.0	57.5	76.0	32.0	54.0	0.0
4	60.0	30.0	45.0	96.0	43.0	69.5	0.0
5	60.0	45.0	52.5	92.0	44.0	68.0	0.24
MEAN	65.4	36.8	51.1	91.0	37.8	64.4	0.24
6	62.0	29.0	45.5	96.0	38.0	67.0	0.0
7	61.0	27.0	44.0	96.0	38.0	67.0	0.0
8	64.0	30.0	47.0	94.0	36.0	65.0	0.0
9	64.0	48.0	56.0	64.0	35.0	49.5	0.0
10	62.0	44.0	53.0	88.0	40.0	64.0	0.04
MEAN	62.6	35.6	49.1	87.6	37.4	62.5	0.04
11	64.0	31.0	47.5	90.0	35.0	62.5	0.0
12	66.0	33.0	49.5	90.0	33.0	61.5	0.0
13	59.0	28.0	43.5	90.0	38.0	64.0	0.0
14	64.0	29.0	46.5	91.0	34.0	62.5	0.0
MEAN	63.3	30.3	46.8	90.3	35.0	62.6	0.0
MONTHLY MEAN	63.8	34.5	49.1	89.6	36.9	63.2	0.28

SITE 3 MAY 1970

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
20	70.0	32.0	51.0	100.0	22.0	61.0	0.0
MEAN	70.0	32.0	51.0	100.0	22.0	61.0	0.0
21	72.0	33.0	52.5	100.0	22.0	61.0	0.0
22	72.0	41.0	56.5	100.0	26.0	63.0	0.0
23	73.0	43.0	58.0	100.0	30.0	65.0	0.01
24	69.0	43.0	56.0	100.0	24.0	62.0	0.01
25	72.0	35.0	53.5	100.0	20.0	60.0	0.57
MEAN	71.6	39.0	55.3	100.0	24.4	62.2	0.59
26	69.0	35.0	52.0	100.0	22.0	61.0	0.0
27	68.0	30.0	49.0	100.0	20.0	60.0	0.0
28	68.0	31.0	49.5	100.0	17.0	58.5	0.0
29	66.0	41.0	53.5	100.0	31.0	65.5	0.0
30	65.0	47.0	56.0	86.0	42.0	64.0	0.0
31	76.0	31.0	53.5	100.0	34.0	67.0	0.02
MEAN	68.7	35.8	52.3	97.7	27.7	62.7	0.02
MONTHLY MEAN	70.0	36.8	53.4	98.8	25.8	62.3	0.61

SITE 3 JUNE 1970

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	68.0	42.0	55.0	100.0	30.0	65.0	0.05
2	60.0	40.0	50.0	100.0	42.0	71.0	0.0
3	68.0	32.0	50.0	100.0	34.0	67.0	0.0
4	74.0	34.0	54.0	100.0	22.0	61.0	0.0
5	73.0	49.0	61.0	100.0	26.0	63.0	0.02
MEAN	68.6	39.4	54.0	100.0	30.8	65.4	0.07
6	76.0	35.0	55.5	100.0	24.0	62.0	0.0
7	76.0	37.0	56.5	100.0	20.0	60.0	0.0
8	64.0	38.0	51.0	97.0	22.0	57.0	0.0
9	57.0	23.0	40.0	100.0	32.0	66.0	0.0
10	58.0	33.0	45.5	100.0	31.0	65.5	0.17
MEAN	66.2	33.2	49.7	98.4	25.8	62.1	0.17
11	61.0	43.0	52.0	90.0	36.0	63.0	0.06
12	66.0	45.0	55.5	87.0	25.0	56.0	0.0
13	70.0	48.0	59.0	68.0	22.0	45.0	0.01
14	69.0	47.0	58.0	88.0	26.0	57.0	0.21
15	60.0	46.0	53.0	90.0	39.0	64.5	0.19
MEAN	65.2	45.8	55.5	84.6	29.6	57.1	0.47
16	68.0	46.0	57.0	100.0	36.0	68.0	0.02
17	68.0	47.0	57.5	100.0	40.0	70.0	0.03
18	68.0	51.0	59.5	94.0	32.0	63.0	0.0
19	69.0	41.0	55.0	96.0	32.0	64.0	0.0
20	70.0	32.0	51.0	100.0	30.0	65.0	0.0
MEAN	68.6	43.4	56.0	98.0	34.0	66.0	0.05
21	72.0	40.0	56.0	100.0	30.0	65.0	0.07
22	65.0	50.0	57.5	100.0	55.0	77.5	0.53
23	72.0	50.0	61.0	100.0	35.0	67.5	0.01
24	74.0	41.0	57.5	100.0	33.0	66.5	0.14
25	77.0	42.0	59.5	100.0	34.0	67.0	0.05
MEAN	72.0	44.6	58.3	100.0	37.4	68.7	0.80
26	72.0	48.0	60.0	100.0	44.0	72.0	0.04
27	68.0	48.0	58.0	100.0	50.0	75.0	0.13
28	67.0	49.0	58.0	100.0	48.0	74.0	0.67
29	66.0	48.0	57.0	100.0	49.0	74.5	0.34
30	55.0	47.0	51.0	100.0	69.0	84.5	0.04
MEAN	65.6	48.0	56.8	100.0	52.0	76.0	1.22
MONTHLY MEAN	67.7	42.4	55.0	96.8	34.9	65.9	2.78

SITE 3 JULY 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	72.0	51.0	61.5	100.0	44.0	72.0	0.0
2	77.0	56.0	66.5	100.0	36.0	68.0	0.0
3	77.0	54.0	65.5	100.0	38.0	69.0	0.30
4	67.0	55.0	61.0	100.0	50.0	75.0	0.23
5	70.0	49.0	59.5	100.0	34.0	67.0	0.0
MEAN	72.6	53.0	62.8	100.0	40.4	70.2	0.53
6	70.0	46.0	58.0	100.0	36.0	68.0	0.0
7	71.0	47.0	59.0	96.0	36.0	66.0	0.03
8	66.0	50.0	58.0	100.0	50.0	75.0	0.20
9	67.0	50.0	58.5	98.0	42.0	70.0	0.0
10	64.0	48.0	56.0	98.0	52.0	75.0	0.0
MEAN	67.6	48.2	57.9	98.4	43.2	70.8	0.23
11	72.0	48.0	60.0	100.0	30.0	65.0	0.0
12	72.0	42.0	57.0	100.0	30.0	65.0	0.0
13	72.0	46.0	59.0	100.0	28.0	64.0	0.01
14	72.0	41.0	56.5	100.0	27.0	63.5	0.01
15	66.0	47.0	56.5	100.0	50.0	75.0	0.0
MEAN	70.8	44.8	57.8	100.0	33.0	66.5	0.02
16	68.0	49.0	58.5	100.0	48.0	74.0	0.0
17	72.0	45.0	58.5	100.0	32.0	66.0	0.0
18	72.0	52.0	62.0	100.0	32.0	66.0	0.29
19	54.0	46.0	50.0	100.0	78.0	89.0	0.08
20	73.0	48.0	60.5	100.0	32.0	66.0	0.06
MEAN	67.8	48.0	57.9	100.0	44.4	72.2	0.43
21	72.0	39.0	55.5	100.0	42.0	71.0	0.0
22	76.0	53.0	64.5	96.0	36.0	66.0	0.0
23	71.0	43.0	57.0	100.0	44.0	72.0	0.0
24	75.0	46.0	60.5	100.0	40.0	70.0	0.0
25	77.0	40.0	58.5	100.0	38.0	69.0	0.0
MEAN	74.2	44.2	59.2	99.2	40.0	69.6	0.0
26	77.0	41.0	59.0	100.0	30.0	65.0	0.0
27	83.0	43.0	63.0	100.0	29.0	64.5	0.0
28	85.0	55.0	70.0	96.0	30.0	63.0	0.05
29	65.0	46.0	55.5	100.0	66.0	83.0	0.01
30	68.0	47.0	57.5	100.0	50.0	75.0	0.13
31	64.0	39.0	51.5	100.0	54.0	77.0	0.19
MEAN	73.7	45.2	59.4	99.3	43.2	71.3	0.38
MONTHLY MEAN	71.2	47.2	59.2	99.5	40.8	70.1	1.59

LOWLAND BLACK SPRUCE

SITE 3 AUGUST 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	65.0	48.0	56.5	100.0	50.0	75.0	0.14
2	69.0	39.0	54.0	100.0	50.0	75.0	0.02
3	67.0	39.0	53.0	100.0	46.0	73.0	0.19
4	63.0	48.0	55.5	100.0	60.0	80.0	0.0
5	61.0	46.0	53.5	100.0	68.0	84.0	0.36
MEAN	65.0	44.0	54.5	100.0	54.8	77.4	0.71
6	62.0	46.0	54.0	100.0	52.0	76.0	0.01
7	65.0	40.0	52.5	100.0	52.0	76.0	0.31
8	61.0	43.0	52.0	100.0	54.0	77.0	0.0
9	66.0	33.0	49.5	100.0	44.0	72.0	0.0
10	68.0	35.0	51.5	100.0	43.0	71.5	0.0
MEAN	64.4	39.4	51.9	100.0	49.0	74.5	0.32
11	68.0	44.0	56.0	100.0	44.0	72.0	0.05
12	66.0	43.0	54.5	100.0	64.0	82.0	0.0
13	74.0	41.0	57.5	100.0	32.0	66.0	0.0
14	76.0	40.0	58.0	100.0	30.0	65.0	0.0
15	72.0	47.0	59.5	100.0	40.0	70.0	0.0
MEAN	71.2	43.0	57.1	100.0	42.0	71.0	0.05
16	64.0	47.0	55.5	100.0	55.0	77.5	0.01
17	66.0	48.0	57.0	100.0	32.0	66.0	0.0
18	67.0	50.0	58.5	66.0	32.0	49.0	0.0
19	66.0	47.0	56.5	82.0	32.0	57.0	0.0
20	64.0	45.0	54.5	78.0	30.0	54.0	0.0
MEAN	65.4	47.4	56.4	85.2	36.2	60.7	0.01
21	61.0	47.0	54.0	100.0	50.0	75.0	0.07
22	56.0	44.0	50.0	100.0	52.0	76.0	0.06
23	56.0	41.0	48.5	100.0	52.0	76.0	0.0
24	55.0	44.0	49.5	100.0	52.0	76.0	0.34
25	54.0	43.0	48.5	100.0	52.0	76.0	0.0
MEAN	56.4	43.8	50.1	100.0	51.6	75.8	0.47
26	63.0	45.0	54.0	92.0	40.0	66.0	0.0
27	69.0	45.0	57.0	100.0	30.0	65.0	0.0
28	68.0	49.0	58.5	74.0	30.0	52.0	0.0
29	67.0	51.0	59.0	92.0	36.0	64.0	0.02
30	59.0	48.0	53.5	100.0	58.0	79.0	0.36
31	56.0	50.0	53.0	100.0	86.0	93.0	0.10
MEAN	63.7	48.0	55.8	93.0	46.7	69.8	0.48
MONTHLY MEAN	64.3	44.4	54.4	96.3	46.7	71.5	2.04

SITE 3 SEPTEMBER 1970

DAY	TEMPERATURE MAX	TEMPERATURE MIN	TEMPERATURE MEAN	RELATIVE HUMIDITY MAX	RELATIVE HUMIDITY MIN	RELATIVE HUMIDITY MEAN	PRECIP
1	63.0	45.0	54.0	100.0	52.0	76.0	0.04
2	63.0	41.0	52.0	100.0	54.0	77.0	0.04
3	59.0	38.0	48.5	100.0	44.0	72.0	0.0
4	59.0	46.0	52.5	100.0	45.0	72.5	0.0
5	59.0	42.0	50.5	100.0	54.0	77.0	0.0
MEAN	60.6	42.4	51.5	100.0	49.8	74.9	0.08
6	53.0	31.0	42.0	100.0	36.0	68.0	0.0
7	52.0	27.0	39.5	100.0	36.0	68.0	0.0
8	41.0	20.0	30.5	100.0	50.0	75.0	0.0
9	48.0	15.0	31.5	100.0	42.0	71.0	0.01
10	56.0	16.0	36.0	100.0	38.0	69.0	0.0
MEAN	50.0	21.8	35.9	100.0	40.4	70.2	0.01
11	61.0	28.0	44.5	100.0	28.0	64.0	0.0
12	61.0	44.0	52.5	100.0	32.0	66.0	0.07
13	55.0	51.0	53.0	100.0	84.0	92.0	0.32
MEAN	59.0	41.0	50.0	100.0	48.0	74.0	0.39
MONTHLY MEAN	56.2	34.2	45.2	100.0	45.8	72.9	0.48

SITE 3 MAY 1971

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
26	63.0	30.0	46.5	90.0	20.0	55.0	0.0
27	62.0	36.0	49.0	90.0	24.0	57.0	0.0
28	66.0	47.0	56.5	64.0	30.0	47.0	0.0
29	65.0	46.0	55.5	94.0	20.0	57.0	0.0
30	65.0	29.0	47.0	96.0	21.0	58.5	0.0
31	69.0	46.0	57.5	50.0	27.0	38.5	0.0
MEAN	65.0	39.0	52.0	80.7	23.7	52.2	0.0
MONTHLY MEAN	65.0	39.0	52.0	80.7	23.7	52.2	0.0

SITE 3 JUNE 1971

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	64.0	41.0	52.5	92.0	20.0	56.0	0.0
2	60.0	33.0	46.5	87.0	30.0	58.5	0.0
3	64.0	30.0	47.0	98.0	28.0	63.0	0.0
4	73.0	30.0	51.5	100.0	22.0	61.0	0.0
5	80.0	39.0	59.5	92.0	18.0	55.0	0.0
MEAN	68.2	34.6	51.4	93.8	23.6	58.7	0.0
6	83.0	40.0	61.5	92.0	16.0	54.0	0.0
7	83.0	41.0	62.0	94.0	16.0	55.0	0.0
8	77.0	38.0	57.5	98.0	18.0	58.0	0.0
9	82.0	40.0	61.0	94.0	16.0	55.0	0.0
10	82.0	50.0	66.0	80.0	18.0	49.0	0.0
MEAN	81.4	41.8	61.6	91.6	16.8	54.2	0.0
11	78.0	44.0	61.0	86.0	28.0	57.0	0.0
12	71.0	39.0	55.0	95.0	27.0	61.0	0.0
13	68.0	38.0	53.0	98.0	28.0	63.0	0.0
14	62.0	37.0	49.5	100.0	26.0	63.0	0.06
15	69.0	36.0	52.5	100.0	28.0	64.0	0.01
MEAN	69.6	38.8	54.2	95.8	27.4	61.6	0.07
16	69.0	42.0	55.5	88.0	28.0	58.0	0.0
17	72.0	47.0	59.5	88.0	26.0	57.0	0.0
18	73.0	46.0	59.5	86.0	25.0	55.5	0.0
19	76.0	41.0	58.5	98.0	34.0	66.0	0.0
20	73.0	44.0	58.5	98.0	40.0	69.0	0.0
MEAN	72.6	44.0	58.3	91.6	30.6	61.1	0.0
21	82.0	48.0	65.0	98.0	34.0	66.0	0.0
22	81.0	47.0	64.0	95.0	28.0	61.5	0.0
23	86.0	51.0	68.5	94.0	24.0	59.0	0.0
24	86.0	54.0	70.0	70.0	17.0	43.5	0.0
25	86.0	53.0	69.5	72.0	16.0	44.0	0.0
MEAN	84.2	50.6	67.4	85.8	23.8	54.8	0.0
26	84.0	48.0	66.0	82.0	19.0	50.5	0.0
27	83.0	50.0	66.5	88.0	23.0	55.5	0.0
28	80.0	40.0	60.0	90.0	24.0	57.0	0.0
29	59.0	48.0	53.5	98.0	24.0	61.0	0.13
30	54.0	31.0	42.5	94.0	34.0	64.0	0.0
MEAN	72.0	43.4	57.7	90.4	24.8	57.6	0.13
MONTHLY MEAN	74.7	42.2	58.4	91.5	24.5	58.0	0.20

LOWLAND BLACK SPRUCE

SITE 3 JULY 1971

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	60.0	29.0	44.5	100.0	33.0	66.5	0.01
2	66.0	42.0	54.0	96.0	38.0	67.0	0.40
3	73.0	39.0	56.0	98.0	28.0	63.0	0.0
4	74.0	40.0	57.0	98.0	26.0	62.0	0.0
5	75.0	39.0	57.0	98.0	24.0	61.0	0.0
MEAN	69.6	37.8	53.7	98.0	29.8	63.9	0.41
6	78.0	40.0	59.0	100.0	20.0	60.0	0.0
7	78.0	43.0	60.5	98.0	24.0	61.0	0.0
8	72.0	52.0	62.0	96.0	34.0	65.0	0.0
9	78.0	43.0	60.5	99.0	32.0	65.5	0.0
10	79.0	46.0	62.5	98.0	32.0	65.0	0.0
MEAN	77.0	44.8	60.9	98.2	28.4	63.3	0.0
11	79.0	57.0	68.0	95.0	36.0	65.5	0.19
12	66.0	57.0	61.5	100.0	60.0	80.0	0.59
13	64.0	58.0	61.0	100.0	84.0	92.0	0.44
14	63.0	47.0	55.0	100.0	62.0	81.0	0.33
15	62.0	34.0	48.0	100.0	40.0	70.0	0.06
MEAN	66.8	50.6	58.7	99.0	56.4	77.7	1.61
16	69.0	39.0	54.0	100.0	34.0	67.0	0.0
17	72.0	39.0	55.5	100.0	36.0	68.0	0.0
18	79.0	42.0	60.5	100.0	30.0	65.0	0.0
19	80.0	51.0	65.5	100.0	26.0	63.0	0.05
20	76.0	45.0	60.5	98.0	31.0	64.5	0.0
MEAN	75.2	43.2	59.2	99.6	31.4	65.5	0.05
21	72.0	50.0	61.0	92.0	32.0	62.0	0.02
22	66.0	32.0	49.0	100.0	30.0	65.0	0.0
23	71.0	35.0	53.0	100.0	28.0	64.0	0.0
24	72.0	41.0	56.5	94.0	28.0	61.0	0.0
25	72.0	38.0	55.0	100.0	30.0	65.0	0.01
MEAN	70.6	39.2	54.9	97.2	29.6	63.4	0.03
26	74.0	41.0	57.5	100.0	24.0	62.0	0.0
27	74.0	40.0	57.0	100.0	22.0	61.0	0.0
28	64.0	44.0	54.0	96.0	38.0	67.0	0.25
29	63.0	44.0	53.5	96.0	38.0	67.0	0.40
30	64.0	43.0	53.5	98.0	38.0	68.0	0.0
31	64.0	47.0	55.5	98.0	58.0	78.0	0.07
MEAN	67.2	43.2	55.2	98.0	36.3	67.2	0.72
MONTHLY MEAN	70.9	43.1	57.0	98.3	35.4	66.8	2.82

SITE 3 AUGUST 1971

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	66.0	49.0	57.5	100.0	56.0	78.0	0.17
2	65.0	50.0	57.5	100.0	44.0	72.0	0.03
3	64.0	36.0	50.0	98.0	43.0	70.5	0.0
4	58.0	46.0	52.0	98.0	43.0	70.5	0.26
5	60.0	35.0	47.5	100.0	44.0	72.0	0.0
MEAN	62.6	43.2	52.9	99.2	46.0	72.6	0.46
6	60.0	41.0	50.5	100.0	56.0	78.0	0.0
7	59.0	51.0	55.0	96.0	70.0	83.0	0.10
8	58.0	50.0	54.0	98.0	74.0	86.0	0.21
9	60.0	55.0	57.5	96.0	84.0	90.0	0.61
10	60.0	54.0	57.0	96.0	76.0	86.0	0.21
MEAN	59.4	50.2	54.8	97.2	72.0	84.6	1.13
11	69.0	45.0	57.0	100.0	38.0	69.0	0.0
12	69.0	39.0	54.0	100.0	36.0	68.0	0.0
13	68.0	44.0	56.0	96.0	34.0	65.0	0.0
14	64.0	30.0	47.0	100.0	32.0	66.0	0.03
15	69.0	30.0	49.5	100.0	33.0	66.5	0.0
MEAN	67.8	37.6	52.7	99.2	34.6	66.9	0.03
16	69.0	30.0	49.5	100.0	30.0	65.0	0.0
17	70.0	39.0	54.5	98.0	28.0	63.0	0.0
18	73.0	38.0	55.5	98.0	29.0	63.5	0.0
19	73.0	44.0	58.5	98.0	27.0	62.5	0.0
20	64.0	44.0	54.0	98.0	50.0	74.0	0.58
MEAN	69.8	39.0	54.4	98.4	32.8	65.6	0.58
21	51.0	42.0	46.5	98.0	60.0	79.0	0.29
22	63.0	36.0	49.5	100.0	52.0	76.0	0.0
23	67.0	46.0	56.5	100.0	44.0	72.0	0.01
24	67.0	35.0	51.0	100.0	50.0	75.0	0.0
25	64.0	34.0	49.0	100.0	48.0	74.0	0.05
MEAN	62.4	38.6	50.5	99.6	50.8	75.2	0.35
26	66.0	34.0	50.0	100.0	42.0	71.0	0.0
27	66.0	32.0	49.0	100.0	36.0	68.0	0.0
28	68.0	32.0	50.0	100.0	34.0	67.0	0.0
29	72.0	32.0	52.0	100.0	30.0	65.0	0.0
30	72.0	32.0	52.0	100.0	30.0	65.0	0.0
31	65.0	50.0	57.5	94.0	44.0	69.0	0.25
MEAN	68.2	35.3	51.8	99.0	36.0	67.5	0.25
MONTHLY MEAN	65.1	40.5	52.8	98.8	45.1	71.9	2.80

SITE 3 SEPTEMBER 1971

DAY	TEMPERATURE MAX	MIN	MEAN	RELATIVE HUMIDITY MAX	MIN	MEAN	PRECIP
1	59.0	42.0	50.5	98.0	62.0	80.0	0.15
2	48.0	42.0	45.0	98.0	86.0	92.0	0.56
3	44.0	34.0	39.0	100.0	88.0	94.0	0.07
4	47.0	39.0	43.0	100.0	72.0	86.0	0.44
5	51.0	31.0	41.0	100.0	52.0	76.0	0.0
MEAN	49.8	37.6	43.7	99.2	72.0	85.6	1.22
MONTHLY MEAN	49.8	37.6	43.7	99.2	72.0	85.6	1.22

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

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

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A FIELD METHOD FOR MEASURING PATTERNS OF WATER DROPPED FROM HELICOPTERS

by

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ABSTRACT

Detailed instructions allow field units to determine the concentrations of water or retardant applied on a fireline.

KEYWORDS: Helicopters, aerial fire control.

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A quick and economical method for field use has been developed to measure ground distribution patterns of water and fire-retarding liquids dropped from aircraft. The method was used successfully at the Institute of Northern Forestry in studying water requirements for suppressing fine fuel fires.

The measurement capability was developed for helicopters using helibuckets to drop water. The system can be used for retardants, but the problem of cup contamination has to be recognized. The system can be used for fixed-wing aircraft, but there are possible problems with splash from the ground surface into the cups.

Collecting drop pattern information and interpreting the results demand judgment and forethought. Planning and analyzing the drop pattern measurement is the responsibility of the professional fire control officer. Clearly defining the purpose of the test, establishing criteria for acceptance or rejection, and considering alternative recommendations will be time well spent. This article concerns detailed procedures which allow field units to measure drop concentration patterns for current and new equipment.

This simple measurement system is limited by area coverage and sample size. Even for helicopters with helibuckets, the sampling grid is limited to the central portion of the pattern and the extreme edges are left undefined. Researchers are beginning to deal with the problem of setting criteria for system measurement accuracy and developing procedures to define resolution or sensitivity. The absolute accuracy or variability of this system has not been established.

Equipment

A set of specialized cupholders that can be easily built is required. One cupholder is required for each sampling point in a grid covering an area slightly larger than the estimated drop pattern. The cupholders are wooden receptacles constructed from 2x10 dimensional lumber cut to make 9½- by 9½-inch squares. Seventy of the wooden receptacles allowed the layout of a suitable sampling grid in this study. However, the size and shape of the grid can be adjusted to suit specific needs.

The concentration of water or retardant falling at each point in the array is sampled with open plastic cups. A certain amount of efficiency is built into the system by constructing the cupholders to accept more than one cup. Holders that accept nine cups give the system capability to make that many consecutive passes without stopping to replace cups. A sampling grid of 70 cupholders with nine cups each would require 630 cups with lids--4½-ounce plastic cups[1/] serve satisfactorily.

The 9½- by 9½-inch wooden cupholder blanks should be drilled with nine equally spaced 2¼-inch-diameter holes into which the plastic cups can be inserted by twisting to a friction fit (fig. 1). Each block should be numbered so that its place within the grid can be identified. Each hole within the wooden receptacles should also be numbered so that it can be identified. A two-number system, i.e., 70-9, allows each cup to be associated with a block in the sampling array and a particular cup within the block. The cups should be numbered with permanent ink or an etching tool. This numbering scheme is useful for developing systematic procedures for laying out the array and, later on, in keeping track of the data. Another reason for etching the numbers on the cups is array reassembly in case a concentration of drop material should tip the receptacles and scatter the plastic cups.

Figure 1.--*Wooden receptacles with nine friction-mounted plastic cups with tags that identify their location within the grid.*

[1/] The plastic containers with lids can be obtained from Falcon Plastics, Division of V-D Laboratories, Inc., 5500 West 83rd Street, Los Angeles, Calif. 90045. (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.)

Procedures

Preparation.--A simple form will facilitate recording information for each pass (fig. 2). The form should provide a place to record aircraft speed, altitude, windspeed, pass number, type of aircraft and gate settings if applicable, and information on any other factors that are being evaluated. The form should provide space to enter four values for each sample point in the array. Values recorded for each sample point are weight of the capped cup with water, tare weight of the capped cup, weight of the water, and concentration. The form layout should provide space for subtracting to obtain the weight of water and converting this value to a standard unit of measure, such as gallons per 100 square feet.

Most of the equipment needed to conduct the tests is available to a forestry-oriented fire control organization. Equipment required in preparation is:

1. Portable tape recorder (desirable)
2. Set of forms (one for each pass)
3. Belt weather kit
4. F. M. radio communication (two each, one in plane, one on ground)
5. Haga altimeter (or Abney level with a percent scale)
6. Approximately 70 wooden receptacles with 630 plastic cups and lids properly numbered for identification
7. 100-foot tape
8. Weighing scale (top loading type, accurate to 0.1 gm.).

The portable tape recorder records remarks and observations during the flight. The Abney level or Haga altimeter measures aircraft height. Lack of an accurate weighing scale is not a problem, as the cups can be transported to an available scale.

Plot layout.--A 100-foot tape and the simplest of survey techniques are appropriate for laying out the sample grid (fig. 3). A hard surface such as a runway taxi strip is a preferred location to set up. A hard surface does not get muddy after repeated drops and makes it easier to work. Some retardants cannot be dropped on a hard surface if they are corrosive. A 7 by 10 array with 5 feet between columns (parallel to the line of flight) and 50 feet between rows (perpendicular to the flightpath) samples an area 35 feet across and 450 feet long. This sampling array has been used to measure 450-gallon helibucket drops.

The wooden receptacles should be located accurately. A point 240 feet from the flightpath, the centerline of the grid should be located as the station for measuring aircraft height with the Haga altimeter. This permits the

Figure 2.--*Aircraft drop pattern data summary form.*

Pass No. 1

Type of aircraft HF-1100

Aircraft height 100

Windspeed Calm

Aircraft speed 45 knots

Wind direction N/A

Point No.	1	2	3	4	5	6	7
Wt. H_2O + cup	15.4	15.4	15.7	16.1	16.9	16.2	16.0
Wt. cup	15.4	15.2	15.2	15.2	15.1	15.1	15.1
Wt. H_2O	0.0	0.2	0.5	0.9	1.8	1.1	0.9
Gals./100 ft.^{2}	0.0	0.2	0.4	0.7	1.4	0.9	0.7

Point No.	8	9	10	11	12	13	14
Wt. H_2O + cup	15.5	16.9	16.9	17.0	18.0	17.4	16.3
Wt. cup	15.2	15.6	15.2	15.2	15.2	15.1	15.1
Wt. H_2O	0.3	1.3	1.7	1.8	2.8	2.3	1.2
Gals./100 ft.^{2}	0.2	1.0	1.3	1.4	2.1	1.8	0.9

Point No.	15	16	17	18	19	20	21
Wt. H_2O + cup	15.5	17.1	18.0	19.7	17.9	18.3	17.5
Wt. cup	15.1	15.1	15.5	15.3	15.1	15.2	15.2
Wt. H_2O	0.4	2.0	2.5	4.4	2.8	3.1	2.3
Gals./100 ft.^{2}	0.3	1.6	1.9	3.5	2.1	2.4	1.8

Figure 3.--*The sampling system, including the seven rows and 10 columns of blocks, the location of a man measuring aircraft height, a man measuring windspeed, and one of the two pylons for guiding the aircraft over the area.*

altimeter to be read directly in feet. A point 200 feet from the flightpath provides for reading an Abney level with a percent scale directly in feet. It may be advisable to locate some readily visible colored pylons along the flightpath to aid the pilot in alining and identifying the sampling array.

Conducting the test.-- An important part of the test procedure is assigning specific responsibilities to each crewmember. A briefing with the pilot and a predetermined, mutually agreeable schedule of aircraft altitude, airspeed, etc. should be established. The purpose of the drop test should be discussed with each crewmember so that he thoroughly understands his function. A supervisor and three assistants are a suitable crew.

The supervisor should use the radios to direct the pilot and be responsible for taking notes and recording information for each pass such as aircraft speed, aircraft height, and windspeed and direction (see procedure checklist). One person should be familiar with the Haga altimeter. The second crewmember should be familiar with the use of the wind-measuring device provided in the belt weather kit. The third man describes the general character of the drop or makes other appropriate weather measurements. The three assistants cover the filled sample cups after each pass and remove a second lid in preparation for the next pass. Three men can make this lid change in approximately 5 minutes, which is less time than a helicopter normally requires to hover, fill a helibucket, and return.

The greatest hazard associated with the operation is falling masses of retardant or the accidental release of a helibucket during the pass. A lesser hazard is poor footing after drops of retardant. Personnel should be warned and kept well to the side of the drop zone. Passes should not be made from an aircraft height less than 100 feet over terrain.

Data Reduction

After the passes have been made, receptacles and cups should be collected systematically, loaded, and transported to a sheltered work area with a weighing scale. The outside of each cup should be wiped clean and dry and the covered cup of liquid weighed. The cup should then be emptied, the inside thoroughly cleaned, and the dry cup and lid weighed. The difference between the first weight and the second is the amount of liquid per cup. A conversion factor must be determined for converting the amount of liquid per cup to a standard unit. A standard unit often used is gallons per 100 square feet. Each gram of liquid collected over the area covered by the open cup mouth should be expressed in these units.

An example of how this conversion factor was computed for the 4½-ounce cups described in this article follows:

$$\text{A conversion factor to gallons/100 ft.}^2 = \frac{1 \text{ gram liquid}}{\pi\ (r \text{ inches})^2}$$

$$\times \frac{1}{\text{liquid specific gravity}} \times \frac{144 \text{ inches}^2}{1 \text{ ft.}^2} \times \frac{1 \text{ gallon } (H_2O)}{3{,}785.43 \text{ grams } (H_2O)} \times 100$$

where:

r = average diameter of several cups divided by 2, and

π = 3.1416

The weight measurement is in grams per cup-mouth area. The two-step conversion involves (1) expressing a unit (grams or ounces) of the liquid in terms of gallons, and (2) expressing the cup-mouth area in terms of 100-square-foot units.

There are 3,785.43 grams of water per gallon; thus each gram of water equals 1/3,785.43, or 0.000264 gallon.

Cup area is computed by the familiar formula: $A = \pi r^2$. The radius for the 4½-ounce cups is 1.25 inches, or 4.9072 square inches. This is divided by 144 square inches per square foot, converted to 0.034077 square foot, and divided by 100 to yield 0.00034077 100-square-foot unit. The new numerator (0.000264 gallon) is divided by the denominator (0.00034077/100 square feet). Each gram of water collected represents a concentration of 0.775 gallon/100 square feet.

This conversion value (0.775), multiplied by the weight of water in each cup (in grams), gives the concentration at a sample point. The final answer is not accurate to more than the nearest 0.1 of a gallon and should be rounded off. The conversion value (0.775) applies to the 2½-inch diameter plastic cups described. A new conversion value will have to be determined if different size cups are used. The conversion value (0.775) applies to water and must be divided by the specific gravity if retardant is being measured.

Data Summary and Presentation

The information from each pass is then plotted on a graph (fig. 4). The scales of the graph represent distance in feet along the flightpath and distance in feet across the flightpath. The water concentration expressed in gallons per 100 square feet is then entered at each sampling point on the graph paper for the pass. Isolines are drawn through points of equal concentration at appropriate intervals.

Discussion

The maps themselves are very useful descriptions of the ground distribution pattern. They should be subjectively examined for uniformity and other desirable characteristics. Hodgson[2/] has developed criteria for evaluating and summarizing the maximum lengths of contours in feet at the

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[2/] Brian S. Hodgson. A procedure for evaluating ground distribution patterns for water dropping aircraft. For. Fire Res. Inst., Inf. Rep. FS-X-9, 29 p. Ottawa, Ont. 1967.

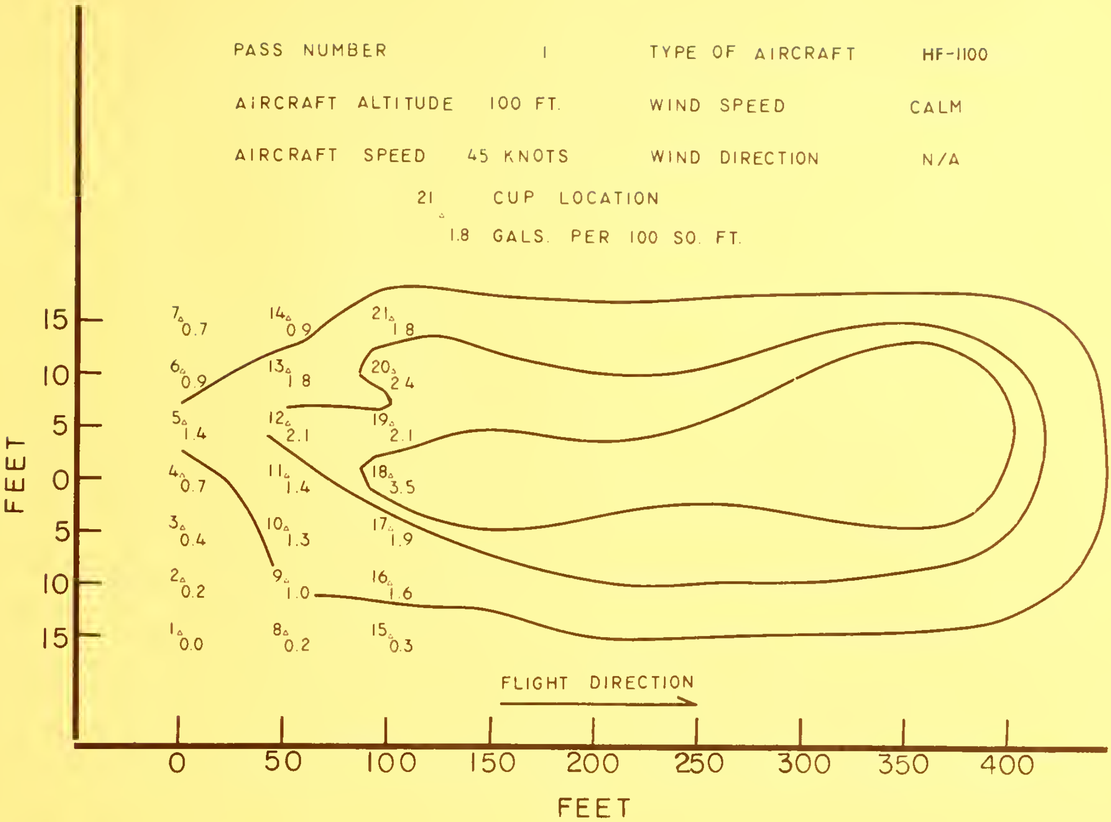

Figure 4.--*Ground distribution pattern showing plotted water concentration information and isolines.*

various concentration levels within drop patterns. Other measures that can be examined are width, area, and portion or drop load accounted for (recovery). Each drop pattern can be considered a sample and hypotheses tested about certain drop pattern parameters. Procedures for establishing a test design to provide a basis for answering questions are readily available.[3/] Forestry training in timber cruising provides the background for applying these statistical methods. The technique used for summarizing the data will vary with the purpose of making the drop pattern. However, the technique to be used and the criteria for judging whether the patterns are acceptable should be established during the preplanning period.

The fabrication of cup receptacles, array layout, testing, weighing, and summarizing data can be done by crews on standby. Aircraft flight time costs

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[3/] Frank Freese. Elementary statistical methods for foresters. U.S. Dep. Agric. Handb. 317, 1967.

can be negligible if tests are run during periods when aircraft are not being flown enough to meet minimum contract flight time guarantees. Considerable cost can be justified if an aircraft can be detected that has an undesirable drop pattern that wastes retardant. Cost of materials and special equipment is small. A three-man crew can set up the system, sample nine patterns, and have the field activities completed in less than 4 hours. The biggest time factor is weighing the cups and plotting the patterns.

Developing a capability to measure ground distribution patterns opens the door to quality control over retardant and water dropping operations. New equipment can be compared with that currently used. Contract aircraft and pilots can be checked and given guidelines for dropping. Field evaluation of aerially applied liquids will be more effective when variation in application rates can be controlled or quantified.

A Procedure Checklist

Predrop

- Define purpose and acceptance criteria
- Purchase cups
- Make cupholders
- Number cups and holders
- Prepare a form
- Purchase or locate a scale (readable to 0.1 gram)
- Assemble equipment:
    - portable tape recorder
    - set of forms
    - belt weather kit
    - cups and lids
    - pylons
    - F.M. radios
    - Haga altimeter
    - 100-foot tape
    - cupholders
- Contact air traffic control and arrange for use of test area
- Establish drop schedule
- Brief crew on safety and assign jobs
- Lay out array

During Drop

- Remove lid from Pass No. 1 cups
- Describe drop on recorder
- Record measured information on form
- Open Pass No. 2 cups and cap Pass No. 1 cups
- Continue

Postdrop

- Systematically collect cupholders with cups
- Weigh cups with water, empty, clean, and reweigh
- Determine weight of water, convert to standard units, plot the data on a graph
- Analyze

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

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STREAM CHEMISTRY FOLLOWING A FOREST FIRE AND UREA FERTILIZATION IN NORTH-CENTRAL WASHINGTON

by

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ABSTRACT

During 2 years of study, nitrate-N in streamflow increased from background levels of 0.005 part per million (p.p.m.) in a control stream to 0.042 and 0.310 p.p.m. in streams from burned and burned, urea-fertilized watersheds, respectively.

Cation concentration increased on the burned, unfertilized watershed, but because of dilution effects, decreased to levels of the control stream on the burned, fertilized watershed.

Neither burning nor urea fertilization caused increases in nitrogenous constituents to levels above those recommended for municipal water supplies. Concentrations of nitrate-N observed indicate that losses of N in this form will have a negligible effect on future productivity of these forest ecosystems.

Keywords: Streams, forest fire effects, fertilization (plants), urea.

INTRODUCTION

During July 1970, 6,400 hectares (1 ha. = 2.47 acres) of forested land on the north edge of Lake Chelan west of Chelan, Washington, were burned by an intense wildfire. After the fire, a U.S. Forest Service rehabilitation team recommended that the burned areas be seeded with grasses and legumes and fertilized with urea to help prevent soil erosion and restore plant-soil nutrient cycles.

Urea is an organic nitrogen fertilizer that hydrolyzes to ammonium carbonate and may be converted eventually to nitrate-N in the soil. The addition of large quantities of urea as fertilizer to the soil thus serves as a potential supply of both ammonia-N and nitrate-N in streamflow, as snowmelt moves these nutrient ions into and through the soil profile. The application of urea to burned areas is of particular concern because soil-plant nutrient cycles have been temporarily severed. Without vegetation to utilize added nitrogen, the potential for movement of nitrogen ions from the soil profile into streamflow is greater than in an undisturbed forest. Since streams draining the area are a source of municipal water, the U.S. Forest Service, administrator of these lands, was concerned that nitrate-N and ammonia-N might exceed the proposed permissible limits of 10 and 0.5 p.p.m. (parts per million), respectively (Federal Water Pollution Control Administration 1970) and render the water unsafe.

This study was initiated in response to a request by the U.S. Forest Service administration to assess the impact of urea fertilizer on the chemistry of water flowing from the burned area.

THE STUDY AREA

Several large watersheds affected by the fire are located in T. 30 N., R. 20 and 21 E., Willamette meridian, on the north side of Lake Chelan. Topography is steep, with deeply incised slopes ranging from 30 to 100 percent. Elevation ranges from 360 m. (meters) at Lake Chelan to 2,400 m. (1 m. = 3.28 feet) at the crest of Sawtooth Ridge.

Prefire vegetation below 900 m. was characterized by scattered ponderosa pine (*Pinus ponderosa* Laws.), with an understory of bitterbrush (*Purshia tridentata* (Pursh) DC.), bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. and Sm.), cheatgrass (*Bromus tectorum* L.), and arrowleaf balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.). At intermediate elevations (900 to 1,800 m.) Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and ponderosa pine shared the overstory. Pinegrass (*Calamagrostis rubescens* Buckl.), Ross sedge (*Carex rossii* Boott), snowbrush ceanothus (*Ceanothus velutinus* Dougl.), alder (*Alnus sinuata* (Reg.) Rydb.), and willow (*Salix* spp.) were ubiquitous in the understory. Above 1,800 m., overstory consisted primarily of subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and whitebark pine (*Pinus albicaulis* Engelm.). Prominent understory plants were Ross sedge, princes pine (*Chimaphila umbellata* (L.) Bart.), and whortleberry (*Vaccinium* spp.).

Soils are quite variable across the three watersheds but in general, well-drained, developing in coarse ash or fine pumice deposits overlying granitic or schist bedrock to depths of 3 m., or more.[1/]

Precipitation ranges from 76 centimeters (1 cm. = 2.54 inches) at Lake Chelan to 100 cm. at the upper elevations, occurring mostly as snow. Minimum monthly mean temperature is -4° C. in January with a mean monthly maximum during July and August of 18° C.

METHODS

Because burning itself may exert an influence on stream chemistry, it was necessary to separate this effect from that of urea fertilization. To account for changes in water chemistry caused by burning only, an unburned and unfertilized watershed, a burned and unfertilized watershed, and a burned and fertilized watershed were sampled. A basic assumption to the study was that water chemistry of all three streams was similar before the fire.

The selected streams were: Grade Creek--unburned, unfertilized (control), 2,800 ha.; Camas Creek--burned, unfertilized, 680 ha.; Falls Creek--burned, fertilized, 2,500 ha.

The two burned watersheds (Camas and Falls Creeks) were seeded by fixed-wing aircraft in October 1970 with 9.5 kilograms per hectare (1 kg./ha. = 0.89 lb./acre) of hard fescue (*Festuca ovina* L. var. *duriuscula*), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), orchardgrass (*Dactylis glomerata* L.), and yellow sweetclover (*Melilotus officinalis* (L.) Lam.). Falls Creek was fertilized by fixed-wing aircraft October 19-21, 1970, with 78 kg./ha. of urea.

Between September 17, 1970, and July 20, 1972, 21 water samples were collected in plastic jugs at the mouth of each stream. Samples were taken at monthly intervals during fall and summer, and at biweekly and bimonthly intervals during spring and winter between September 1970 and September 1971. Sampling was discontinued between September 1971 and January 1972, then was reinstated at approximately monthly intervals until July 1972. Samples were collected from a free-falling portion of each stream, cooled with ice during transit, and stored at 3° C. No preservatives were added.

Samples were analyzed in the laboratory for pH, total alkalinity, and electrical conductivity using procedures described by Golterman and Clymo (1969) and Hem (1970).

Ionic and elemental constituents measured were: nitrate-N by cadmium reduction (Wood et al. 1967); urea-N by diacetyl monoxime (Beale and Croft 1961, Newell et al. 1967); ammonia-N by the phenol-hypochlorite reaction (Weatherburn 1967, Sagi 1969); total organic N by Kjeldahl digestion (Chapman and Pratt 1961) with phenol-hypochlorite determination of ammonia; Ca, Mg, K, and Na by atomic absorption

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[1/] Soil survey report by U.S. Forest Service Region 6 personnel, Portland, Oregon (unpublished).

spectroscopy (Robinson 1966). The detection limit for nitrogenous constituents was 0.001 p.p.m. Detection limits for cations were 0.1, 0.01, 0.03, and 0.03 p.p.m. for Ca, Mg, Na, and K, respectively.

RESULTS AND DISCUSSION

Nitrogen

Levels of nitrogenous constituents observed during the sample period in Grade Creek, the unburned, unfertilized control stream, showed that water from undisturbed forested ecosystems of this area is extremely low in these compounds. Total organic N in the control stream fluctuated widely between 0 and 0.089 p.p.m. and averaged 0.046 p.p.m. (1 p.p.m. = 1 milligram per liter). Nitrate-N levels in the control stream were very minute during the entire sample period, ranging from 0 to 0.016 p.p.m. (fig. 1). On most sample dates, the nitrate-N concentration was less than 0.002 p.p.m. Urea-N was found in the control stream on one date--in May 1972, 0.450 p.p.m. was detected. This most likely resulted from animal activity (urination) in the stream. Ammonia-N, ranging in concentration from 0.001 to 0.011 p.p.m., was detected on four sample dates between March and July 1972 in the control stream. Nitrite-N was not observed in any stream during the period of study. Levels of nitrate-N and other nitrogenous constituents observed in the control stream support the results of other workers (Johnson and Needham 1966, Fredriksen 1971, Moore 1971, Malueg et al. 1972), which indicate that nitrogen losses from undisturbed forested ecosystems are negligible.

The level of total organic N in Camas Creek (burned, unfertilized) was consistently above that of the control stream, ranging from 0.013 to 0.164 p.p.m., with an average of 0.109 p.p.m. Nitrate-N levels in Camas Creek were at the same level as in the control during the 1970-71 sample period, but there was an increase from background levels to 0.042 p.p.m. in March 1972. Except for the occurrence of 0.006 p.p.m. of urea-N in Camas Creek on October 23, 1970, urea-N and ammonia-N concentrations were at the same level as in the control stream. Drift of urea during fertilization of adjacent Falls Creek probably caused the increase in urea-N in Camas Creek.

Although the change was not as great in the present study, the behavior of nitrate-N after burning followed a pattern similar to that observed by Fredriksen (1971). He found that mean annual nitrate-N concentration in streamflow increased from less than 0.004 p.p.m. on a control watershed to 0.05 and 0.20 p.p.m. during the first and second years, respectively, after slash was burned on a clearcut watershed.

In Falls Creek, the stream from the watershed that was fertilized with 78 kg./ha. of urea after burning, there were increases in concentrations of urea-N and nitrate-N. Total organic N and ammonia-N remained at the same concentration as in the control stream. Urea-N was observed on four sample dates in the stream from the burned, fertilized watershed. Detection of 0.029 p.p.m. of urea on October 23, 1970, can

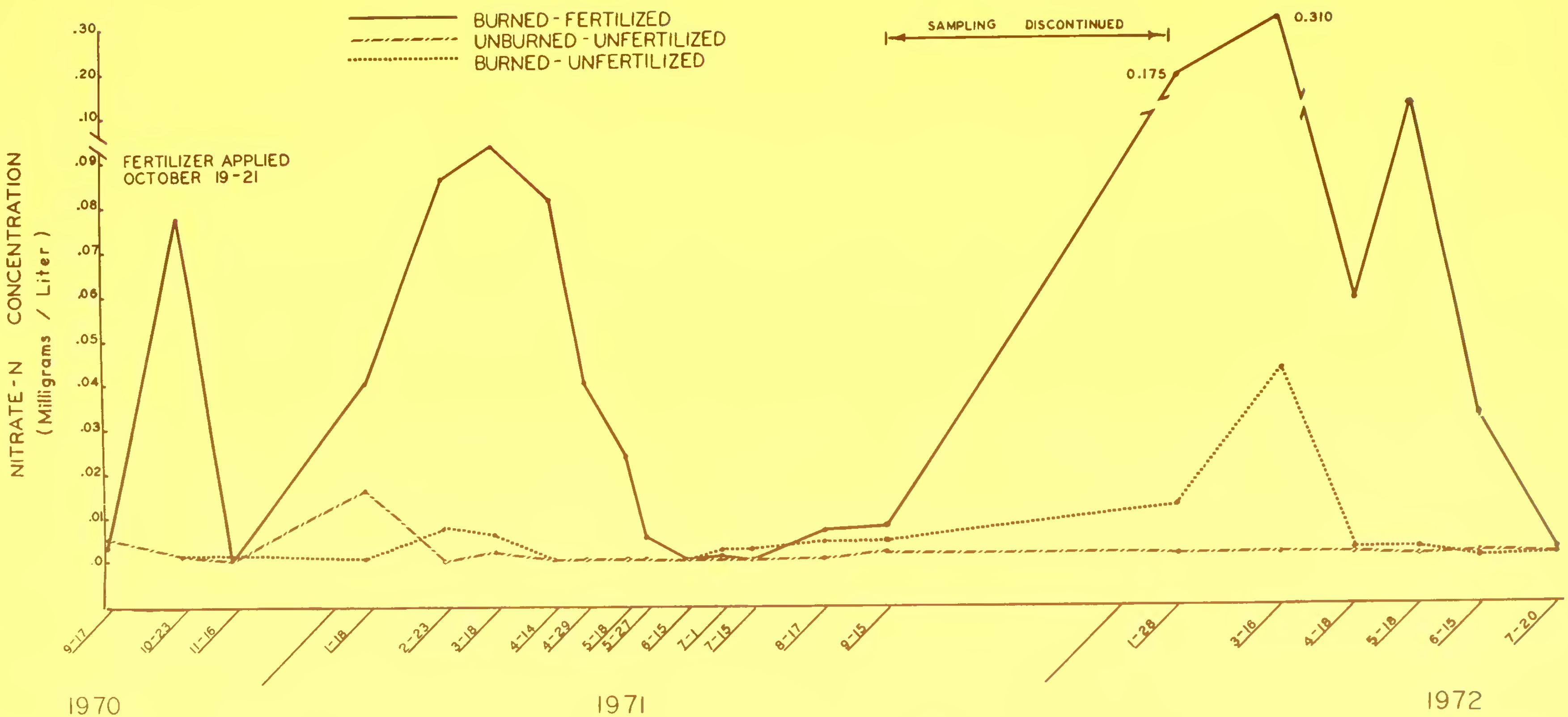

Figure 1.--*Concentration of nitrate-N in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

be directly related to the fertilizer application; but occurrence of urea on the other three dates probably resulted from animal activity. The largest concentration observed was 0.330 p.p.m. in April 1972.

The response of nitrate-N concentration to urea fertilization after burning was a distinct contrast to the behavior of other nitrogen species. Fluctuations of nitrate-N in the stream from the burned, fertilized watershed were manifested by four distinct peaks that were not observed in the control stream (fig. 1). Concentration of nitrate-N increased from less than 0.005 p.p.m. on the first sample date to 0.077 p.p.m. on October 23, 1970 (2 days after fertilization). Concentration then dropped below detection limits (0.001 p.p.m.) by November 1970. This rapid decline was followed by a steady increase to a peak of 0.093 p.p.m. by mid-March 1971. However, by June 1971, concentration of nitrate-N had again declined to background levels where it remained through September 1971. When sampling resumed in January 1972, nitrate-N was 0.175 p.p.m. and eventually reached a peak concentration of 0.310 p.p.m. by mid-March. Another peak (0.108 p.p.m.) occurred in May, but by July, nitrate-N had returned to background levels.

The nitrate-N peak that occurs immediately after urea fertilization is a result of direct application of urea to the stream (Moore 1971, Klock 1971, Malueg et al. 1972). Although the cause of this is not known, it possibly results from exchange of carbonate and bicarbonate ions for nitrate ions at anion exchange sites in the stream by mass ion effect. This would depend on rapid conversion of urea to ammonium carbonate at temperatures of 2° to 8° C. Malueg et al. found that urea pellets contained 19.33 mg./kg. of nitrate-N and concluded that this was the source of the nitrate peak that follows fertilization. Using Klock's (1971) data for total discharge and total nitrogen loss in streamflow after urea fertilization and data from Malueg et al. (1972) for nitrate-N concentration in urea fertilizer, the resultant nitrate-N concentration in streamflow was calculated. Nitrate-N concentration in streamflow from this source would be 1.8×10^{-6} p.p.m.--more than 1,000 times less than the concentrations observed in these studies. Therefore, the concentration of nitrate-N in urea fertilizer does not appear to be sufficient to account for the observed concentrations following direct application to the stream. There is a need for further study to elaborate the pathways and mechanisms involved in this rapid increase in nitrate-N following urea contamination of mountain streams.

For 1971 and 1972, the maximum observed level of nitrate-N in Falls Creek (burned, fertilized) occurred in mid-March. Peak runoff from these streams characteristically occurs between late May and mid-June.[2/] Occurrence of the

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2/ Personal communication from Mr. Gran Rhodus, Wenatchee National Forest. Data furnished were for Safety Harbor and Gold Creeks which are watersheds adjacent to the study area.

nitrate-N peak before the time of maximum discharge indicates that moisture moved from the snowpack into and through the soil during the winter. It is unlikely that nitrate ions would migrate such distances in response to a concentration gradient. Haupt (1972) has observed percolation of water from the snowpack into the soil during winter months.

During the first winter after fertilization, conversion of urea-N to nitrate-N in the soil was the most likely source for nitrate-N in streamflow. Although the activity of enzymes is slowed considerably by low temperatures, urea continues to hydrolyze to ammonia at 2^{o} C. (Broadbent et al. 1958). Conversion of ammonia-N to nitrate-N has also been shown to occur at 2^{o} C. (Frederick 1956).

The data indicate that part of the increase in nitrate-N concentration the second year resulted from burning alone. A similar study by Tiedemann and Helvey (1973) showed that nitrate-N increased from a maximum of 0.015 p.p.m. before fire to a maximum of 0.56 p.p.m. during the second year after a severe wildfire. In the stream from a burned watershed that was fertilized with 54 kg./ha. of N as urea, the maximum nitrate-N concentration during the second year after fire was 1.47 p.p.m. Because of differences in fire intensity between Camas and Falls Creeks, the two burned watersheds, the data of the present study probably do not give a true indication of the actual increase that results from burning alone. Camas Creek (burned, unfertilized) is a small watershed (680 ha.) that had coniferous vegetation in the upper half, and except for trees near the stream channel, supported a shrub-grass vegetation in the lower half (see footnote 2). Fire intensity in the upper half was about equally light and heavy with the exception of one small area of medium burn; the lower half of the watershed was unburned or only lightly burned. Falls Creek (burned, fertilized), in contrast, is a large (2,500 ha.) watershed that was covered mostly with coniferous vegetation. Much of this watershed received medium to heavy burn.

Cations

Total concentration of the four measured cations was substantially higher in the stream from the burned, unfertilized watershed than from either the unburned, unfertilized control or the burned, fertilized watershed (20.2 p.p.m. compared with 13.2 and 12.0 p.p.m., respectively).

Calcium was the predominant cation in all three streams, averaging 10.3 p.p.m. for the burned, unfertilized watershed and 6.5 p.p.m. for the other two watersheds (table 1). Calcium fluctuated more widely over time than any other cation, ranging from 2 to 19 p.p.m. (fig. 2). Potassium had the lowest concentration of the cations. Concentration fluctuated narrowly between 0.4 and 2.0 p.p.m. (fig. 3), and there were essentially no differences in average K concentration among streams (table 1).

Magnesium displayed different trends among streams than the other cations. Concentration was

Table 1.--*Average concentration of cations in three streams, north edge of Lake Chelan, Washington*

Stream and treatment	Cation				
	Ca	Mg	Na	K	Total
	Parts per million				
Grade Creek, unburned and unfertilized	6.49	2.46	3.20	1.09	13.24
Camas Creek, burned and unfertilized	10.29	2.58	6.03	1.26	20.16
Falls Creek, burned and fertilized	6.51	1.49	2.96	1.04	12.00

consistently lower by about a third in the stream from the burned, fertilized watershed (1.49 p.p.m.) than in the streams from the control (2.46 p.p.m.) or the burned, unfertilized watershed (2.58 p.p.m.) (table 1, fig. 4).

The comparison among streams for Na was similar to that for Ca--average Na concentration in the stream from the burned, unfertilized watershed was nearly twice as great (6.03 p.p.m.) as in the unburned control (3.20 p.p.m.) and burned, fertilized (2.96 p.p.m.) streams (fig. 5).

Seasonal trends among streams were most evident for Mg and Na. Concentrations of these two cations in the control and burned, fertilized streams were lowest between mid-May and mid-June, the period of peak discharge (figs. 4 and 5). In the stream from the burned, unfertilized watershed, the lowest concentrations occurred during mid-April.

Considering the mineralizing effect of fire on cations tied up in plant tissue and detritus (Ahlgren and Ahlgren 1960), it was surprising that this was not manifested by an increase in cation concentration in the stream from the burned, fertilized watershed as apparently occurred in the stream from the burned, unfertilized watershed. However, the results concur with those obtained by Johnson and Needham (1966) who also failed to detect changes in ionic composition of streams draining burned coniferous forest watersheds in California. This was attributed to an increase in runoff following fire which diluted the ion concentration, thereby

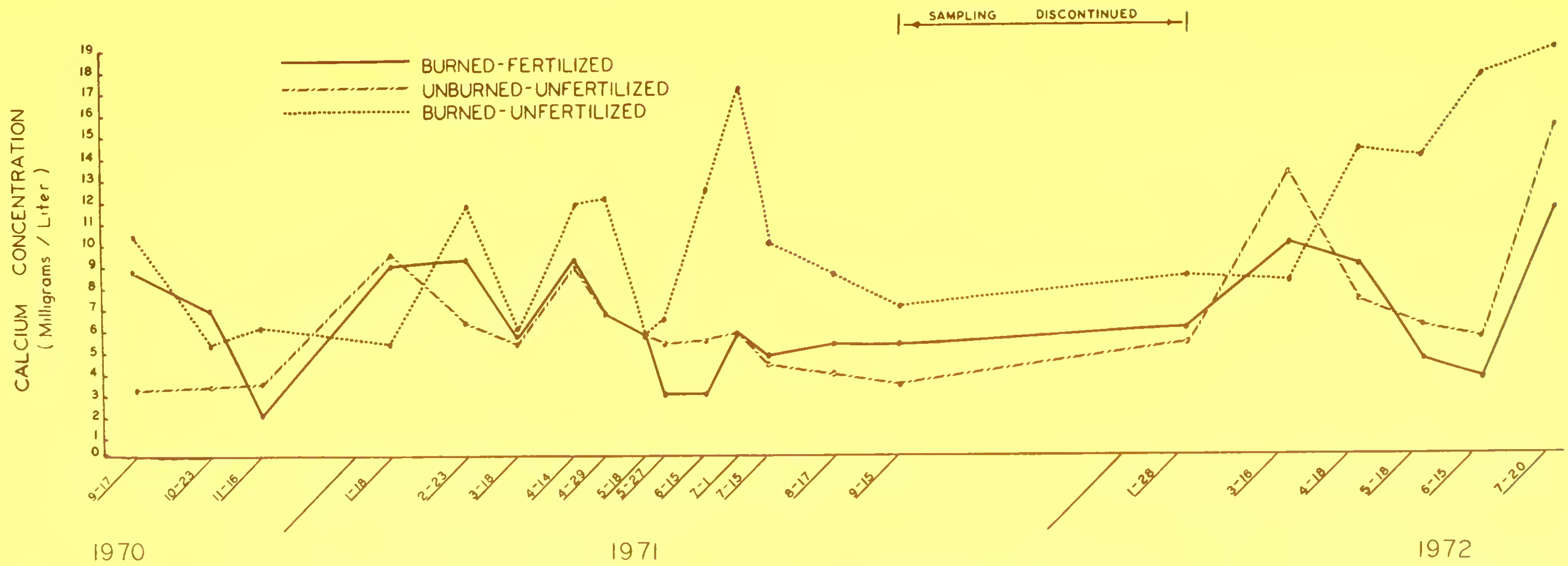

Figure 2.--*Concentration of calcium in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

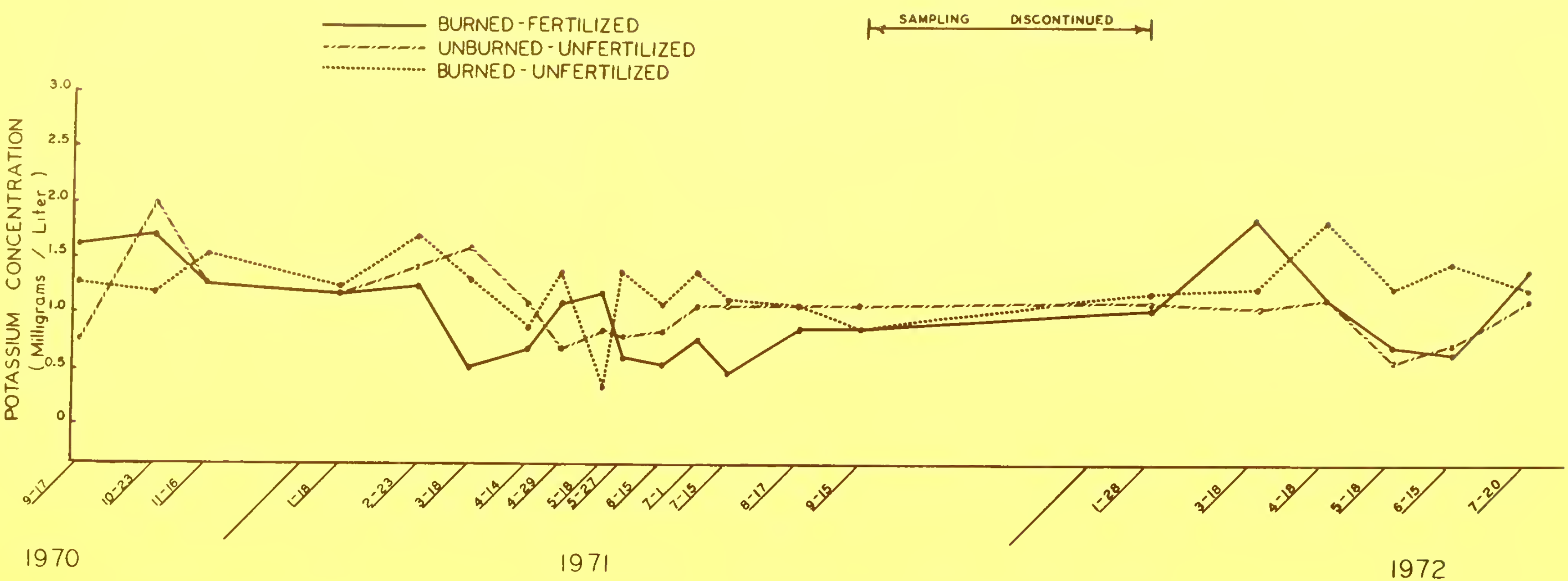

Figure 3.--*Concentration of potassium in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

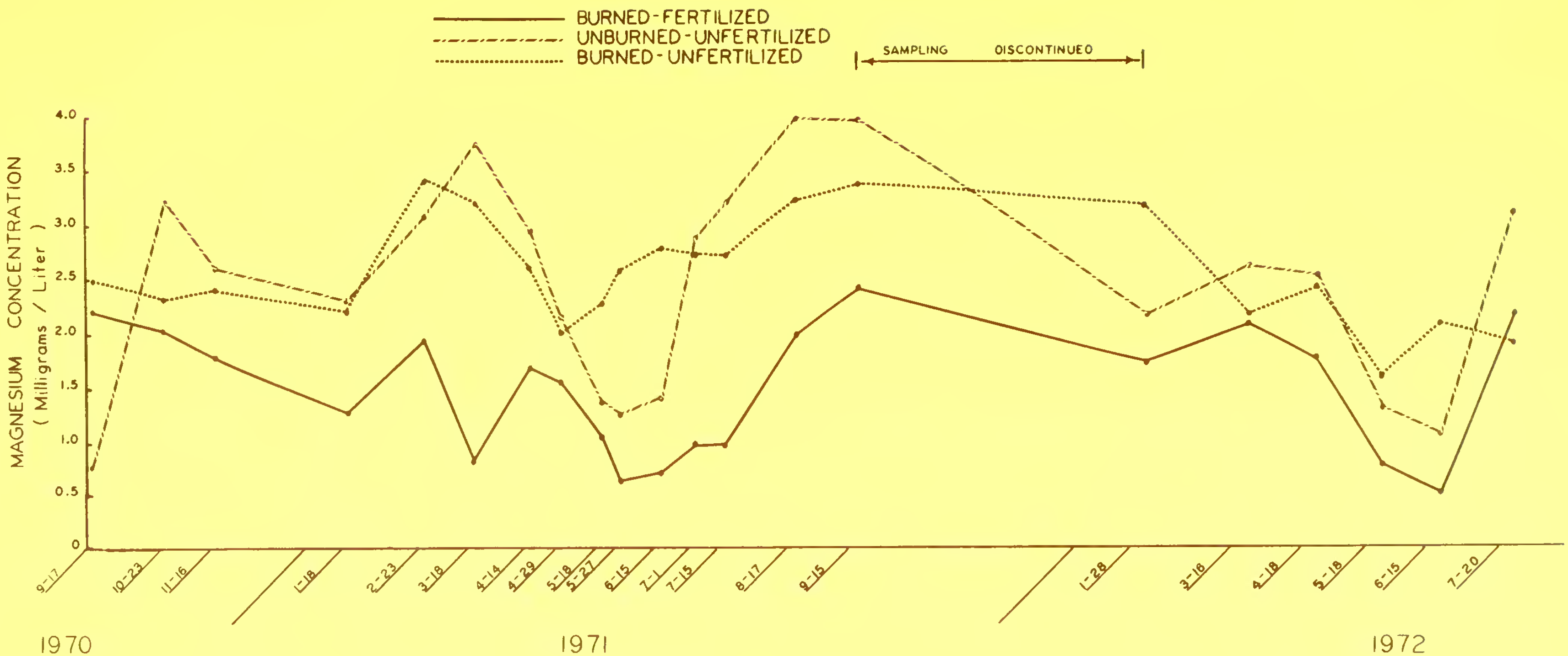

Figure 4.--*Concentration of magnesium in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

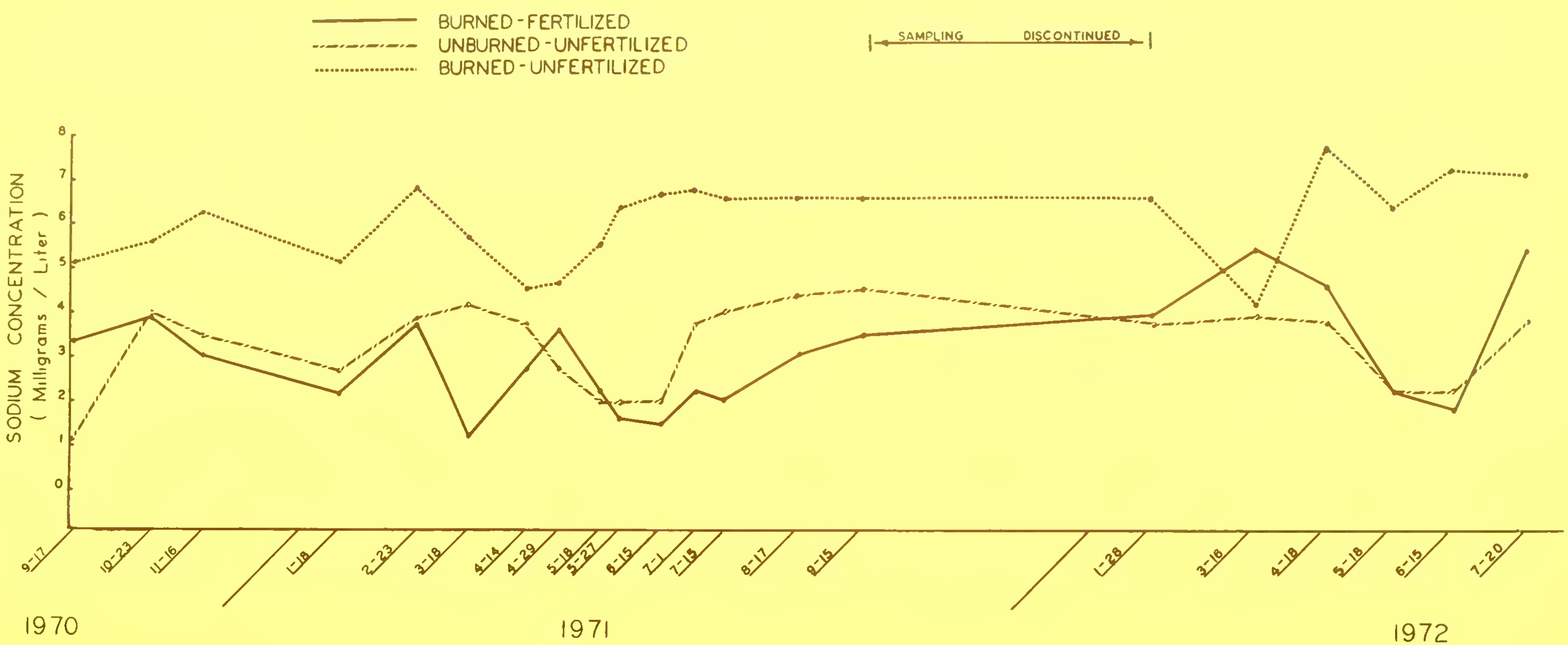

Figure 5.--*Concentration of sodium in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

masking true losses of ions from the watersheds. Fredriksen (1971) reached a similar conclusion in studies of ion concentration and total ion losses following clear-cutting and broadcast slash burning. Studies on the Entiat Experimental Forest indicate that dilution resulting from increased runoff is an important factor to consider in assessing the impact of fire on total cation losses. Helvey (1972) observed an average increase in runoff of 3.5 inches the first year after fire from the Entiat Experimental Forest. Nutrient budget studies on the same watersheds by Tiedemann and Helvey (1973) showed that average concentrations of Ca, Mg, K, and Na during the first 2 years after fire were similar to or less than before the fire. However, because of increased runoff, total losses of the four cations increased from 19.3 to 60.6 kg./ha./yr.

Differences in cation concentration among streams in the present study can probably be related to differential increases in runoff.

Because much of the Falls Creek watershed (burned, fertilized) was in a medium to heavy burn category, it appears likely that the greatest streamflow response to the fire occurred on that watershed, thus resulting in the greatest dilution of the cation concentration. Camas Creek, because less of the watershed was burned and the burn was less severe than Falls Creek, probably had a smaller increase in runoff and less dilution of cation concentration.

The observed seasonal trends of cations probably also result from the dilution effect, since lowest concentrations coincide with peak runoff on the unburned control and burned, fertilized watersheds.

The low concentration of K in runoff presents an anomaly to its concentration at the soil surface after fire and the solubility of its carbonate salt. Grier (1972) measured concentrations of cations in ash of the burned Entiat Experimental Forest and found the ash contained 217 kg./ha. of Ca, 59 kg./ha. of Mg, 39 kg./ha. of K, and 7 kg./ha. of Na. Of these amounts, 31 percent of the Ca, 80 percent of the Mg, 84 percent of the K, and 92 percent of the Na were transferred to the soil in 670 millimeters of flow. Since potassium carbonate is a highly soluble salt and K is a more mobile ion than either Ca or Mg, the ratio of concentration in runoff to concentration at the surface would be expected to be similar to the ratio for Ca and Mg. Grier (1972) speculates that K concentration is not proportional to the other elements in water draining the upper 36 cm. of profile because of fixation of K in interlamellar sites of vermiculite clays.

Total Alkalinity, Electrical Conductivity, and Hydrogen Ion Activity

Total alkalinity, which represents the concentration of carbonate and bicarbonate ions and other anions in the stream, maintained a narrow range between 0.5 and 2.2 milliequivalents per liter and showed the same general trends among streams and sampling dates as the concentration of cations (fig. 6). Total alkalinity was similar in Grade (control) and Camas (burned, unfertilized) Creeks and lowest in Falls Creek (burned, fertilized). Seasonally, the lowest levels of alkalinity coincided with peak discharge.

Concurrence of trends of total alkalinity with those of cations was not surprising since it has been shown that the bicarbonate ion is primarily responsible for cation transport within the soil (McColl and Cole 1968). Bicarbonate probably accounts for 80 to 90 percent of total alkalinity observed in this study since pH is between 7 and 8 (Golterman and Clymo 1969, Hem 1970). The data show that there is no shortage of bicarbonate ions after fire. If anything, the supply is greater; but because of dilution effects, the concentration remains at a level similar to that in the control stream. Increased activity of micro-organisms (Ahlgren and Ahlgren 1960) and rapid conversion of oxides of metals to carbonates apparently replace root respiration by higher plants as a source of bicarbonate ions.

Electrical conductivity in the unburned control and burned, unfertilized streams fluctuated widely during the first year, but there were no consistent differences between the two streams to indicate that burning had any effect on ionic concentration of the stream water (fig. 7). Seasonal changes during 1971 on these two streams, however, were striking, with a sharp rise in the early spring to over 225 micromho per centimeter (μmho/cm.) followed by a decline to less than 90 μmho/cm. in April at the start of spring runoff. In July, conductivity rose above 200 μmho/cm. again and remained at that level until the end of sampling. Electrical conductivity on Falls Creek (burned, fertilized) was a distinct contrast, remaining below 105 μmho/cm. until August 1971. During 1972, electrical conductivity was more uniform and similar among the three streams with the lowest values occurring between mid-May and mid-June during peak discharge. Electrical conductivity and cation trends were similar because the ability of streamwater to conduct an electric current is directly related to the quantity and degree of dissociation of solutes (Hem 1970).

Hydrogen ion activity (pH) fluctuated between 7.1 and 9.5 during the sampling period from September 1970 through April 1971 with no apparent trends among streams or sample dates (fig. 8). During the sample period from April 1971 through July 1972, pH was generally lowest in the stream from the burned, fertilized watershed. During this period, pH reached the lowest levels in mid-June of 1971 and again in mid-April of 1972.

Except for the first two sample occasions in the stream from the burned, fertilized watershed, pH was within the range Hem (1970) describes for most natural waters (6.0 to 8.5).

The high pH value (9.5) observed October 23, 1970, just 2 days after fertilization, appears linked

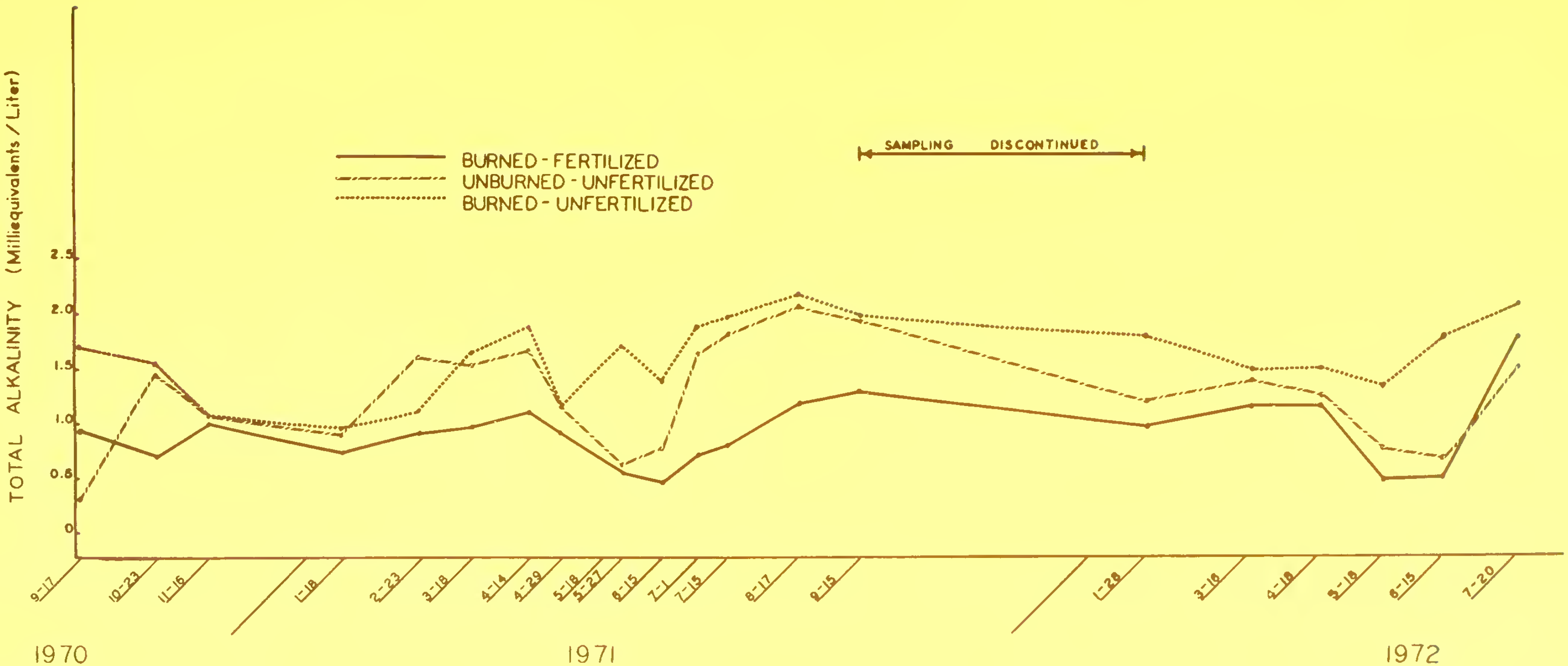

Figure 6.--*Total alkalinity in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

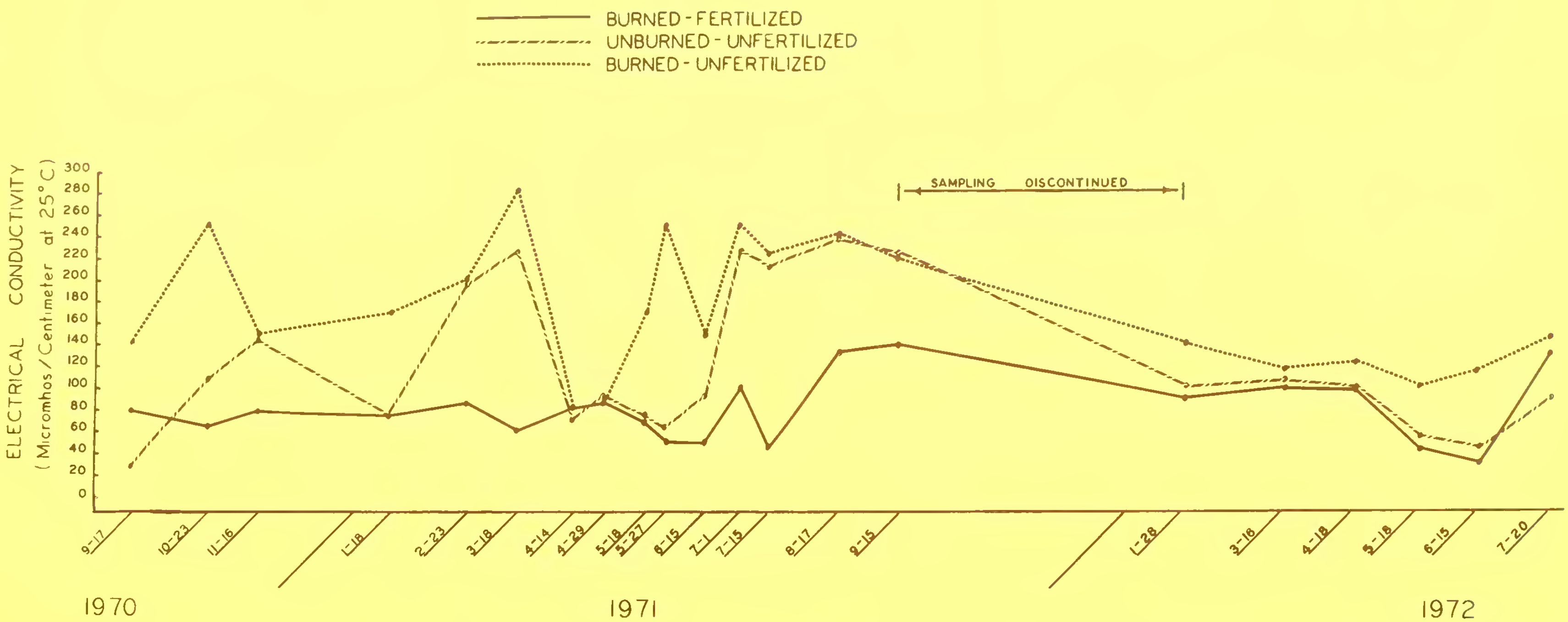

Figure 7.--*Electrical conductivity in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

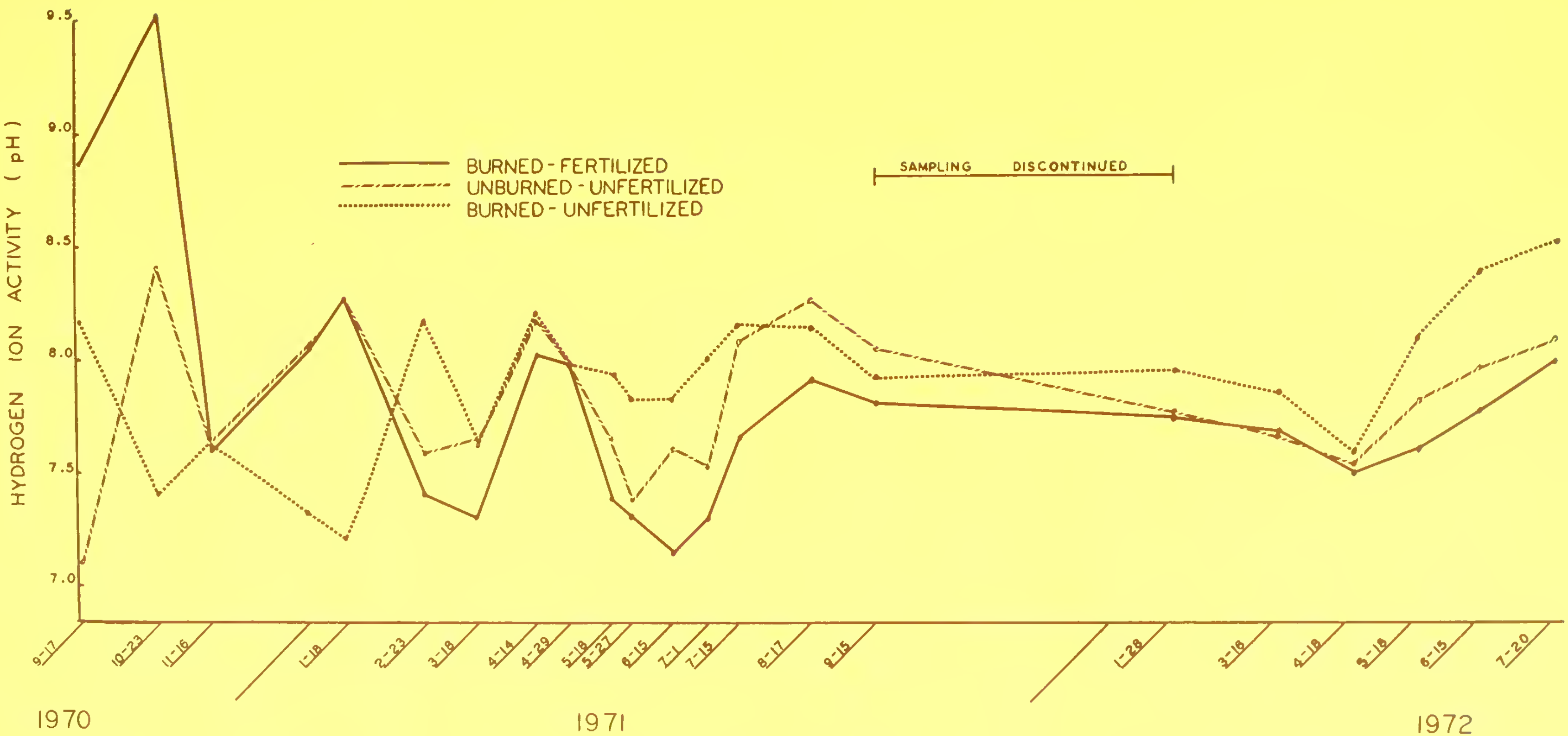

Figure 8.--*Hydrogen ion activity (pH) in streams from unburned and unfertilized, burned and unfertilized, and burned and fertilized watersheds, north edge of Lake Chelan, Washington.*

to direct application of urea to the stream. Hydrolysis of urea causes a temporary increase in soil pH (Broadbent et al. 1958). However, since the pH value was 8.9 on the sample date just prior to fertilization, the high values observed are more likely the result of instrument error and accidental freezing of a few of the early samples before analysis. Separate laboratory tests by the author showed that freezing a sample causes an increase in pH units of 0.5 to 1.00.

CONCLUSIONS

The quality of water for municipal use from watersheds involved in the fire does not appear to be threatened by either burning or urea fertilization during the first and second year after these treatments. Even though urea fertilization after fire at 78 kg./ha. apparently caused immediate and protracted increases in nitrate-N levels, the maximum observed level of 0.31 p.p.m. poses no hazard. This value is 30 times less than the proposed permissible level. Nitrate-N losses from the burned, unfertilized and burned, fertilized watersheds are probably less than those observed by Tiedemann and Helvey (1973). Nitrate-N losses on a burned watershed of the Entiat Experimental Forest increased from 0.008 kg./ha./yr. before fire to 1.92 kg./ha./yr. the second year after fire. On a watershed that was burned and fertilized with 54 kg./ha. of urea, losses increased from 0.0002 to 3.28 kg./ha./yr. Thus, it is not likely that losses of nitrate-N in streamflow are substantial enough to affect future productivity of these ecosystems.

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

·USDA FOREST SERVICE RESEARCH NOTE

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NATURAL REGENERATION OF LODGEPOLE PINE IN SOUTH-CENTRAL OREGON

by

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ABSTRACT

A sequence of events is necessary for natural regeneration in the pumice soil region: Adequate seed must be produced and distributed over the area, germination must be favored by warm and moist surface soils, daily surface temperature variation must be moderate, seedlings must survive summer drought, and weather conditions must prevent severe frost heaving the fall after germination and the next spring. This sequence does not always occur within a reasonable time after cutting, and natural regeneration is often delayed. Four possibilities are open to the land manager: (1) declare as noncommercial some severe sites such as lodgepole pine/needlegrass and lodgepole pine/bitterbrush/needlegrass plant communities on flat or basin topography; (2) depend more on a planting program; (3) leave a light slash cover on the surface after shelterwood or narrow strip cutting; and (4) leave a shelterwood on the area after a more thorough slash treatment and be willing to wait much longer than 5 years for natural regeneration. Some problems now exist in obtaining good lodgepole planting stock. Also the slash cover does not guarantee success of natural regeneration and option 3 might turn into option 4.

Keywords: Lodgepole pine, forest regeneration (natural), soil temperature, soil moisture, forest management.

INTRODUCTION

Increased logging of lodgepole pine (*Pinus contorta* Dougl.) in south-central Oregon has emphasized the need for additional information on factors influencing stand regeneration. Abundant lodgepole regeneration along roadsides, under powerlines, and in small openings in natural stands has tended to give foresters the impression that natural regeneration of this species would be easily obtained. However, since the 1950's, lodgepole logs have periodically been in demand, and many of the resulting clearcuts have failed to regenerate. Also, there are many poorly stocked lodgepole stands, a number of old burns which have failed to regenerate, and scattered "pumice deserts" ranging from less than 5 to over 100 acres in size. These "pumice deserts" are a result of very old burns or are areas which have yet to be afforested since pumice deposition.

This note summarizes information gained from two studies pertinent to the regeneration problem in south-central Oregon and from additional observations made in field and laboratory. One of the studies concerned germination and survival of both lodgepole and ponderosa pine (*Pinus ponderosa* Laws), and the other dealt with lodgepole pine only.

THE LODGEPOLE-PONDEROSA STUDY

Ponderosa and lodgepole pine germination and survival were studied in three different areas which differ slightly in severity of night minimum temperatures.

All three areas are on pumice-mantled, level topography. The soils are developing on a Mazama pumice layer about 30 inches thick. Soils under stands of timber and in clearcuts have an A1 horizon 2 inches thick and a 10-inch AC horizon over unweathered pumice which is partially mixed with materials from the buried profile and the weathered A horizons. The A1 horizon is absent in the pumice deserts. Area I is a 5-acre clearcut made in 1948 in a mixed ponderosa-lodgepole stand with an understory of bitterbrush/needlegrass-sedge. The clearcut is located just inside the east boundary of the Pringle Falls Experimental Forest, 7 miles west of Lapine, and now contains lodgepole pine seedlings and saplings of varying density. Part of the area is still open. Area II is a 7.4-acre clearcut made in 1938 in a lodgepole pine stand with a bitterbrush/needlegrass understory. This area is located at the northwestern corner of the Experimental Forest and is only partially regenerated. Area III is an 80-acre pumice desert approximately 5 miles north and one-half mile east of Lapine. The desert is surrounded by a lodgepole pine/bitterbrush/needlegrass plant community.

Methods

Lodgepole and ponderosa pine seeds were sown in 4- by 4-foot screened seed beds in the fall of 1969, 1970, and 1971.[1/] Eight, 6, and 14 beds were planted in each area for the 3 respective years. Seventy-two seeds of each species were placed in each bed resulting in totals of 576, 432, and 1,008 seeds per species sown at each location for the different periods. The screens were made of 1/4-inch mesh hardware cloth to protect the seed from small mammals. Some natural seed may have fallen into the seed beds, particularly in areas I and II, but no attempts were made to take natural seed fall into account.

Germination in the laboratory before seeding was 78 percent for the lodgepole pine and 25 percent for the ponderosa pine seeds used in the 1969 and 1970 sowings; for the 1971 sowing, germination was 55 and 80 percent, respectively, for lodgepole and ponderosa pine. All seed were collected on the Experimental Forest. Germination (emergence) and mortality were observed at intervals ranging from 3 days to 2 weeks each year; and in August 1972, some seed that did not germinate from the 1971 sowing were retrieved from the beds and examined. The apparently sound seed were subjected to a germination test in the laboratory.

Results

Percent germination in the field was:

Year and area		*Lodgepole pine*	*Ponderosa pine*
1970	I	1.2	0.2
	II	.6	0
	III	1.2	0
1971	I	45.5	3.5
	II	36.4	2.3
	III	4.4	0
1972	I	.7	.8
	II	2.4	.6
	III	2.2	2.2

Most of the viable seed failed to germinate in 1970 and 1972. In 1971, germination of both species was lowest on the desert (area III) where no ponderosa pine germinated, and ponderosa pine germination was much lower than lodgepole germination in the other two areas.

[1/] These experiments are split plot designs allowing objective testing of the following null hypotheses where sufficient numbers of seedlings are involved: (1) location caused no difference in germination or survival, (2) location affected both species alike, and (3) there is no species by location interaction.

A total of 70 lodgepole and 101 ponderosa seed were removed from the seed beds in August 1972, and some of the seed did not appear to be sound (table 1). Most of the seed not classed as apparently sound were cracked, and the contents were shriveled. Some of these seed were just slightly cracked, and the endosperm appeared to be sound. After dissecting the endosperm we could see that the radicle had begun to develop and then stopped. In a few cases, a withered radicle protruding about one-eighth of an inch from the seedcoat was present. Since the seed lots contained less than 2 percent cracked seed, damage to the seed must have occurred after sowing.

Table 1.--*Number of seed removed in August 1972 from beds sown in the fall of 1971*

Area	Total seed removal		Apparently sound seed	
	Lodgepole	Ponderosa	Lodgepole	Ponderosa
I	22	33	19	10
II	26	28	19	4
III	22	40	18	22

The apparently sound seed were then planted in A1 horizon soil material in the greenhouse under a 15-hour photoperiod where day-night air temperatures were 75-55° F. The soil was kept moist. Germination of the seed taken from different areas was:

Area	*Lodgepole pine (Percent)*	*Ponderosa pine (Percent)*
I	15.8	0
II	10.5	0
III	72.2	33.3

Although the sample size was small, the decrease in soundness and in ability to germinate after seeding appeared greater for ponderosa pine than for lodgepole pine seed in the first few months after sowing.

During the spring and summer of 1971, no germinants were observed in the eight beds which had been sown in 1969.

Mortality after germination.--While lodgepole pine seed is germinating, cold night temperatures can cause some mortality. Mortality of ponderosa seedlings is probably greater during this period because ponderosa is not as tolerant to night minimum temperatures below 20° F.

as lodgepole pine seedlings,[2/] but some lodgepole pine mortality is possible. During the period between May 12 and May 30, 1972, a total of 15 ponderosa pine and seven lodgepole pine seedlings in the screened seed beds apparently died from exposure to low night temperature. Temperatures in standard weather shelters (4½ feet from the soil surface) reached a minimum of 18° F. during this period.

Drought and heat injury during the summer and frost heaving at other seasons have been widely and consistently observed as causes of lodgepole pine seedling mortality. However, during some years, losses due to any one of these factors can be low. For example, the number and percent mortality attributed to drought and heat during 1971 were 14 (7.3 percent), 6 (3.9 percent), and 4 (2.2 percent) for areas I, II, and III, respectively.

Frost heaving can occur during the germination period, resulting in mortality of seedlings just a few days old. This happened occasionally, and the new seedlings were replanted and usually survived. Older seedlings are often frost heaved in the fall and early spring before new germinants appear. Many seedlings were lost in the screened seed beds between September 1971 and the following spring (table 2). Although it is impossible to account for all mortality between these examinations, presence of large numbers of seedlings with roots attached lying on the surface in the spring indicated that frost heaving caused most of the losses.

Table 2.--*Number of live seedlings present in screened seed beds in early fall 1971 and spring 1972*

Area	September 1971		Spring 1972	
	Lodgepole	Ponderosa	Lodgepole	Ponderosa
I	182	12	32	4
II	147	10	16	1
III	15	0	1	0

[2/] Carl Martin Berntsen. Relative low temperature tolerance of lodgepole and ponderosa pine seedlings. (Unpublished Ph.D. thesis on file at Oreg. State Univ., Corvallis.) 158 p., 1967.

THE LODGEPOLE STUDY

This study explored the possibility of improving germination and survival by modifying the environment at the soil surface.

Observations indicate that certain soil surface treatments favor germination and survival. A powerline and pipeline right-of-way west of Chemult is covered, for the most part, by dense natural regeneration. This strip was highly scarified and probably compacted. The felled timber was piled and burned. The strip is 5 to 6 chains wide, runs north-south, and transects flats, depressions, slopes, and both north and south aspects. Scarification may have buried the seed so that moist soil favored germination. Surface temperatures may have been modified by soil surface treatments thus favoring both germination and survival. Or, perhaps the seed bed was prepared in one of those unusual years when natural conditions were favorable for both germination and survival. Bordering the powerline are a number of small clearcuts 3 to 10 acres in size, mostly on flat topography, and broadcast burned. These areas remained inadequately stocked 7 years after cutting. The soil is developing on parent material deposited by the glowing avalanche from ancient Mount Mazama and has a 2-inch A1 horizon above a 10-inch AC horizon over parent material several feet thick.

Methods

Three small unregenerated clearcuts made 6 years earlier in a lodgepole stand with a bitterbrush/needlegrass understory were chosen for the study. These clearcuts are located 2 miles north and one-half mile west of Chemult, Oregon.

Strips 144 feet long and 16 feet wide were staked out and given the following treatments: (1) control, (2) scarified, (3) rolled with a pneumatic roller, and (4) scarified and rolled with a pneumatic roller. Strips were laid out in groups of four, and the groups were replicated a total of four times.

Scarification of the clearcut was accomplished with brush blade mounted on a crawler tractor. The soil was disturbed to remove the grasses and forbs. Care was taken to remove as little soil as possible. Pneumatic rolling was an attempt to compact the surface soil, increase thermal conductivity and heat capacity, and thus reduce surface temperature variations. The strips were scarified or rolled or both in late October, and seed were sown on November 10, 1971. Seed source was the Davis Flat area about 9 miles east of the study area and 250 feet higher in elevation. Laboratory germination of the seed was 86 percent. There were 66,200 seeds per pound, and the sowing rate was 1½ pounds per acre (99,300 seeds per acre or 2.3 viable seed per square foot).

In addition to broadcast sowing the strips, we laid out an additional strip with each replication and spot seeded it. Spots 2 by 2 feet square were prepared with a McLeod tool and a rake. Five-tenths gram of lodgepole seed (73 seeds) were scattered on each spot. Spacing of the spots in each strip was approximately 5 by 8 feet center to center resulting in a sowing rate of 79,500 seeds per acre.

A rodent census taken in October showed that sufficient numbers of deer mice as well as chipmunks and golden-mantled ground squirrels were present to warrant baiting under guidelines then in use by the Forest Service. The area was baited once by hand with 1080-treated wheat on November 10. Bait, method of placement, and amount followed prescriptions then current in the 1968 USDA Forest Service Animal Damage Control Handbook, 2609.22 of Region 6.

After we sowed the seed, we divided each strip into four rectangles 16 feet wide and 36 feet long. Two of the four rectangles on each strip were randomly chosen to receive a light slash cover.[3/] Lodgepole saplings up to 10 feet in height were cut and laid on the soil. Branches of adjacent saplings touched each other but did not overlap.

The following spring 10 rectangular plots 1 by 3 feet in size were randomly located in each quarter of each broadcast-sown strip, and these initially located plots were checked once a week for seedlings. In the strips that were spot seeded, 10 seed spots in each quarter were randomly selected for observation.

Results

Of the 80 plots examined for each soil surface condition, the number of plots where seedlings had germinated by June 1 was:

	Open	*Slash covered*
Control	0	8
Rolled	0	20
Scarified	3	12
Scarified and rolled	11	43

[3/] The design of this experiment is a split plot with four treatments (seed-spotting was not analyzed in conjunction with the other four treatments because different amounts of seed were sown on an area basis) and four replications. Orthogonal degrees of freedom were also designed before installation to test the following hypotheses: (1) germination and survival is as good on the control as the average of the rest of the treatments, (2) rolling is as good as the average of scarifying and scarifying plus rolling, and (3) rolling a scarified area is no better than merely scarifying it.

The number of plots where seed germinated was significantly greater under slash cover, and tests of orthogonal individual degrees of freedom showed that the scarified and rolled treatment resulted in a significantly greater number of plots with seedlings than scarification alone.

Seedlings germinated on 46 seed spots beneath slash and on only 12 seed spots in the open, further indication of the beneficial influence of a light slash cover on germination.

The slash apparently keeps the surface soil from drying out as rapidly, thus prolonging the duration of the period when temperature and moisture are optimum for germination.

More seedlings were lost beneath the slash cover during the 3-week period after germination started because many more seedlings germinated beneath slash. However, when mortality is expressed as percent of germinants, slash resulted in a reduction in percent mortality for treatments where germination occurred both in the open and beneath slash (table 3). Percent germination of viable seed was

Table 3.--*Mortality of lodgepole seedlings for the Chemult study between the start of germination in the second week of May and June 1, 1972*[1/]

Treatment	Uncovered soil		Slash covered soil	
	Number of seedlings	Percent[2/]	Number of seedlings	Percent[2/]
Control	([3/])	([3/])	1	8.3
Rolled	([3/])	([3/])	22	56.4
Scarified	15	100	9	39.0
Scarified-rolled	14	66.7	72	28.4
Spot seeded	29	60.5	47	6.8

[1/] Each number of seedlings represents the total number lost from 80 3-square-foot plots or 80 seed spots.

[2/] Total number of germinants from 80 3-square-foot plots or 80 seed spots divided into the number of seedlings lost times 100.

[3/] No germinants.

greater beneath slash and the survival of seedlings through the summer appeared to be greater beneath slash (table 4) for all treatments except the control where no seedlings survived. The absence of survival in the uncovered portion of each treatment and the very low survival under slash in three of the five treatments prohibit establishment of a firm statistical conclusion that slash definitely increased survival in this study. On the other hand, not one seedling was found in the open on any treatment at the end of the summer.

Penetrometer measurements showed that pneumatic rolling did not compact the surface soil as was planned because on the day of treatment the soil was too dry and was covered with about 2 inches of powder snow. Rolling did smooth the surface after scarification. Smoothing the surface probably reduced evaporation and prevented the soil from drying as rapidly as the scarified treatment.

Average maximum temperatures per week at the soil-air interface, determined by weekly examination of thermotubes and tempil pellets[4/] placed on the control strips on all four replications, were over 145° F. for the open areas and over 132° F. for the slash covered areas during the May 15 to September 5 period. Maximum temperatures during this time were over 160° F. in the open and 140° F. under the slash.

4/ Use of brand names does not imply endorsement by the U.S. Department of Agriculture.

Table 4.--*Total germination and survival of viable lodgepole pine seed on October 1, by treatment and by soil surface condition*

Treatment	Open soil[1/]		Slash covered soil			
	Germinants	Germination of viable seed	Germinants	Germination of viable seed	Trees surviving (per acre basis)	
	Number	*Percent*	*Number*	*Percent*	*Percent*	*Number*
Control[2/]	0	0	12	2.2	0	0
Rolled[2/]	0	0	32	5.8	12.5	726
Scarified[2/]	15	2.6	23	4.2	8.7	363
Scarified-rolled[2/]	22	4.0	253	46.0	1.6	726
Spot seeded[3/]	48	1.0	691	13.8	2.9	272

1/ No trees survived.

2/ Each number represents a total of 80 3-square-foot plots containing the sum of 552 viable seeds.

3/ Each number represents a total for 80 spots containing the sum of 5,022 viable seeds.

Slash cover also offers some protection from drought. Depth to visible wetting fronts are greater in the open than under slash as shown by the following results from the Chemult study:

	Depth to visible wetting front (inches)	
Date	*Open soil*	*Slash covered soil*
May 30	1.5	0.8
June 5	1.4	.5
June 26	1.6	.7
July 5	2.4	1.2
July 10	3.0	1.9
July 17	3.5	2.5
July 31	2.9	1.8
August 7	2.9	1.9
August 14	3.7	2.3
August 28	2.5	1.9

Each point represents an average of one measurement taken on each of the four replications on the control strip.

The vast majority of seedling losses in the Chemult study were attributed to drought or heat or both. The lowest temperature after the start of germination in a weather shelter 4.5 feet above the surface was 18° F. on May 24. Insufficient numbers of seedlings survived for examination of mortality during fall frost heaving. In the summer 1971 when conditions were favorable for germination and survival in the study using the screened seed beds, subsequent frost heaving destroyed the seedlings. In the spring and summer 1972, conditions were poor for germination and survival in both studies.

DISCUSSION

A sequence of events is necessary for establishment of lodgepole seedlings in south-central Oregon. Adequate seed must be produced and distributed over the area, and germination must be favored by warm, moist surface soils; after germination, soil and weather conditions must minimize frost heaving, soil-air interface temperature variation must be moderate, seedlings must survive summer drought, and soil and weather conditions must limit severe frost heaving in the fall and following spring.

Other factors such as small mammal and bird damage, vegetation competition, insect and disease attacks, and hail impact at times further complicate the sequence. I will discuss each item and where possible suggest ways to modify the environment to increase probability of seedling establishment.

Seed production.--In the uncut stand, Dahms (1963) found the fall of sound seeds to range from 14,000 to over 500,000 per acre per year over a 4-year period. For 2 of those years, seed fall was 178,200 and 230,400 sound seed per acre. For the 1960-62 period of Dahms' study, "number of seeds decreased from 272,300 per acre within the timber to 17,200 seed at 66 feet from the timbered edge, to 2,450 seeds at 198 feet, and to only 540 seeds per acre at a distance of 462 feet." Pine squirrels (*Tamiasciurus* spp.) harvest large quantities of lodgepole cones but the seriousness of this has yet to be investigated. Lodgepole cones in south-central Oregon are not serotinous, and the bulk of the seed is shed by November 1 and, in some cases, by early October (Dahms 1963).

After seed fall, rodents such as deer mice (*Peromyscus* spp.), golden-mantled ground squirrels (*Citellus lateralis*), and chipmunks (*Eutamias* spp.), as well as birds and fungi, destroy some of the seed. No studies have been conducted to determine the importance of seed depredation. Some of the lodgepole seed are cached by rodents and later germinate.

Seed germination.--As the study using the screened seed beds shows, the presence of viable seed in the field does not guarantee germination. In the spring of 1970 and 1972 when germination was very low, minimum night temperatures averaged 27.2° and 24.5° F. for the May 3 to May 19 period. In 1971 when lodgepole seed germination was considerably greater, the average night minimum temperature was 31.5° F. for the May 3 to May 19 period. Average daytime highs for this period were 64° (1970), 61.7° (1971), and 62.3° F. (1972). The soil surface of the ponderosa and lodgepole areas was also wetter during this period in 1971 than in 1970 or 1972. It is possible that low temperatures in the spring, combined with dry surface soils once temperatures become warmer, inhibit germination. Fraser (1968) stated that "natural, simultaneous occurrence of optimum moisture and temperature for germination of a given species is less frequent and of shorter duration than we might suppose."

In some preliminary experiments to determine the effects of temperature and soil water on germination of lodgepole and ponderosa pine seed, 20 seeds of each species were planted in each of 22 soil moisture cells (Cochran 1972) containing A1 horizon material where water contents could be maintained at optimum for germination. Further, 100 seeds of each species were planted in A1 horizon soil material in plastic trays 12 by 8 inches wide and 6 inches deep.

Six of the cells and three trays were placed in each of three growth chambers. In each of the growth chambers one tray was watered 5 days a week, the second tray was watered 3 days a week, and the third tray was watered every 3 days. Photoperiod in each growth chamber was 15 hours, but the day-night temperatures were 70°-34°,

60^{o}-34^{o}, and 50^{o}-34^{o} F., respectively. No germination had occurred after 59 days in the 50^{o}-34^{o} F. chamber. In the 60^{o}-34^{o} F. chamber, a total of 15 lodgepole and two ponderosa seeds had germinated in the cells where moisture content was optimum. No germination occurred in the trays. In the 70^{o}-34^{o} F. chamber no germination took place in the driest tray. In the tray watered 5 days a week, 13 ponderosa and 53 lodgepole seed germinated, and in the tray watered 3 days a week nine ponderosa and 29 lodgepole germinated. A total of 61 ponderosa and 90 lodgepole seeds germinated in the six cells.

In the greenhouse during the same period where day-night temperatures averaged 75^{o}-55^{o} F., germination of 20 seeds per species in four cells was 80 percent for ponderosa pine and 55 percent for lodgepole pine. The results in the growth chambers were not subjected to statistical analysis because of probable additional variables besides temperature regime. However, these preliminary observations support the hypothesis that both temperature and moisture are important factors controlling seed germination in the field.

The low germination in the pumice desert in 1971 is attributed to the fact that this area became bare of snow earlier in the spring and had dried out at the surface much more than the other two areas when temperatures warmed to permit germination.

Low night temperatures during germination.--Although some mortality due to low temperatures at night was observed in the screened seed beds, the small numbers of seedlings involved do not permit evaluation of the relative importance of this factor. In growth chamber experiments, Cochran and Berntsen[5/] found lodgepole mortality occurred when temperatures at night dropped below 20^{o} F. at the plant level but mortality was not complete until temperatures dropped to 11^{o} F.

Frost heaving.--Frost heaving, as observed in the first study reported here, has been widely and consistently observed as a cause of seedling mortality in the pumice soil region.

Frost heaving is most pronounced when the soil is wet to the surface, is initially free of frost, and when air temperatures drop below freezing at night after being above freezing during the day. At night when water freezes in a thin layer of surface soil, additional water moves upward in the profile in response to the water potential gradient created by freezing. This water then freezes and forms ice crystals. The upper ends of these ice crystals are attached to the frozen soil layer and lower ends are in contact with water in the

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5/ P. H. Cochran and Carl M. Berntsen. Tolerance of lodgepole and ponderosa pine seedlings to low night temperatures. For. Sci. (In press.)

unfrozen soil. As water freezes these ice crystals of segregated water elongate forcing the frozen soil layer next to the surface upward. Plants with bases solidly encased in the frozen layer are displaced upward; and when the surface layer thaws and the ice columns melt, these plants are left on the surface with a portion of the root system exposed or destroyed (Schramm 1958, Portz 1967).

Enough precipitation usually occurs in October and November to moisten the soil surface, and the pumice soils are always very wet throughout the profile after snowmelt in the spring. The wet soils in combination with the same factors which cause high frequency of radiation frosts (high altitude, relatively dry airmass, clear nights, and the thermal properties of pumice soils) also cause severe frost heaving.

High soil surface temperatures and drought.--Surface temperatures in the open on control strips in the study near Chemult exceeded 160° F., and no seedlings survived. It is difficult to separate the influence of high soil surface temperature and drought in the field because both factors are influenced by the same weather conditions. High insolation increases evaporation rates, increases the internal water stresses in the plant, and dries the soil. Dry surface soils have lower thermal conductivities and volumetric heat capacities than similar wet soils; consequently, surface temperature variation becomes more extreme. The thermal properties of pumice soils cause wide surface temperature variations even when the soil is wet; and as a result, seedlings on these soils are subjected to both lower and higher temperatures than if grown on a more dense mineral soil under the same meteorological conditions (Cochran 1969b).

Other factors.--Hail, ants, and small mammals cause small amounts of lodgepole seedling mortality. Other insects and disease probably contribute to mortality also. The relative importance of these factors has not been determined. Vegetation competition for soil moisture, particularly from sedges and fescue, increases the probability of losses to drought.

Probability for seedling establishment.--To further consider the sequence of events necessary for natural establishment of lodgepole pine, a preliminary model is proposed. The model could predict probability of natural establishment of lodgepole pine after fire or cutting in the pumice soil region in similar plant communities and at the same elevations as the two field studies.

Suppose seed is available 3 out of every 4 years, conditions favorable for germination exist 1 of every 2 years, low temperatures cause mortality only once every 10 years, seedlings can survive the summer drought and high surface temperatures once every 2 years, and that frost heaving causes significant mortality 1 of every 2 years.

Assuming each of the above factors operates independently and that all other factors such as seed and seedling depredation and vegetative competition are not limiting, the probability of seedling establishment for any given year is 3/4 x 1/2 x 9/10 x 1/2 x 1/2 = 27/320 or approximately once every 12 years. Stated in another way, there is only 25-percent probability of establishing lodgepole pine from seed under these hypothetical conditions in any given 3-year period without consideration of other factors which further decrease probability of establishment. Actually, the probability may be much lower than 25 percent, and this model needs testing with data collected over a long time period from each important plant community at several elevations. Also, the model may need modification because all the factors may not be independent, the occurrence of seed crops may not have the same probability each year, and other factors may need to be incorporated.

The actual conditions influencing establishment vary with elevation and with plant communities. At higher elevations, snow remains on the ground longer and the soil surface remains moist longer during the growing season. Germination is later and seedlings are subjected to shorter periods where low temperatures and frost heaving can cause mortality.

Volland[6/] has done an excellent job describing some of the plant communities in the pumice soil region having lodgepole as a component and presenting problems associated with their management. These plant communities such as lodgepole/needlegrass or lodgepole/bitterbrush/needlegrass are easily recognized and often are indicative of areas where temperature extremes and frost heaving will be problems. Some of these communities--lodgepole/needlegrass or lodgepole/bitterbrush/needlegrass--can be extremely difficult to regenerate and perhaps should be considered as noncommercial when found in frost pockets.

Improving chances for seedling establishment.--Proper planting of site-adapted lodgepole stock capable of growing well would circumvent many of the factors that cause seed and seedling mortality including frost heaving. Schramm (1958) found that planted conifers were not very susceptible to frost heaving because wind blowing against the foliage displaced soil from the base of the stems and the stems did not become solidly encased in a frozen surface layer. Frost heaving has not been serious in plantations in the pumice soil region. Unfortunately, good planting stock has not always been available, and there are questions about the proper size of planting stock. If planting is not possible, the land manager should be concerned about modifying surface temperature extremes, preventing the soil surface from drying during the germination period, and modifying conditions which promote drought and severe frost heaving to encourage natural reproduction.

6/ L. A. Volland. USDA Forest Service R6-2210-71. 1971.

At present, only one management practice capable of causing these modifications seems feasible--leaving a light slash cover over the soil surface after logging. A light slash cover is defined as sufficient material lying on the surface so a well-stocked stand would result if only seedlings which germinated beneath this slash survived. Harvest cuts should be either narrow strips less than two tree heights wide if clearcut (Cochran 1969a) or a shelterwood leaving standing trees with good crowns at a spacing not to exceed one-half tree height.

For the latitude 42°30' on June 21 the percent of the area shaded sometime between 1100 and 1500 hours is only about 22.8 percent for a spacing equivalent to one tree height, 25 percent for a spacing equivalent to 0.75 tree height, and 55 percent for a spacing equivalent to one-half tree height. Further, spacing must not exceed one tree height to provide any protection from radiative cooling at night (Moen 1968). However, leave trees will not always offer adequate protection from frost heaving. Heaving takes place at temperatures just below freezing, and no amount of overstory cover will prevent occurrence of these temperatures near the soil surface in the pumice soil region on many nights in the fall and spring.

Beneficial effects of slash.--Slash modifies temperature extremes at the soil surface, prevents the surface from drying rapidly, and offers some protection from frost heaving. A consideration of the energy balance at the earth's surface is helpful in understanding how slash is beneficial to seedling establishment.

The net radiation flux density, Rn (cal./cm.^{2}-min.), of the earth's surface is equal to the amount of short and longwave radiation striking the earth minus the amount of short and longwave radiation leaving the earth. Rn can be expressed by:

$$Rn = R_1 + S\ (1-a)$$

where R_1 is the net longwave radiation, S is the shortwave radiation and a is the albedo or reflectivity. The term $S\ (1-a)$ expresses the solar energy available for evapotranspiration, sensible heat (the heat that changes the air temperature), soil heat, vegetative storage, and photosynthesis.

The albedos of pumice soil surfaces are high (23 percent), but the albedo of the lodgepole forest is much lower (9 percent).[7/] Adding a light slash cover to a bare pumice soil decreases the albedo and increases the $S\ (1-a)$ term. Some of the extra energy available near the surface is used in heating the slash. The slash shades the surface during the day thereby lowering maximum temperature at the soil-air interface and reducing evaporation from the shaded surface. At night

7/ Harold Richard Holbo. The energy budget of pumice desert. (Unpublished Ph.D. thesis on file at Oreg. State Univ., Corvallis.) 136 p., 1972.

the covered soil surface exchanges longwave radiation with the slash as well as with the surrounding vegetation and the water vapor, carbon dioxide, and ozone in the atmosphere. Therefore, not as much radiation is lost to the sky from the covered soil, and the soil surface stays warmer beneath the slash at night than in the open.

The warmer soil surface beneath the slash protects the seedling from injury from low temperature and frost heaving. The protection from frost heaving has been noted in the field on several occasions and was very evident in the fall of 1969. In strip clearcuts above 5,200 feet on the Chemult District of the Winema National Forest, lodgepole seedlings were unusually abundant in the spring of 1968. Although considerable mortality occurred during the summer, apparently from drought, large numbers of seedlings were present in September. However, fall frost heaving was severe, and the vast majority of the seedlings present the following spring were beneath slash.

The longwave radiation exchange between the soil surface and the slash prevents the water in a thin layer of soil from freezing to form a solid ice-soil layer which is then pushed upward as ice crystals from beneath. Field observations indicate that ice crystals do form beneath the slash cover but they form right at the soil-air interface and then elongate upward into the air and seedlings are not heaved. When the weather becomes colder, the freezing layer penetrates deep into the soil and no frost heaving takes place in the open or beneath the slash.

It may be argued that the presence of slash increases danger from wildfire and that seedlings established with the aid of the slash protection stand a good chance of being destroyed by fire later. Timber management and fire control personnel must determine the amount of slash necessary for seedling establishment and the smount which would create an unacceptable fire hazard.

Slash cover does not guarantee seedling establishment. The number of seedlings present under slash in the Chemult study (table 4) may be inadequate if subsequent mortality is high. Further, the amount of cover from slash sharply decreases because of needle loss after 2 to 3 years while competing vegetation increases, so probability of seedling establishment from seed fall during years following treatment is reduced. When a shelterwood is left on the area, natural regeneration will probably be obtained; however, foresters will have to accept a regeneration period of longer than 5 years.

CONCLUSIONS

Natural regeneration of lodgepole pine in some areas within the pumice soil region may take decades because at least five factors have to operate in sequence to allow seedling establishment. Planting good site-adapted lodgepole stock would circumvent many of the factors, including frost heaving, that hinder establishment from seed. At present, there are problems in obtaining this stock associated with seed collection and nursery mortality. Also, there is a question about the best age to outplant. The problems are being worked out, and foresters can expect more lodgepole planting stock to be available in the future.

For the present, one possible way to improve the probability of obtaining natural regeneration in a reasonable length of time is to leave a light slash cover on the soil surface even when a shelterwood or narrow strip cut is applied. However, this practice does not guarantee seedling establishment, and the slash cover will be of little help if good seed years are more than 3 years apart. Where thorough slash disposal is performed or when regeneration is not obtained soon after cutting even where some slash is left untreated, foresters will have to accept a regeneration period longer than 5 years.

An additional option open to the land manager is to declare certain lodgepole stands noncommercial. These stands would be those associated with understory vegetation which indicates that temperature extremes, frost heaving, or vegetative competition would limit natural regeneration.

ACKNOWLEDGMENT

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GPO 989-184

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USDA FOREST SERVICE RESEARCH NOTE

PNW-205 August 1973

A FREEZING TECHNIQUE FOR SAMPLING STREAMBED GRAVEL

by

William J. Walkotten, *Forestry Research Technician*

ABSTRACT

This stream sediment sampling method removes a nearly undisturbed, stratified sample containing stream gravel, intergravel water, and organic material and allows sampling in rocky streambeds. The equipment is inexpensive, easy to assemble, and portable.

KEYWORDS: Sampling (-streams), sedimentation, streams.

INTRODUCTION

The need to sample gravel and sediment in rocky, salmon-producing streams of southeast Alaska led to the development of a freezing technique. It provides a nearly undisturbed, stratified sample containing stream gravel, intergravel water, and organic material; it should provide valuable information on gravel resedimentation after cleaning. In addition, the technique can be used to remove samples from some of the less compact soil types. The equipment is portable enough for sampling streams in remote areas. The technique makes it possible to determine percentages of various material sizes by position within the frozen sample, since even the finest sediments are locked into it. Further modifications may facilitate collecting aquatic bottom fauna for productivity studies.

DESCRIPTION

Rapid heat transfer is needed to freeze a gravel sample in a stream channel. My method uses liquid carbon dioxide fed into a copper tube inserted into the gravel. The liquid CO_2 vaporizes at atmospheric pressure and absorbs heat from the streambed, freezing the intergravel water. Once frozen, the sample is not easily damaged by removal from the sampling site. The technique provides a sample varying in size with the type of streambed material at the sampling location. Sample size averages about 500 grams of sediment (dry weight). Sampling depth varies with streambed texture but can reach 4 feet into fine gravel when the copper probe is placed by hand.

The equipment needed for gravel freezing is inexpensive and easy to obtain and assemble (fig. 1). The sampling probe is assembled from 1/2- or 3/4-inch hard-drawn copper pipe and fittings. A four-way-cross pipe is soldered to about 3 feet of pipe, and short 6- to 8-inch lengths of pipe are soldered into the three remaining openings on the four-way cross. This provides a strong handle needed to remove the frozen sample and a place to tie down the CO_2 delivery tube. A point, machined from brass, is soldered to the other end of the sampling probe; this must be a watertight joint. The 3/8-inch soft-drawn copper tube is cut to reach to the bottom of the probe; a flare tube fitting on the upper end is connected to the wire-reinforced CO_2 delivery hose with brass fittings.

The most convenient liquid CO_2 supply is an ordinary CO_2 fire extinguisher. The fire extinguisher bottle has an internal tube reaching to the bottom to provide liquid CO_2 in the upright position and also has a convenient valve and handle. A reasonable choice is the 15- to 25-pound size for portability, ease of handling, and adequate supply. Pipe fittings replace the fire horn on the bottle so the wire-reinforced supply hose can be attached. An additional valve is needed in the line to regulate the flow of CO_2 to the probe. Standard

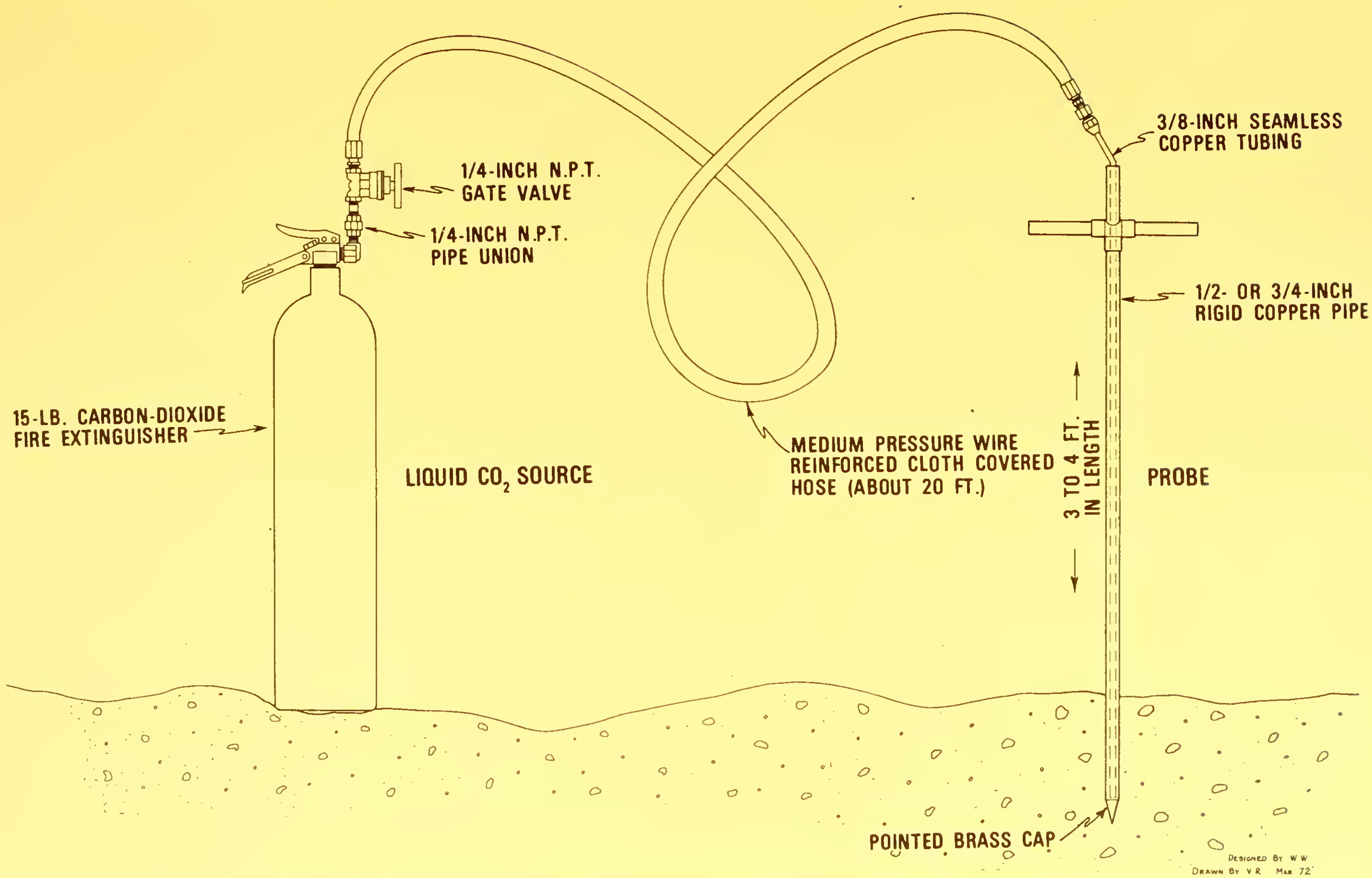

Figure 1.--*Equipment for freeze-sampling streambed gravel.*

gas cylinders can be used; but they must be inverted to supply liquid CO_2, are heavy and difficult to handle, but have the advantage of providing a large gas supply.

OPERATION

This freeze-sampling technique allows great freedom in selecting sample locations (fig. 2). Any streambed location can be sampled, provided the probe can be pushed into it. Neither water movement nor depth seems to affect sample freezing. After site selection, (1) the probe is pushed into the streambed, (2) the 3/8-inch copper tube is inserted full depth into the probe, and (3) the tube is fastened to the probe handles. The CO_2 is turned on at a rate that blows carbon dioxide "snow" out the top of the probe. The best flow rate is about 1 pound per minute, but this is impractical to measure in the field so the proper rate is determined by watching the escape of gas from the probe. A little practice soon shows the most efficient use of the CO_2. If no "snow" or dry ice is blowing from the probe, use a faster flow rate; an excessive flow is spectacular, but wasteful. There is usually some momentary plugging of the 3/8-inch copper delivery tube during the freezing process when dry ice forms in the bottom of the probe. The plug clears in a few seconds with the release of CO_2 pressure in the hose. Back pressure can cause the delivery tube to jet out of the probe if it is not tied down.

Insulating properties of ice limit the size of sample that can be obtained. A maximum-size sample is frozen in 2 to 3 minutes and is solid enough to allow removal of the delivery tube and preparation of sample container before extracting the frozen plug from the streambed (fig. 3). The probe, with the adhering frozen sample, is then pulled from the streambed and is ready for examination.

Figure 2.--*Freeze-sampling a small salmon stream.*

Figure 3.--*Examples of frozen gravel "plug" as removed from streambed. Arrow points to a live salmon egg.*

When sampling conditions are good and two probes are available, a sample can be taken every 5 minutes. About 2-1/2 to 3 pounds of CO_2 are used to obtain each sample. While sample weights vary greatly, primarily due to the particle size of gravel removed and probe depth, the average contains about 500 grams (dry weight) and 150 cc. of water.

The "plug" of frozen gravel provides a vertical section of the streambed to the full depth of sampling. It is certain that samples contain disproportionate amounts of larger gravel sizes, but for purposes of examining streambed deposition and sediment distribution this technique removes a nearly undisturbed sample. Intact frozen samples can be taken from the stream to the laboratory in cold weather.

Some caution is necessary when working with compressed CO_2. At atmospheric pressure, the released gas temperature is -108° F. (-78° C.), so dry, insulated gloves are needed for handling the valves, hoses, and probe. Tank pressure can exceed 800 p.s.i., so good tested hose and fittings are necessary in the event of plugging, and the delivery tube must be tied securely to the probe with a strong cord. CO_2 should not be used in a closed area,and safety glasses should be worn by the user.

Do not get water into the sampling probe or into the CO_2 delivery tube because ice will form rapidly and prevent escape of CO_2.

SAMPLE RESULTS

Both East Creek and West Creek, on the Young Bay Experimental Forest (northern Admiralty Island), were sampled above extreme high tide. These small, salmon-spawning streams are very rocky, fast-flowing, and carry high sediment loads during stormflow. Their rocky beds make standard gravel sampling extremely difficult.

By freezing the gravel, we pulled several random samples from each stream (table 1). The < 12.70-mm. screened fractions show a close percentage correlation between the two streams. The large difference in total sample weights between the two streams reflects the higher percentage of gravel in the >12.70-mm. size class in West Creek. It is interesting to note that the West Creek sample No. 8 also included 43 salmon eggs.

Table 1.--*Results of freeze-sampling two streams on the Young Bay Experimental Forest*

EAST CREEK

Sieve opening (mm.)	Sample number											$\bar{X}$	S.D.	S.E.
	1	2	3	4	5	6	7	8	9	10	11			
	Weight retained (grams)													
12.70	179.6	135.2	657.2	0	280.5	265.7	0	120.3	25.6	70.1	33.6			
1.68	183.6	89.6	66.9	14.0	85.6	167.1	118.7	122.5	132.9	40.4	152.6			
.84	34.5	18.9	8.2	5.7	19.9	31.1	35.9	20.6	27.0	12.9	60.9			
.50	23.8	8.2	4.7	5.6	11.0	15.2	16.7	6.1	18.7	9.2	21.2			
.21	10.7	2.3	1.9	4.2	3.7	2.7	6.4	1.1	6.2	3.6	7.3			
.10	2.9	.7	.5	1.7	1.1	.5	2.6	.3	1.4	1.0	3.0			
< .10	1.9	.6	.2	.6	.8	.4	2.6	.3	1.0	.9	2.4			
Total weight	437.0	255.5	739.5	31.8	402.6	482.7	182.9	271.2	212.2	138.1	281.0			
Total weight (< 12.70 mm.)	257.4	120.3	82.4	31.8	122.1	217.0	182.9	150.9	187.2	68.0	247.4	166.7		
	Percent passing													
12.70	71.3	74.5	81.2	44.0	70.1	77.0	65.0	81.2	71.0	59.4	61.7	68.8	10.90	3.29
1.68	13.4	15.7	10.0	17.9	16.3	14.3	19.6	13.7	14.4	19.0	24.6	16.3	3.90	1.18
.84	9.2	6.8	5.7	17.6	9.0	7.0	9.1	4.0	10.0	13.5	8.6	9.1	3.74	1.13
.50	4.2	1.9	2.3	13.2	3.0	1.2	3.5	.7	3.3	5.3	3.0	3.8	3.39	1.02
.21	1.1	.6	.6	5.3	.9	.2	1.4	.2	.7	1.5	1.2	1.2	1.41	.43
.10	.7	.5	.2	1.9	.7	.2	1.4	.2	.5	1.3	1.0	.8	.56	.17

Table 1.--*Results of freeze-sampling two streams on the Young Bay Experimental Forest*--Continued

WEST CREEK

Sieve opening (mm.)	Sample number									X̄	S.D.	S.E.
	1	2	3	4	5	6	7	8	9			
	Weight retained (grams)											
12.70	251.3	357.3	545.6	57.4	1,152.3	686.1	1,178.0	511.3	1,005.7			
1.68	79.5	115.6	198.5	153.2	219.4	276.2	240.2	162.6	174.9			
.84	26.8	42.6	42.5	33.0	46.3	70.6	64.0	39.4	35.1			
.50	16.9	34.2	23.4	18.8	24.0	20.9	34.2	23.2	17.2			
.21	5.4	14.4	10.1	8.5	11.0	6.7	14.5	6.8	7.1			
.10	1.4	4.5	4.3	3.7	5.1	2.6	6.6	1.9	3.3			
<.10	1.0	3.3	4.5	4.2	5.2	2.5	7.7	1.5	3.3			
Total weight	382.3	571.9	828.9	278.8	1,463.3	1,065.6	1,545.2	746.7	1,246.6			
Total weight (<12.70 mm.)	131.0	214.6	283.3	221.4	311.0	379.5	367.2	235.4	240.9	264.9		
	Percent passing											
12.70	60.7	53.9	70.1	69.2	70.5	72.8	65.4	69.1	72.6	67.1	6.22	2.07
1.68	20.5	19.9	15.0	14.9	14.9	18.6	17.4	16.7	14.6	16.9	2.29	.76
.84	12.9	15.9	8.3	8.5	7.7	5.5	9.3	9.9	7.1	9.5	3.17	1.05
.50	4.1	6.7	3.6	3.8	3.5	1.8	3.9	2.9	2.9	3.7	1.33	.44
.21	1.1	2.1	1.5	1.7	1.6	.7	1.8	.8	1.4	1.4	.46	.15
.10	.8	1.5	1.6	1.9	1.7	.7	2.1	.6	1.4	1.4	.54	.18

GPO 988-979

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· · USDA FOREST SERVICE RESEARCH NOTE

PNW-206 *October 1973*

RESPONSE OF INDIVIDUAL PONDEROSA PINE TREES TO FERTILIZATION

by

P. H. Cochran, *Soil Scientist*

ABSTRACT

Circular 1/10-acre areas in thinned stands were fertilized with nitrogen in northeastern Oregon and with nitrogen, phosphorus, sulfur, and boron in three central Oregon locations. Diameter and basal area growth of test trees at the center of these treated areas were substantially increased by fertilization. Height growth was also increased by fertilization except where top damage apparently confounded results. Fertilization significantly increased volume growth except in the central Oregon area with the lowest effective moisture, and even here the response was rather large. These results for individual trees indicate the necessity of further study to determine the kinds and amounts of elements necessary to produce maximum response on an area basis and the duration of these responses.

Keywords: Fertilizers, ponderosa pine, tree increment measure.

INTRODUCTION

Diameter and height growth of sapling ponderosa pines can be accelerated on certain sites by thinning some trees and removing understory vegetation (Barrett 1970). The increased growth caused by these cultural treatments is probably a result of increased water and nutrients available to the remaining trees. Therefore, we can speculate that fertilization might increase production of usable wood in ponderosa pine stands.

There is little information about fertilization of ponderosa pine stands. Mosher (1960) conducted an irrigation and fertilization experiment in a 90-year-old ponderosa stand in eastern Washington. Fertilizer was ammonium nitrate (33.3 percent N) applied at the rate of 66.6 lbs N/acre. Some plots were not irrigated, some were irrigated once, and others twice during the growing season. Apparently, the amount of water supplied per irrigation was 7 area inches. Mosher found the following increases in diameter growth over controls for a 2-year period:

	Percent
Fertilized only	29
Irrigated only	76
Irrigated once and fertilized	127
Irrigated twice	139
Irrigated twice and fertilized	94

Wagle and Beasley (1968) fertilized thinned ponderosa pine in Arizona with 75 lbs N/acre (NH_4NO_3), 150 lbs of P_2O_5/acre ($CaH_4(PO_4)_2$), 5 lbs/acre Fe, 2.5 lbs/acre Zn, 2.5 lbs/acre Mn, 1.25 lbs/acre Cu, and 2.5 lbs/acre Bo. Fe, Zn, Mn, and Cu were applied together in a chelated form. At the end of 2 years, added nutrients appeared to inhibit height growth and stimulate radial growth.

Youngberg (1968) applied nitrogen at the rate of 200 lbs/acre to plots in a dense ponderosa stand in central Oregon and to plots in an adjacent stand thinned to a 12- x 12-foot spacing. Five years after treatment, increases in basal area per acre were:[1]

	Percent
Unfertilized unthinned	19
Fertilized unthinned	25
Unfertilized thinned	35
Fertilized thinned	50

Agee and Biswell (1970) applied a total of 4,450 lbs/acre ammonium sulfate (934 lbs N/acre) in nine equal applications over a 3-year period to thinned and unthinned ponderosa pine stands in northern California. For the 12-year period following initial fertilization, increases in basal area growth per acre were:

	Percent
Unfertilized unthinned	8.2
Fertilized unthinned	45.9
Unfertilized thinned	82.8
Fertilized thinned	134.1

Barrett and Youngberg (1970) reported that 11.4 ounces of magnesium ammonium phosphate fertilizer placed in the planting hole increased leader growth of ponderosa pine in central Oregon. However, the increase in leader growth over the controls (10 inches in 7 years) was not large.

Personnel at Weyerhaeuser's Klamath Falls tree farm recently

[1] Data in the text were obtained by personal communication with Dr. Youngberg, Oregon State University, Corvallis.

began fertilizing thinned ponderosa pine with 200 lbs N/acre (urea). This decision was based on success the company has had with fertilization in the Douglas-fir and southern pine regions and with trials on the Klamath Falls tree farm.[2]

The purpose of my studies reported here was to determine the response of height and diameter growth to fertilization for small saw-log and pole-sized ponderosa pine in thinned stands. The first study was conducted in the Sumpter Valley in northeastern Oregon, and the second study was conducted in three central Oregon locations.

THE SUMPTER VALLEY STUDY

Location and site description.--The first study was located on a terrace just above the floor of the Sumpter Valley in the SW 1/4 of sec. 10, R. 37 E., T. 10 S., 17 airline miles west-southwest of Baker, Oregon, at an elevation of 4,200 feet. The loam soil on the terrace has A1 and A3 horizons each 7 inches thick over a B horizon that extends to a 40-inch depth. From 40 to 50 inches, the soil is gravelly clay loam; and at 50 inches, unconsolidated rock is present. A partial physical and chemical analysis of the soil is given in table 1. Understory vegetation is predominately pinegrass with small amounts of bitterbrush. The stand was 64 years old at the time of thinning in 1967. Trees selected for study within the stand averaged 51 feet in height and 10.0 inches in diameter.

Methods.--This study was installed before thinning in November 1967 during a time when foresters were concerned about influence of slash decomposition on availability of soil nitrogen. Eight groups of three dominant or codominant trees were selected within the quarter section. The terrace sloped slightly to the north and east, and there was an abandoned irrigation canal running through the area. Tree groups were chosen so that each tree within the group was on the same slope and aspect and was the same distance from the canal.

Treatments equivalent to 0, 200, and 400 pounds of nitrogen per acre were randomly assigned to each tree within each group. Fertilizer (urea, 45-0-0) was applied to a circular 1/10-acre plot with the test tree at the center. Heights of each tree were measured with a transit from a permanently staked location, and breast heights were marked with aluminum nails and diameters measured. The entire stand was thinned to a 15- x 15-foot spacing by Ranger District personnel during the winter of 1967-68, and the slash was tomahawked[3] 2 years later. Height was remeasured after four growing seasons. In

[2]This information was obtained from a letter dated September 21, 1972, from B. Z. Agrons, Timberlands Manager, Weyerhaeuser Company, to Earl E. Nichols, Supervisor, Deschutes National Forest.

[3]Tomahawking is a method for reducing fire hazard in slash by mechanical crushing with an instrument called a "Tomahawk" mounted on the front of a crawler tractor (Dell and Ward 1969).

addition, increment borings were made on the north, east, south, and west sides of each tree; and measurements were made of the radial growth of each core for 4 years before thinning and 4 years after thinning. Height growth measurements were subjected to analysis of variance. Diameter growth determined from cores was subjected to analysis of covariance, with growth for 4 years previous to treatment as the covariant.

Basal area growth for the 4-year period was determined from the data obtained from the increment borings. Bark thickness was assumed to remain the same for the period. Percent basal area growth was also subjected to analysis of covariance, with initial basal area as the covariant.

Volume growth was also estimated for each tree for the study period. Volume at the start and end of the period above a 1-foot stump was estimated by using the equation

$$\text{Volume (ft}^3) = 0.53 + 0.0017163D^2H \qquad (1)$$

where D is the diameter outside bark at 4.5 feet and H is total height. D at the end of the period was determined by taking the diameter growth determined from increment borings and adding this growth to the starting diameter. Equation 1 was obtained from dendrometer measurements of 457 trees in another study located approximately 15 miles south of Bend, Oregon. The equation accounted for 96.8 percent of the variation in volume among these individual trees. These 457 trees encompassed the size range of the trees in the Sumpter Valley study, but to use the equation to determine the volume growth the following assumptions were made:

(1) Bark thickness and form for trees from these different areas are identical.
(2) Thinning and fertilization did not result in form changes.

Estimated percent volume growth was subjected to analysis of covariance with initial volume as the covariant.

Results.--Average height growth per year for the control and two levels of nitrogen application was:

Treatment	*Height growth*	*Range*
	- - - - - - *Feet* - - - - - - -	
Control	0.42	0.05-0.65
200 lbs/acre	.71	.42-1.0
400 lbs/acre	1.00	.35-2.2

Effect of treatment was significant at the 1-percent level.

Diameter, basal area, and volume growth per tree for 4 years after thinning were increased by fertilization (table 2). However, differences in these growth rates between the 200- and 400-pound application rates were not significant.

THE CENTRAL OREGON STUDY

Locations.--Available soil water is one of the factors limiting growth of ponderosa pine over much of its natural range. Therefore three different areas with plant communities indicating differences in effective moisture (Dyrness and Youngberg 1966) were chosen for study in central Oregon.

The area thought to have the highest amount of annual precipitation is located along Road 1808 in the SE 1/4 of section 7, R. 9 E., T. 21 S., 27 airline miles southwest of Bend, Oregon. Elevation is 4,400 feet. The soil (Lapine series) is developed from Mazama pumice and has a sandy loam A1 horizon 2 inches thick, a sandy loam AC horizon extending to 14 inches, and a C1 horizon extending to 30 inches. There is approximately 50-percent mixing in the C horizon with material from the AC horizon and from the older buried loam soil beneath. Roots are concentrated in the A1 and AC horizons, although roots are found throughout the 30 inches of Mazama material. A partial physical and chemical analysis of the soils at all three locations is given in table 3. Topography is very gently rolling. Trees were thinned in the winter of 1962-63 when 62 years old to a 12- x 12-foot spacing. The soil surfaces are covered with heavy slash, and there is little understory vegetation. Apparently the present stand is a seral stage in the *Abies concolor/Ceanothus velutinus* habitat type. In nearby areas where understory occurs, snowbrush is the predominant shrub, and true firs occur where fire has been excluded for a sufficient length of time. Average diameter and height of the dominant and codominant trees selected for study in 1969 were 14.6 inches and 65.4 feet.

The area picked as intermediate in precipitation is within the Pringle Falls Experimental Forest (SW 1/4 section 25 and the NW 1/4 section 36, R. 9 E., T. 21 S.) on a gentle to moderate slope (less than 10 percent) on a north aspect at an elevation of approximately 4,400 feet. This location is about 4 airline miles southeast of the Road 1808 area. Pumice is about 30 inches deep here, and the appearance of the Lapine soil profile is almost identical to the profile in the Road 1808 area except that the lower boundary of the AC is 2 to 4 inches shallower. About 50-percent mixing occurs in the C horizon. The buried soil is a sandy loam. The stand was thinned to a 14- x 14-foot spacing in the winter of 1961-62 when 72 years old. Heavy slash is present in parts of the area with an understory consisting primarily of snowbrush but with some bitterbrush, manzanita, and needlegrass also present. The habitat type is *Pinus ponderosa/ Ceanothus velutinus-Purshia tridentata*. Average height and diameter of the individual dominant and codominants chosen for study in 1968 were 52.1 feet and 10.2 inches.

The study area with the lowest precipitation is located 6 miles south of Bend (W 1/2 of section 6, R. 12 E., T. 19 S.) on the Fort Rock Ranger District at an elevation of about 4,100 feet. The topography is gently rolling. The soil (Shanahan series) has a sandy loam A1 horizon 2 inches thick, a sandy loam AC horizon 8 inches thick, and a 20-inch C horizon consisting of Mazama pumice and ash which has apparently been reworked after initial deposition by wind and water. The buried soil is a loam containing a very high volume of basalt rock. Roots are concentrated in the A1 and AC horizons, although roots are found throughout the upper 30 inches.

Thinning took place in the winter of 1961-62. The stand age is variable, and trees are residuals left after railroad logging in the 1920's and subsequent natural reproduction. Some 2- to 10-acre openings exist in the area which have not restocked since logging. Tree spacing now ranges from a minimum of 10 x 10 feet upward. Slash concentrations are light, and the main components of the understory vegetation are bitterbrush, needlegrass, and fescue with occasional snowbrush and manzanita. The habitat type is *Pinus ponderosa/Purshia tridentata/Festuca idahoensis*. Average tree height and diameter for dominant and codominant trees chosen for treatment in this area were 47 feet and 12.2 inches.

Methods.--For the Road 1808 and Pringle Falls locations, 24 trees were selected at each location and placed into eight groups according to d.b.h. Then trees of each group were randomly chosen for a control and for one of two levels of fertilizer application.

In addition to nitrogen fertilizer, phosphorus, sulfur, and boron were also applied. Youngberg and Dyrness (1965) found that ponderosa pine seedlings responded to N, P, and S in greenhouse tests using soil developed from Mazama pumice. In addition, there was some indication that small boron additions might also increase growth (Dyrness 1960, p. 181). Estimation from the data of Youngberg and Dyrness (1965) indicated that reasonable balance would be equivalent to application rates of 200, 100, and 30 lbs/acre of elemental N, P. and S. Unpublished data for a field trial by Youngberg (see footnote 1) indicated that 1.88 and 3.75 pounds of elemental boron per acre would also be in balance with amounts of N, P, and S to be added. The three treatments were:

N0: control

N1: 200 lbs/acre N, 100 lbs/acre P, 30 lbs/acre S, 1.88 lbs/acre B

N2: 400 lbs/acre N, 200 lbs/acre P, 60 lbs/acre S, 3.75 lbs/acre B

Nitrogen was applied in the form of ammonium nitrate (34-0-0), P in the form of triple superphosphate (0-45-0), S in the form of gypsum ($CaSO_4 \cdot 2H_2O$), combined sulfur 16.74 percent), and B in the form of borax ($Na_2B_4O_7 \cdot 5H_2O$, boron equivalent 14.3 percent).

Fertilizers were applied by hand, using grass seeders to a 1/10-acre circular area (radius 37.2 feet) with the test tree at the center. Application dates were the last week in October for the Road 1808 area and the first week in November for the Pringle Falls area.

For the Fort Rock location 48 dominant and codominant trees were selected. These trees were listed according to decreasing diameter and then divided into eight groups of six. Additional trees were selected in the Fort Rock area so a shrub vegetation removal treatment for the 1/10-acre area could be superimposed on the fertilizer treatments used in the other two central Oregon areas. In the treatment where shrubs were removed, the grasses (fescue, western needlegrass, and bottlebrush squirreltail) were undisturbed. Each of the eight replications then contained six treatments:

Abbreviation	*Treatment*
NOS	control
NOSR	not fertilized; shrubs removed
N1S	fertilized with 200, 100, 30, and 1.88 lbs/acre of N, P, S, and B; shrubs not removed
N1SR	fertilized with 200, 100, 30, and 1.88 lbs/acre N, P, S, and B; shrubs removed
N2S	fertilized with 400, 200, 60, and 3.75 lbs/acre of N, P, S, and B; shrubs not removed
N2SR	fertilized with 400, 200, 60, and 3.75 lbs/acre N, P, S, and B; shrubs removed

Fertilizer was applied with hand-operated grass seeders in March on a snow cover.

After the fourth growing season following treatment, tree heights in all areas were measured with a transit. Pretreatment heights were found by counting back four whorls from the tip and measuring the angle of elevation with the transit. Height growth data were subjected to analysis of variance. Diameter, basal area, and volume growth were determined and analyzed as previously described for the Sumpter Valley study.

The equation used to determine volume growth (equation 1) was derived from trees growing between the Fort Rock and Pringle Falls locations. Thus an assumption that bark thickness and form are very similar for the trees in this study and those from which the equation was determined ought to be reasonable because of the close proximity of the stands. A second assumption that fertilization does not result in form changes may not be true and is being tested.

Both basal area growth and volume growth were subjected to analysis of covariance, with initial basal area and volume as the respective covariants for each of the three study areas.

Results.--Yearly height growth averages for the Road 1808 and Pringle Falls areas were:

Area	*Treatment*	*Height growth*	*Range*
		- - - - - *Feet* - - - - - -	
Road 1808	Control	1.1	0.6-1.4
	N1	1.6	.9-2.2
	N2	1.4	.9-2.0
Pringle Falls	Control	1.0	.8-1.3
	N1	1.4	1.0-1.9
	N2	1.4	1.1-1.9

Fertilization increased height growth for the Road 1808 area. Effect of treatment on height growth was almost but not quite significant at the 5-percent level for the Pringle Falls area. Lack of significance is attributed to erratic leader growth in some of the trees possibly caused by the insect *Eucosma sonomana*, the western pine shoot borer. For both areas, fertilization significantly increased diameter, basal area, and volume growth (table 4); and in the Pringle Falls area, the N2 level of fertilization caused a significant increase in diameter growth over the N1 level.

Height growth averages per year for the Fort Rock location were:

Treatment	*Height growth*	*Range*
	- - - - *Feet* - - - - -	
N0S	1.1	0.5-1.4
N0SR	1.3	.6-1.8
N1S	1.5	1.1-1.8
N1SR	1.4	1.1-1.9
N2S	1.3	.8-1.8
N2SR	1.4	.8-2.3

The increase in height growth from fertilization was almost significant at the 5-percent probability level when all the trees at the Fort Rock location were analyzed together. Separate analysis of the different shrub treatments showed that fertilization did not influence height growth where shrubs were removed but increased height growth where shrubs were not removed. Again top damage was frequent in this area and may have confounded results.

Fertilization caused a significant increase in diameter and basal area growth; however, there was no difference between the N1 and N2 levels of fertilization (table 4). Shrub removal did not influence diameter or basal area growth. Effect of fertilization on volume growth was almost but not quite significant at the 5-percent level for the Fort Rock area (F value was 3.9076 with 1 and 34 degrees of freedom but 4.13 is needed at the 5-percent level of probability).

DISCUSSION

Some individuals familiar with ponderosa pine forests feel that water is so limiting that nutrient additions could not be beneficial. These studies show that in some thinned stands, nutrient additions do substantially increase individual tree growth, at least for a period of 4 years. The questions of duration of response, production on an area basis, possibilities of tree form changes with fertilization, and kinds and amounts of fertilizers necessary for maximum volume production cannot be answered at this time. Results here indicate that these questions are worthy of study for ponderosa pine forests in this region; consequently fertilization studies are continuing.

Speculation on some of these questions is possible at present, however. First, ring width and internodal lengths of fertilized trees had not started to decrease at the close of the first 4-year period, indicating duration of response is greater than 4 years. Further, response of individual trees was so large that increases in stand growth will probably be substantial. Also, response on an area basis will probably be greater on the sites with the most available moisture. Increases in volume production per tree were least in the Fort Rock area (table 4), the driest of the three central Oregon study locations, and the volume per unit area is probably less on this site also. Volume per unit area was greatest on the Road 1808 area, the site with the highest available soil moisture. Even though percent increase in growth for individual trees was larger at the Pringle Falls location, actual volume increase per tree is greatest for Road 1808; and increase in volume production per acre in response to fertilizer would be greatest on this site also.

There is indication that additions of S and P in combination with N would produce greater response than N alone in the Sumpter Valley area. Geist (1971) studied the response of orchardgrass to N, P, and S fertilization on seven soils from the Blue Mountain area north of Sumpter Valley. He found a significant N-S interaction for all soils and, for two soils, a significant response to P was obtained in combination with N and S. In six of the seven soils, addition of N alone produced little if any response.

Partial soil analyses (tables 1 and 3) are not presented here to correlate nutrient status with response to fertilization but to provide information that can be used in combination with later studies to make these correlations.

Lack of response to removal of shrub vegetation in the Fort Rock location is interesting as Barrett (1970) found that removal of all understory vegetation increased growth of thinned pine in a study on the Pringle Falls Experimental Forest. However, shrub cover is estimated to be between only 15 and 20 percent in the study area. Much of the understory at the Fort Rock location is fescue. This plant has a large root system and is quite competitive

(Larson and Schubert 1969). Gordon (1962) in California found that understory vegetation adversely affected growth of ponderosa and Jeffrey pine poles. Further, he concluded that perennial grass had a greater effect than broad-leaved plants.

An important finding here is that even though the grass was quite competitive, fertilization still increased diameter growth in an area of low available soil water. Observations during the growing seasons at the Fort Rock location indicated that the deer utilized the fescue on the fertilized areas very heavily, and possibilities of increasing the animal-carrying capacity as well as tree growth rates deserve investigation.

SUMMARY AND CONCLUSIONS

Four years after fertilizing 1/10-acre areas around individual ponderosa pine test trees in thinned ponderosa pine stands in central and eastern Oregon, the following results were obtained:

(1) Diameter and basal area growth of individual trees were substantially increased by fertilization.

(2) Height growth of individual trees was increased by fertilization where results were not confounded by top damage.

(3) Volume growth of individual trees was significantly increased by fertilization in all but the Fort Rock location. Even at this location, increase in volume growth due to fertilization approached significance at the 5-percent level.

These results indicate that further study to determine the amounts and kinds of elements necessary to produce maximum response and the duration of these responses is necessary.

It should be emphasized that these responses to fertilization were in connection with thinning, a proven tool for producing more usable wood. Considerable work is necessary before the use of fertilizers in standard pine management practice can be evaluated. This work is underway.

Table 1.--*Some chemical and physical properties of the A1 and A3 horizons of the soil at the Sumpter Valley site. The chemical analyses were performed by the Oregon State University soil testing laboratory according to the methods currently in use (Roberts et al. 1971). Texture was determined by the hydrometer method. Samples for analysis were taken from a pit in the approximate center of the study area*

Horizon	Depth	P	B	Extractable cations				Total N	O.M.[1]	S	C.E.C.[2]	Sand	Silt	Clay
				Ca	Mg	Na	K							
	In	*Ppm*		*Meq/100 gm*			*Ppm*	*---Percent---*		*Ppm*	*Meq/100 gm*	*------Percent------*		
A1	0-7	34	0.65	7.3	1.3	0.16	738	0.081	2.68	1.8	15.8	41	45	13
A3	7-14	16	.70	6.6	1.9	.18	582	.045	1.43	2.1	23.5	45	36	19

1/ O.M. = organic matter.

2/ C.E.C. = cation exchange capacity.

Table 2.--*Average annual diameter, basal area, and volume growth during a 4-year period after treatment for individual test trees in the Sumpter Valley area*

Study area	Mean starting values			Treatment	Annual growth values calculated using adjusted means obtained from covariant analysis					Increase in volume growth over control
	Diameter[1]	Basal area	Volume		Diameter growth	Basal area growth		Volume growth		
	In	*Ft²*	*Ft³*		*In*	*Ft²*	*Percent*	*Ft³*	*---Percent----*	
Sumpter Valley	10.0	0.556	9.66	Control	0.14	0.016	(2.9)	0.41	(4.2)	--
				N1	.21	.026	(4.6)	.59	(6.1)	45.2
				N2	.23	031	(5.5)	.68	(7.0)	66.6

1/ This diameter is the actual mean diameter of the 24 test trees and is not the diameter derived from the average basal area.

Table 3.--*Some chemical and physical properties of the A1 and AC horizons of the soils from the three central Oregon study locations. The methods reported in the caption for table 1 were used for these analyses. Samples for the analyses were composites taken from at least 12 locations in the study area. Chemical analyses were performed at the Oregon State University soil testing laboratory (Roberts et al. 1971). Texture was determined by the hydrometer analysis*

Study locations	Horizon	Depth	P	B	Extractable cations				Total N	O.M.[1/]	S	C.E.C.[2/]	Sand	Silt	Clay
					Ca	Mg	Na	K							
		In	*Ppm*		*Meq/100 gm*			*Ppm*	*----Percent----*		*Ppm*	*Meq/100 gm*	*------Percent------*		
Fort Rock	A1	0-2	17	0.93	4.5	0.71	0.12	333	0.077	4.45	3.0	11.3	62	30	8
	AC	2-10	11	.49	4.2	.98	.18	333	.042	2.17	2.4	11.7	61	29	10
Pringle Falls	A1	0-2	28	.65	5.7	.71	.12	270	.119	8.85	1.8	14.95	64	19	17
	AC	2-12	18	.49	2.8	.60	.12	208	.028	2.86	1.0	9.9	63	28	9
Road 1808	A1	0-2	31	.58	1.9	.43	.10	156	.081	2.68	1.8	15.8	69	25	7
	AC	2-14	15	.46	2.3	.47	.12	156	.045	1.43	2.1	23.5	66	25	9

1/ O.M. = organic matter.

2/ C.E.C. = cation exchange capacity.

Table 4.--*Average annual diameter, basal area, and volume growth during a 4-year period after treatment for individual test trees in three central Oregon locations*

Study area	Mean starting values			Treatment	Annual growth values calculated using adjusted means obtained from covariant analysis					Percent increase in volume growth over control
	Diameter[1/]	Basal area	Volume		Diameter growth	Basal area growth		Volume growth		
	In	*Ft*^{2}	*Ft*^{3}		*In*	*Ft*^{2}	*Percent*	*Ft*^{3}	---*Percent*----	
Road 1808	14.6	1.258	31.43	Control	0.18	0.039	(3.1)	1.70	(5.4)	--
				N1	.27	.057	(4.5)	2.48	(7.9)	46.3
				N2	.30	.062	(4.9)	2.39	(7.6)	40.7
Pringle Falls	10.2	.591	11.02	Control	.23	.034	(5.8)	.88	(8.0)	--
				N1	.33	.042	(7.1)	1.12	(10.2)	27.5
				N2	.40	.046	(7.8)	1.30	(11.8)	47.5
Fort Rock	12.2	.836	13.25	Control (NOS)	.18	.029	(3.5)	.81	(6.1)	--
				NOSR	.19	.027	(3.2)	.83	(6.3)	3.3
				N1S	.24	.036	(4.3)	1.01	(7.6)	24.6
				N1SR	.24	.031	(3.7)	.87	(6.6)	8.2
				N2S	.25	.038	(4.6)	1.03	(7.8)	27.9
				N2SR	.25	.033	(3.9)	1.03	(7.8)	27.9

1/ This diameter is the actual mean diameter of the test trees in each location and is not the diameter derived from the average basal area.

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PERFORMANCE OF WIND-POLLINATION FAMILIES AND INTRA- AND INTER-STAND CROSSES ON CONTRASTING FOREST SOILS

by

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ABSTRACT

Eighteen Douglas-fir families were raised for 3 years in two forest soils of different productivity. Family effects were highly significant, but there was no family x soil interaction. Wind-pollination seeds weighed less and wind-pollination seedlings were shorter than cross-pollination seeds and seedlings.

Keywords: Pollen dissemination, Douglas-fir, seedlings, soils, plant genetics.

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INTRODUCTION

Plant hybridization has been used in crop breeding to increase productivity. However, a number of reports have indicated that the additional vigor associated with hybridization may frequently be environment dependent, that is, it is expressed to a different degree in different environments (Bucio Alanis 1966, Bucio Alanis and Hill 1966, Burton 1968, Harvey 1939, Langner 1951, Lewis 1955, McWilliam and Griffing 1965, and Pederson 1968). Many tests investigating this dependence have looked specifically at the temperature factor (Langridge 1962), where it was found that hybrid superiority tended to increase at higher than optimum growing temperatures. However, other factors of the environment such as plant nutrition (Harvey 1939) and site in general (Langner 1951) have also been shown to influence the expression of hybrid vigor. In total, these observations indicated that a general relationship might exist between the expression of hybrid vigor and environmental conditions such that hybrid superiority is greater in nonoptimal than in optimal growing conditions. The present limited test was established to investigate this by evaluating tolerance of three types of crosses to two soils of greatly different productivity. The three types of crosses are representative of what might be made within a local tree improvement unit.

The three types of progenies were "inter-stand" (male and female parents growing in a similar topographic location but separated by 10-15 miles), "intra-stand" (male and female parents separated by 1/2 to 1 mile), and open-pollination. The two soils were forest top soils brought in to a common nursery environment. Differences in the tolerances of the different progeny groups were evaluated by examining the progeny x soil interaction term in the analysis of variance.

The three types of progenies were originally produced in each of three locations. Progenies from two locations were too greatly reduced during cone handling and by insects for further analysis. This report describes the performance of the remaining set.

MATERIALS AND METHODS

The progenies consisted of the 18 crosses among six seed trees and three pollen mixes. The six seed trees were in a second-growth stand at 800- to 1,000-foot elevation in the western foothills of the Cascade Range.[1/] Pollen mixes were (1) a local mix from six trees growing 1/2 to 1 mile away from

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[1/] The author expresses his gratitude to the U. S. Plywood-Champion Papers, Inc., for permission to work in this area.

and at the same elevation as the seed trees ("intra-stand" crosses), (2) a pollen mix from six trees growing about 10 miles away from the seed trees and at 300- to 500-foot difference in elevation ("inter-stand" crosses), and (3) wind-carried pollen during a year of heavy pollen production.

Pollen trees in group 1 were second growth. Pollen trees in group 2 were both second growth and remnant old growth in land partially cleared for pasture. Both areas were on the rolling foothills which decline in elevation westward from the mountains. Douglas-fir was the dominant tree throughout the area.

Two forest soils of greatly different natural fertility and productivity (Lavender 1962, tables 3, 4, and appendix; this paper, table 3) were used for the test environments. The soils, called Burnt Woods and Black Rock Poor, were from the Oregon Coast Ranges 40-50 miles east of the seed trees. Both soils supported natural stands of Douglas-fir.

In the spring of 1965, newly germinated seeds were pricked-in at 3-inch spacing in two 24-inch-deep coldframes filled with Burnt Woods or Black Rock Poor topsoils. Cultural treatments consisted of summer watering and weeding. Plant heights were measured at the end of each growing season for 3 years. Date of bud burst was recorded at the beginning of the second year. Analyses of third-year height growth and total height and date of bud burst are reported here.

The experiment included the effects of different soils, seed trees, and pollen sources. Within each soil there were three randomized blocks with 10 seedlings per family per block. Soil was treated as a fixed effect, progenies fixed, female parents random, and pollen sources fixed. Pollen sources were fixed in the sense that they sampled pollen coming from selected distances from the seed trees. Because variances were approximately proportional to seedling size and annual height growth, measurements were transformed to natural logarithms before analyzing. Figures in the tables are retransformed from the natural logs.

RESULTS

Plants in Burnt Woods soil were three to four times as large as plants in the Black Rock Poor soil after 3 years (table 1), so the soil environments did provide the contrast of good versus poor growing conditions.

Seed parent (female effect) and pollen source (male effect) were significant for all traits (table 2). None of the interactions was significant. The

Table 1.--*Third-year leader length, 3-year tree heights and second-year dates of bud burst for plants growing on the two contrasting soils*

Trait	Productive soil	Nonproductive soil
Third-year leader length (cm)	40.1	11.4
3-year seedling height (cm)	59.3	17.4
Date of bud burst (days from Jan. 1)	96.2	98.8

Table 2.--*F-values for analyses of variance of third-year leader length, 3-year total height, and date of second-year bud burst*

Source of variation	F-values and significance levels		
	Third-year leader growth	3-year total height	Date of bud burst
Progenies	[1]3.38	[1]3.95	[1]5.63
Females	[1]8.41	[1]9.86	[2]3.40
Males	[1]8.00	[2]6.56	[1]62.63
Wind vs. controlled cross	[1]15.24	[1]27.00	[1]40.77
Intra- vs. inter-stand	.82	.56	[1]84.49
Females x males	.59	.48	.58
Soils x progenies	.57	.60	1.29
Soils x females	.69	.61	1.05
Soils x males	.54	.46	1.56
Soils x females x males	.55	.66	1.27

[1]Calculated F exceeds 1-percent tabular value.

[2]Calculated F exceeds 5-percent tabular value.

families, irrespective of pollen treatment, gave the same relative performance in both of the soils.

If we look only at the growth traits, it can be seen that the pollen-source effect was due to the difference between open-pollination progenies and progenies from controlled crosses. Table 3 shows the development of height-growth differences for the three growing seasons. The differences were quite consistent; cross-pollination families averaged 14 percent greater stem elongation the first year, 8 percent the second year, and 10 percent the third year.

DISCUSSION

Any evidence for differences among progenies in tolerance to the two soils would appear in the soils x progenies interactions. In this test, interaction terms did not even approach statistical significance (table 2). These results contrast with several of the reports cited previously. However, in those tests the crosses were generally between species, varieties, or inbred lines. Such hybrids in Douglas-fir might also show greater tolerance to environmental variability. In this test, the most distant parents were separated by about 15 miles and 500 feet in elevation, a spread that is within the range of our local tree improvement units. Under these conditions, there is no evidence that distance between parents affected the environmental tolerance of the progeny.

Table 3.--*Average leader length of wind- and cross-pollinated progenies during each of 3 years in productive and nonproductive soils*

Year	Productive soil		Nonproductive soil	
	Wind progenies	Cross progenies	Wind progenies	Cross progenies
	- - - - - - - - - - - - - *Cm* - - - - - - - - - - - - -			
First year (epicotyl length)	8.6	10.2	3.0	3.5
Second year	15.3	16.6	4.6	5.0
Third year	38.7	41.4	10.8	12.4

There was, however, a significant difference between progenies. Both male and female effects were highly significant. Of particular interest was the difference in vigor. The male effect was all due to the contrast between cross- and wind-pollination progenies. The yearly height increment of the wind-pollination progenies was consistently 8 to 12 percent less than that of the cross-pollination progenies (table 3). Height growth of inter- and intra-stand progenies did not differ.

The two most likely contributors to this growth difference were differences in coefficients of inbreeding and differences in seed weights. Previous data and calculations on the amount of selfing arising from wind pollination in natural stands have indicated an inbreeding coefficient of about 0.07 in wind-pollinated Douglas-fir progenies and an accompanying inbreeding depression in seedling height growth of about 1.5 to 2.0 percent (Sorensen 1973). The remainder of the growth reduction in height (about 6 to 10 percent, depending on year and soil) was presumably the result of seed weight differences. On the average, wind-pollination seeds were 20 percent lighter than cross-pollination seeds (1.11 and 1.39 grams per 100 filled seeds, respectively).

The exact cause of the seed weight difference is unknown. However, Rohmeder and Eisenhut (1959) have reported that many types of pollination bags create their own particular microenvironments, and it was assumed that some aspect of the bag environment caused the bagged seeds to be heavier. In our pollinations, we used the same isolation bags both to isolate from pollen and to protect from insects, so the cross-pollinated cones were exposed to the bag microenvironment for the entire season.

This effect has been observed in several additional tests and identifies a factor which must be kept in mind when making general comparisons between the growth of wind-pollination and cross-pollination seedlings. How long the effect will last is not known, but it lasted 3 years in this test and in absolute terms was greater at the end of the third year than at the end of the first.

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ALASKA OREGON WASHINGTON PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-208 November 1973

EFFECT OF MONTH OF GRAFTING ON DOUGLAS-FIR GRAFT COMPATIBILITY

by

Donald L. Copes, *Principal Plant Geneticist*

ABSTRACT

When the comparison unions were grafted on the same date, no irregularities in graft compatibility between unions with identical stock-scion combinations were detected, but inconsistent compatibility tests often occurred when the comparison unions were grafted in different months. Some stock-scion combinations were compatible when grafted early in the growing season, whereas the same combinations were incompatible when grafted later that same year. In orchards, it is important that compatibility test grafts and production grafts be grafted on the same date or a less than perfect correlation will exist between the compatibility of the same two unions. Within the same year, the month of grafting had little effect on the average *compatibility of each clone.*

Keywords: Grafting, Douglas-fir, *Pseudotsuga menziesii*.

INTRODUCTION

True graft compatibility is determined primarily by the inherent likeness of stock and scion. Since most incompatibility reactions are growth processes, they are subject to environmental modification. Argles (1937) realized this and stated that graft incompatibility was an inherent antagonism or discordant association somewhat subject to the influence of environment and treatment. Influence of treatment and environment on compatibility have been demonstrated in a number of studies where compatible stock-scion combinations became incompatible due to changes in climate (Ching 1938), bud mutation (Posnette and Cropley 1959), male flowers (Jiménez 1957), fruit formation (Gravel 1954), age (Herrero and Tabuenca 1969), soils (Carlson 1965), seasonal metabolism (Herrero 1951), and double-grafting (Herrero and Tabuenca 1962).

Incompatibility symptoms in Douglas-fir grafts (*Pseudotsuga menziesii* (Mirb.) Franco) (Copes 1970a) are similar to those reported for grafts of horticultural plants which were subject to modification by changes in treatment or environment. Temperature at the graft union had a direct influence on how long incompatible Douglas-fir grafts survived. Graft unions grown at 50° F. died at a younger age than did grafts with unions grown at 70° or 90° F. (Copes 1967b). In another study, compatibility of identical stock-scion combinations was altered by double-grafting (Copes 1971). In this case, incompatibility was induced at the union joining the scion and interstock. In addition, numerous inconsistencies in compatibility test results occurred in a Douglas-fir seed orchard where compatibility test grafts were not made until 3 to 10 years after the production grafts. Anatomical examination of some test graft unions indicated compatible stock-scion combinations, whereas the surviving production grafts of the same scion-stock combination had definite external symptoms of incompatibility (scion overgrowth and bark necrosis) (unpublished seed orchard data). It is thought that lack of correlation between test and production grafts resulted from age-induced changes in the biochemical or physiological constitution of the stock and scion.

The following study explored the hypothesis that the graft compatibility could be altered by grafting at different times during the growing season. Compatibility was determined for grafts which had been grafted on the same stocks during the first week of each month from April to September. The main variables influenced by this treatment were the physiological condition or stage of growth of the stocks at the time of grafting, and the length of the growing season following grafting.

METHODS

Field grafting of the main study was done near Corvallis, Oregon, in 1968 and 1969 with Douglas-fir clones 9, 16, 24, and 26 from the Soleduck block of the Dennie Ahl Seed Orchard near Shelton, Washington. One graft of each clone was cleft-grafted each month on lateral branch tips of 25 stocks.

Grafting was done during the first week of each month from April to September. One experienced grafter did all the grafting and used uniform grafting techniques throughout the study. Scion collection, storage conditions, and initial graft survival have been described in a previous report (Copes 1970b).

A different group of 25 stocks was used each year. Stocks grafted in 1968 were local trees that had naturally regenerated the area 9 to 12 years before with seed from adjacent 30-year-old trees. The stocks grafted in 1969 were all 12-year-old planted trees which came from four different western Oregon seed sources. All stocks were located within 300 meters of each other on nearly identical sites.

Grafts made in 1968 and 1969 were sacrificed for anatomical study in September 1970 and 1972, respectively. Sacrificed unions were fixed in 50 percent alcohol, microtomed into transverse sections, stained with safranin O and fast green and examined under a microscope for the presence of wound-xylem areas (Copes 1967a). Grafts were recorded as incompatible when they contained wound-xylem areas and compatible when free of wound-xylem areas.

In supporting grafting study, variation was checked between unions with identical stock-scion combinations when all unions on each stock were grafted on the same date. Fifty 10-year-cld stocks were each grafted on April 5 and 6, 1971, with five grafts of one scion clone. A different scion clone was used on each of the 50 stocks. The unions were sacrificed in September 1972 and prepared for anatomical study using the techniques previously described.

RESULTS AND DISCUSSION

In the supporting study, no inconsistency between unions with identical stock-scion combinations was found when all were grafted on the same day. All grafts of one clone on one stock were either compatible or incompatible. But inconsistency within identical stock-scion combinations of the primary study often occurred when unions were compared that had been grafted in different months. For example, scion clone 9 and stock No. 1 formed compatible unions when grafted together in April and May, but developed incompatible unions when grafted together in June, July, and August. This inconsistency was the primary cause of monthly within-clone variation (table 1). Some clonal variation was evident in this erratic behavior. Clones 9 and 16 exhibited more inconsistency than did clones 24 and 26. Clones 9 and 16 were inconsistent with 16 to 52 percent of the stocks, whereas only 4 to 8 percent of the stock-scion combinations with clones 24 and 26 showed similar behavior.

Inconsistency in compatibility tests is of great concern to seed orchard managers because it points out the necessity for production and test grafts to be grafted at the same date. If either graft fails to survive, no attempt should be made to regraft it later that same year. If it is felt necessary to utilize the one surviving graft,

Table 1.--*Compatibility of clones 9, 16, 24, and 26 when grafted on 25 stocks each month (April to September) in 1968 and 1969*

Month grafted	Scion clone number								Averages		
	9		16		24		26		1968	1969	1968 + 1969
	1968	1969	1968	1969	1968	1969	1968	1969			
	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	- - - - -	*Percent*[1/]	- - - - -	- - - - -	- - - - -	- - - - -
April 1	65	63	95	70	91	44	84	79	84	64	74
May	59	77	68	89	86	45	86	76	75	72	73
June	40		76	83	82	33	81	79	72	67	70
July							93		73		75
August									87	87	87
September									83		71
Percent compatibility	55	70	74	80	87	45	88	78	77	70	75

1/ Percent equals the $\frac{\text{number compatible grafts}}{n}$ x 100. Percentage values are not given where sample size was less than 10.

regrafting should be delayed until the following year and should only be done on the same date that the surviving graft was grafted the preceding year. Regrafting 2 to 10 years after the first graft is even more undesirable because an even greater chance of discord or inconsistency between compatibility of production and test grafts is likely to occur. The safest method to use is to rogue the surviving graft from the preceding year and make two new grafts.

The month of grafting appeared to have little influence on average compatibility. One exception to this statement might be August. August grafts averaged 87-percent compatibility (table 1), considerably higher than the study average of 75 percent. The August data may simply be small sample variation or may indicate that an actual increase in stock-scion compatibility occurred in August. If the former is true, no practical use of the increase in compatibility is foreseen because only 19 to 35 percent graft take is obtained by field grafting during this hot, dry month (Copes 1970b). No reasonable statistical test of these data can be made.

Comparison of 1968 and 1969 grafting results did not reveal a uniform trend for all four clones (table 1). Clones 24 and 26 had higher average compatibility in 1968, whereas clones 9 and 16 had higher average compatibility in 1969. Part of this clonal variation can be attributed to the use of different stocks each year. The 1968 stocks were from natural seeding which may have come primarily from one adjacent seed tree or from several closely related seed trees. Data from clone 24 in 1968 suggest that this hypothesis may be true. Clone 24 was highly incompatible when grafted in the Washington seed orchard on random, unrelated stocks. The 45-percent compatibility obtained in this study in 1969 on stocks grown from four different seed sources was similar to clone 24's orchard performance. But the 91-percent value obtained in 1968 is far higher than the expected value. This could have resulted from clone 24's having many compatibility factors in common with the 1968 stocks (Copes 1973).

The comparison between grafts made in the same month, but in different years, indicated a difference in average compatibility between April 1968 and 1969 grafts (84- vs. 64-percent compatibility) (table 1). This difference was not thought to have resulted from different stock populations having been used each year; between-year comparisons for the other months showed similar results in both years (table 1).

It appears that the physiological likeness of the stock and scion during the first several months following grafting may determine compatibility. Environmental or treatment changes which occur later have a much smaller effect on the compatibility status of adjacent stock and scion cells.

It is not possible to determine which environmental variables caused the observed inconsistencies. The stocks and scions passed through many different growth phases in the months following grafting.

For example, April grafts were made when the stock's vegetative buds were expanding. May grafts were made shortly after the stocks had burst their vegetative buds. June grafts were made when the stocks were actively elongating their vegetative shoots. July grafts were made as shoot elongation neared completion and as the transition from springwood to summerwood occurred. August and September grafts were made after shoot elongation was completed but while the cambium was still active. Correlated with these growth changes was first the lengthening and then the shortening of growing season as the year progressed. This had a direct effect on the amount of tissues which formed across the graft union before cambial activity ceased or slowed for the winter. Other environmental variables such as temperature, photoperiod, and rainfall also underwent seasonal changes during the study. Physiological changes also may have occurred in the scions while they were being held in cold storage before being grafted. What changes were induced in the stock and scion by these variables are not known, but it is evident that changes occurred which caused some compatible stock-scion combinations to become incompatible and some incompatible combinations to become compatible.

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

ALASKA OREGON WASHINGTON

· USDA FOREST SERVICE RESEARCH NOTE

PNW-209 November 1973

LATEST RESULTS FROM THE PRINGLE FALLS PONDEROSA PINE SPACING STUDY

by

James W. Barrett, *Silviculturist*

ABSTRACT

Logging old-growth ponderosa pine carefully, thinning the understory saplings, and controlling the brushy understory vegetation appear to have distinct growth advantages over clearcutting and planting. Possibly 10 years of stand growth may be saved by treating the brushy understory vegetation in the early part of the rotation. Additional years will be saved by using the existing understory trees instead of planting. Saplings thinned 8 years earlier to 125 trees per acre grew three times the cubic wood volume that was being produced by the old-growth overstory before harvest. Periodic increment of the sapling stand is rising rapidly and may soon produce five to six times that of the overstory.

Keywords: Thinning (trees), ponderosa pine, forest improvement cutting, stand density.

Precommercial thinning prescriptions in ponderosa pine stands following overstory removal offer foresters a remedy when the overstory is producing minimal wood and the understory saplings and small poles are too dense to produce a merchantable log in a reasonable length of time. Results from recent spacing studies[1/][2/] have led some managers to space trees farther apart.

Varying product and land use objectives have contributed to the diversity in tree densities imposed upon the stands in the Northwest. Densities of thinned stands range from 500 to 120 trees per acre. Sites range from heavily grazed pine grass (*Calamagrostis rubescens*) to plant communities having waist high manzanita (*Arctostaphylos parryana* var. *pinetorum*) and snowbrush (*Ceanothus velutinus*). Thinning, spacing, and slash treatment have had an influence on understory vegetation development; and this vegetation in turn has had a competitive effect on tree growth in certain plant communities.

Selection of an initial spacing for a particular stand dictates, to a large degree, the management regime for the rotation. Therefore, this selection must be made carefully with due consideration for products to be produced, the machinery to harvest them, and future markets. Ideally, a spacing should be selected that will promote reasonably free growth until the time when the desired merchantable product can be harvested. If too narrow a spacing is chosen, growth may slow to unacceptable levels before we have a merchantable product. If this happens, the manager is faced with the necessity of making another investment in thinning without a salable product and, in addition, he has lost forever the wood that could have accumulated on usable trees had a lesser density been chosen. In essence, the purpose of spacing studies is to determine that point in time and product size when growth begins to slow because of competition between trees at a particular spacing. Ultimately we want to know the spacing or level of stocking at different points in time that will give us maximum mean annual increment in volume for a given product or product mix.

Forest managers who wish to evaluate past thinning in sapling stands or those contemplating future thinning will find this paper useful. Twelve-year

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[1/] James W. Barrett. Ponderosa pine saplings respond to control of spacing and understory vegetation. USDA For. Serv. Res. Pap. PNW-106, 16 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg. 1970.

[2/] James W. Barrett. Response of ponderosa pine pole stands to thinning. USDA For. Serv. Res. Note PNW-77, 11 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg. 1968.

ERRATA SHEET

USDA Forest Service Research Note PNW-209, 22 p., illus. November 1973, LATEST RESULTS FROM THE PRINGLE FALLS PONDEROSA PINE SPACING STUDY, by James W. Barrett.

The unit of measure "Inches" in Table 3 on page 11 should be "Feet."

The unit of measure "Cubic feet" in Table 4 on page 14 should be "Cubic feet per acre."

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growth results are presented here from a spacing study designed to give the manager a wide range of alternatives from which to choose an initial spacing.

The reader is encouraged to use this note in conjunction with results published in 1970 (see footnote 1) which contain a detailed description of the study design and 8-year growth results.

STAND BEFORE TREATMENT AND THE STUDY AREA

Before study installation, the timber stand consisted of old-growth ponderosa pine with unthinned 40- to 70-year-old sapling understory averaging 1 inch in diameter and 8.2 feet in height (fig. 1). There were about 20 overstory trees per acre that averaged 850 board feet per tree. Shrubs under dense understory trees were small suppressed plants but well developed where the sapling understory was sparse or nonexistent.

Soil is a regosol developed in dacite pumice originating from the eruption of Mount Mazama (Crater Lake) 7,300 years ago. Old-growth ponderosa pine in the area indicates a height of 78 feet at age 100, average site quality. [3/] Experimental plots are in a transition zone between *Pinus ponderosa/Purshia tridentata-Arctostaphylos patula* and *Pinus ponderosa/Ceanothus velutinus-Purshia tridentata* plant communities.[4/] The study area is located on the Pringle Falls Experimental Forest, 35 miles southwest of Bend in central Oregon.

EXPERIMENTAL DESIGN AND METHODS

Study design consists of 30 rectangular 0.192-acre plots thinned to spacings of 6.6, 9.3, 13.2, 18.7, and 26.4 feet. A one-half-chain-wide buffer area around each plot was thinned to the same density as the inner plot. Each spacing was replicated six times. Understory vegetation was removed on three of the six replications for each treatment. Tree and vegetation measurements were made every 4 years for 12 years. Percent cover of understory vegetation on 15 plots was measured by systematic sampling of 100 points per

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3/ Walter H. Meyer. Yield of even-aged stands of ponderosa pine. U. S. Dep. Agric. Tech. Bull. 630 (rev.) 59 p., illus. 1961.

4/ Jerry F. Franklin and C. T. Dyrness. Vegetation of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-80, 216 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg. 1969.

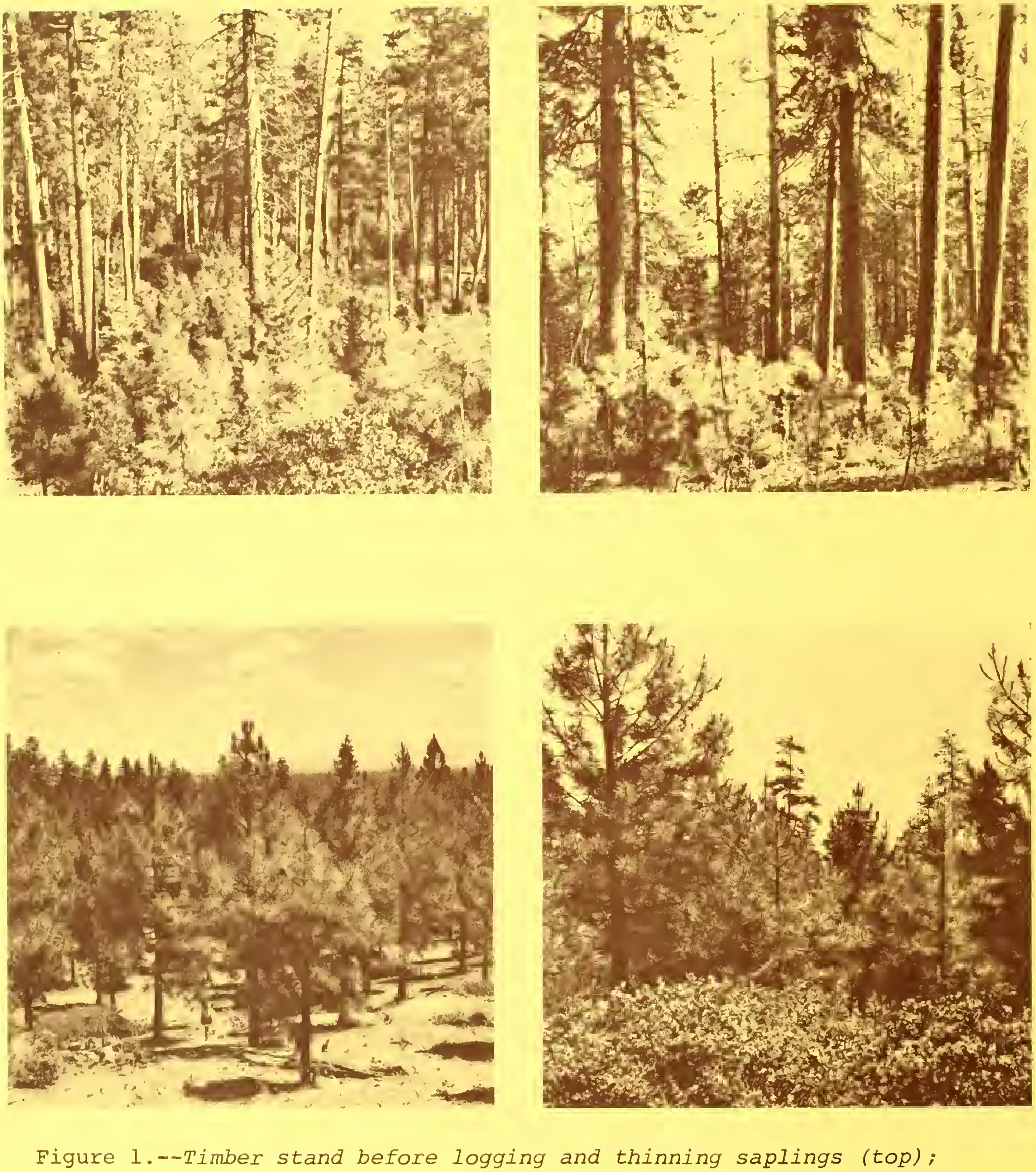

Figure 1.--*Timber stand before logging and thinning saplings (top); 12 years later after thinning saplings to 250 per acre and controlling understory vegetation (bottom left) and allowing understory to develop (bottom right).*

plot.[5] An estimate of average crown width was made by measuring crown diameter on 12 sample trees per plot and then regressing crown width on stem diameter.

RESULTS

Diameter Growth

Widely spaced trees grew significantly better than closely spaced trees during the third period (fig. 2). Growth rate has changed little from the second period to the third although there appears to be a trend of diminishing rates with time at the two narrowest spacings.[6] This may be the first hint of increasing competition between trees. Trees with the two widest spacings continue to grow at a rate of from 3.4 to 5.6 inches per decade.

Understory vegetation, 8 to 12 years after thinning, is still causing substantial reductions in growth at the widest spacings. For example, diameter growth at the widest spacing was reduced 30 percent by understory vegetation, and trees at the 18.7-foot spacing grew 15 percent less where there was understory vegetation. Understory vegetation continues to be most competitive at wider spacings and less at narrow spacings. However, the magnitude of this interaction seems to be diminishing. Relative to the second period, the effect of vegetation appears to be increasing at closer spacing and decreasing at wider spacings. However, there are inconsistencies in these trends which suggest changes are taking place in the interrelationships of tree growth and understory vegetation development that cannot be accurately assessed at present.

The largest diameter trees in each spacing continue to grow fastest (fig. 2). Although these trees appear to dominate the site in a localized area around the tree, competition from other trees does reduce their growth. To illustrate this, figure 2 shows that where 62 trees were left and the brush removed, these trees grew at an average rate of 0.56 inch per year. But where the 62 largest trees were selected from a stand containing 125, 250, 500, and 1,000 trees, growth (indicated by the solid line in figure 2) lessened as stand density increased. The same relationships were true where competitive understory vegetation was left.

At the end of the last measurement period, average diameter (table 1) ranged from 3.7 inches at the narrowest spacing to 8.4 inches where vegetation was removed. Some individual trees at the widest spacing have already attained a diameter of over 10 inches.

[5] Harold F. Heady, Robert P. Gibbens, and Robert W. Powell. A comparison of the charting, line intercept, and line point method of sampling shrub types of vegetation. J. Range Manage. 12: 180-188, illus. 1959.

[6] Spacing x periods interaction was highly significant. Of the plots at the two closest spacings, 83 percent show declining rates from the first period.

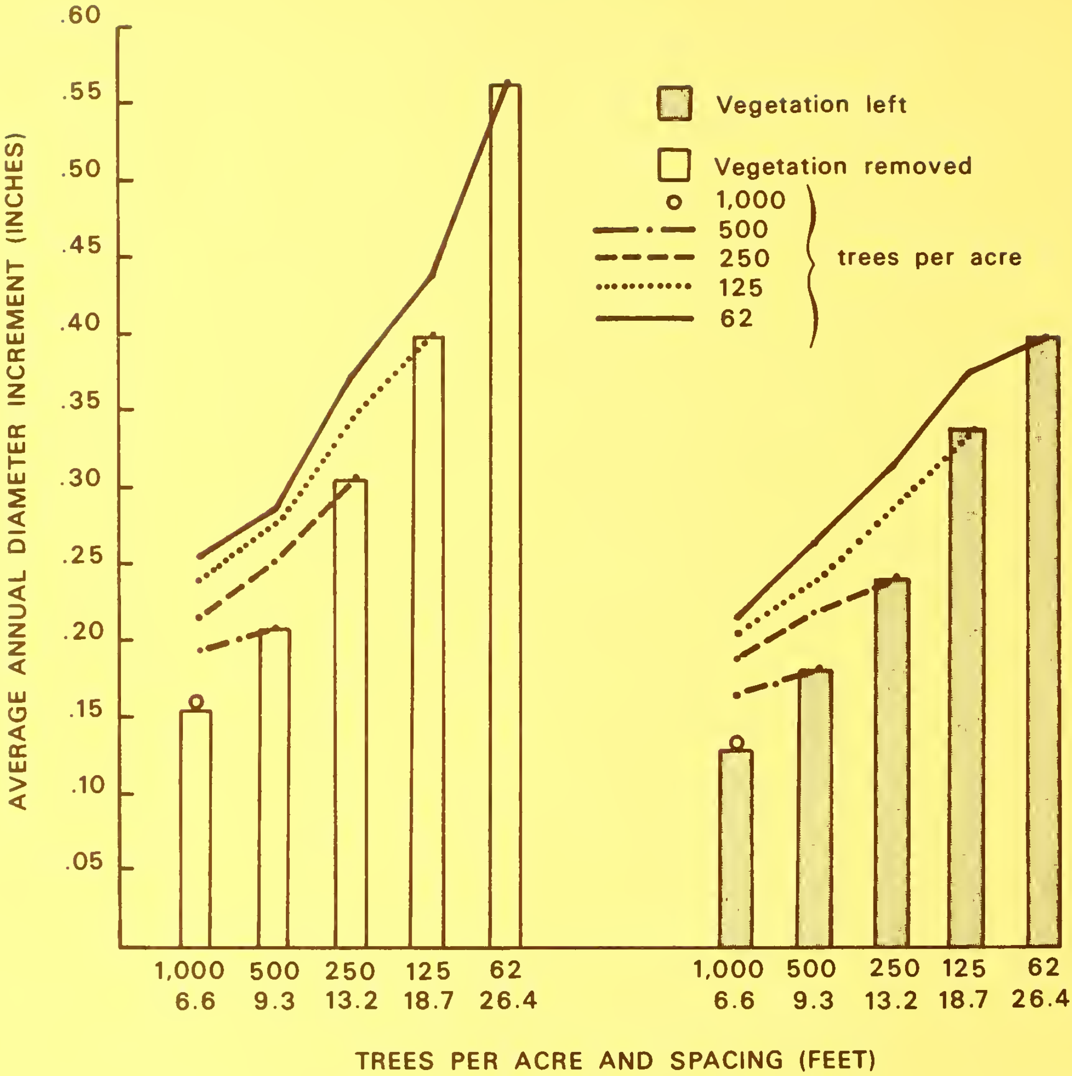

Figure 2.--*Average annual diameter (during third period) increment of ponderosa pine saplings thinned to various spacings (arithmetic average increments based on trees that lived through the period). Bars show diameter growth for total number of trees at each spacing. Points above bars show growth of the stated number of the largest well-distributed trees within the stand.*

Table 1.--*Average diameter*[1] *of ponderosa pine saplings in 1959, 1963, 1967, and 1971*

Treatment and year	Trees per acre and spacing (feet)				
	1,000 (6.6)	500 (9.3)	250 (13.2)	125 (18.7)	62 (26.4)
	Inches				
Vegetation left:					
1959	2.0	1.9	2.1	2.2	2.2
1963	2.6	2.6	3.0	3.4	3.4
1967	3.2	3.4	4.0	4.7	4.7
1971	3.7	4.1	4.9	6.0	6.3
Vegetation removed:					
1959	1.7	1.8	1.9	2.5	2.2
1963	2.4	2.8	3.3	4.1	3.8
1967	3.1	3.7	4.6	5.7	6.2
1971	3.7	4.5	5.8	7.3	8.4

[1] Quadratic mean.

Basal Area

Maximum basal area (74 square feet) at the end of 12 years occurred where 1,000 trees per acre were left (table 2). In contrast, the stand containing 62 trees per acre had only 13.6 square feet where understory vegetation was left and 24 square feet where it was removed.

Periodic basal area growth continues to increase at all spacings, with the highest increment 5.7 square feet per acre per year at the narrow spacing where vegetation was removed. Basal area is still increasing most rapidly per unit of basal area at the wider spacings. At the widest spacing where vegetation was removed, basal area increment averaged 3.7 square feet per acre per year during the last period. This increment on only 62 trees suggests that these widely spaced, fast growing trees can rapidly accumulate a growing stock base capable of reasonable wood production per acre.

Eight years after thinning, no real confidence can yet be placed in basal area as an aid to predicting diameter increment (table 2). When periodic annual diameter increment is regressed on basal area at the beginning

Table 2.--*Average basal area per acre of ponderosa pine saplings directly after thinning and 4, 8, and 12 years later*[1]

Treatment and year	Trees per acre				
	1,000	500	250	125	62
	Square feet				
Vegetation left:					
1959	22.4	9.8	5.8	3.4	1.6
1963	37.1	18.4	12.4	7.8	3.8
1967	54.0	32.0	21.3	14.9	7.7
1971	73.7	46.6	32.8	24.7	13.6
Vegetation removed:					
1959	16.6	8.4	4.9	4.1	1.7
1963	32.0	20.8	14.5	11.4	5.0
1967	51.2	37.2	28.6	22.4	12.9
1971	74.1	55.7	45.3	36.7	24.1

[1] Differences between values reported here and in USDA Forest Service Research Paper PNW-106 (James W. Barrett, Ponderosa pine saplings respond to control of spacing and understory vegetation, Pac. Northwest For. & Range Exp. Stn., Portland, Oreg., 1970) are due to averaging and rounding errors.

of the period, three different regression lines are evident, one for each period (fig. 3). As diameters approach merchantable sizes, periodic regressions may be similar and basal area could become useful separately or in combination with other variables as a predictor of increment.

Height Growth

A marked increase in periodic height growth took place from the first to the third period with threefold increases at the widest spacings (fig. 4 and table 3). With one exception, increase in growth rate between periods 2 and 3 exceeded that between 1 and 2.

Not all individual trees responded at the same time. Increased growth after thinning was visually detected in the first period at the widest spacing

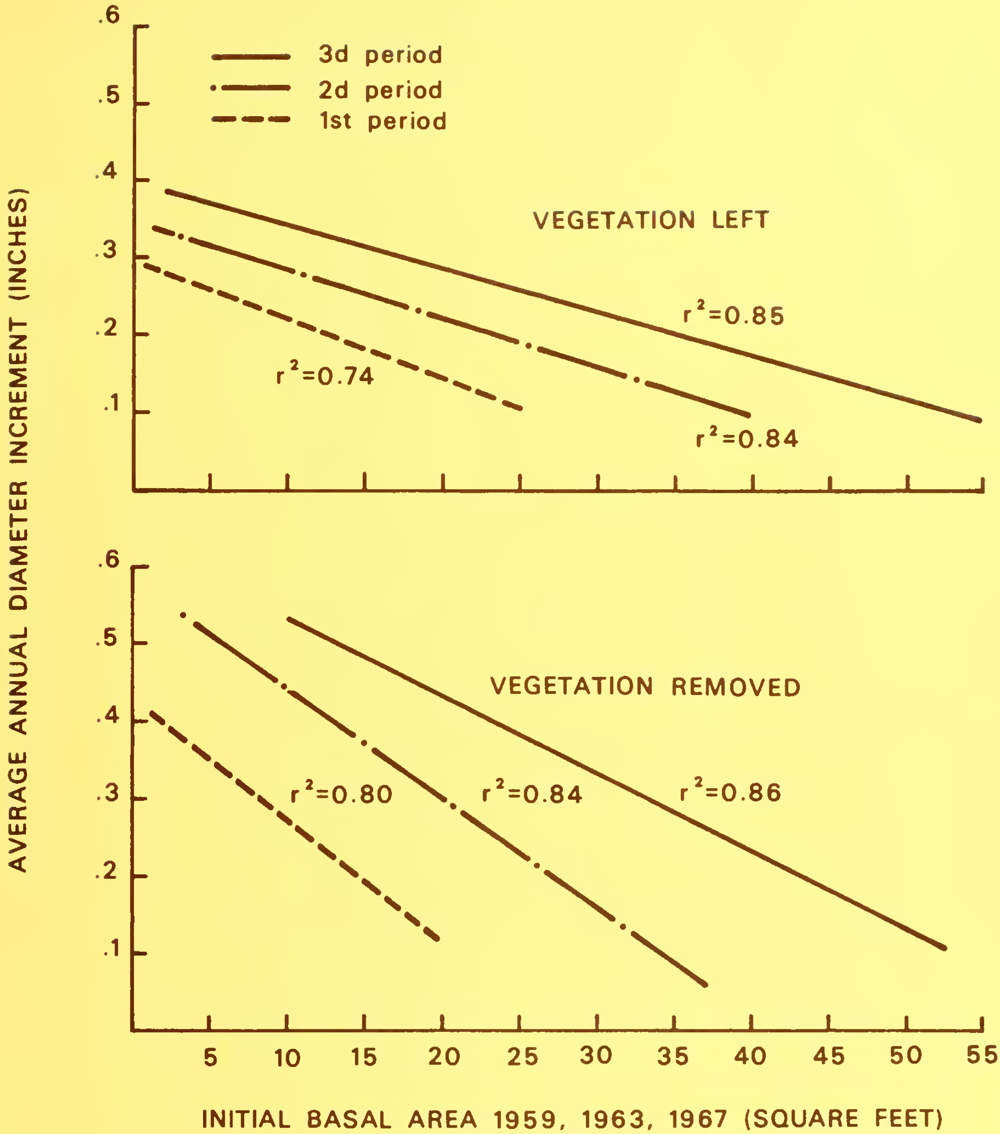

Figure 3.--*Relation of diameter increment to basal area at the beginning of each growth period.*

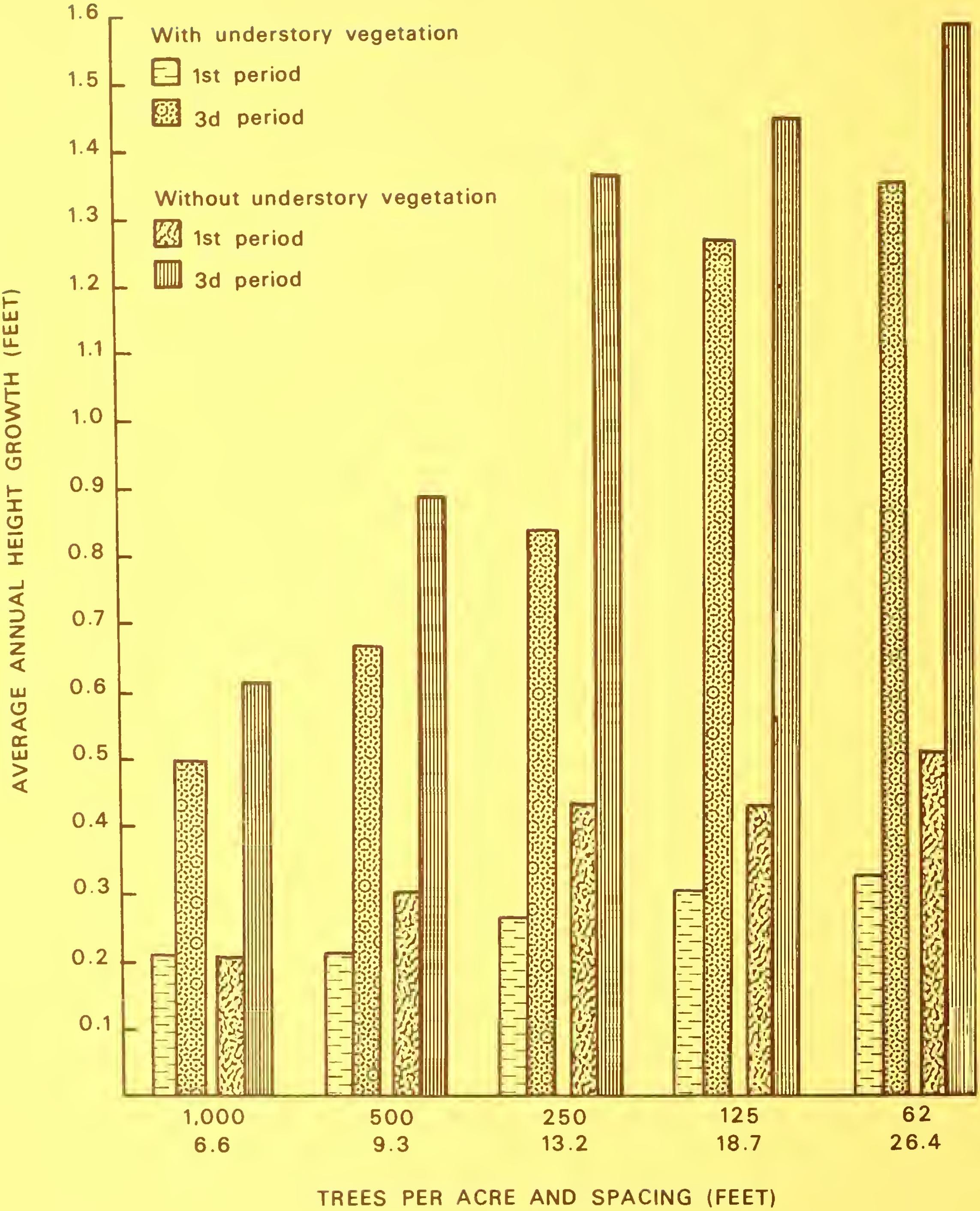

Figure 4.--*Average annual height growth during the first and third 4-year growth periods.*

Table 3.--*Average*[1] *height of ponderosa pine saplings in 1959, 1963, 1967, and 1971*

Treatment and year	Trees per acre and spacing (feet)				
	1,000 (6.6)	500 (9.3)	250 (13.2)	125 (18.7)	62 (26.4)
	Inches				
Vegetation left:					
1959	12.6	11.1	11.5	12.3	11.5
1963	13.4	12.0	12.5	13.5	12.9
1967	14.5	13.3	14.3	15.9	15.6
1971	16.5	15.9	17.6	21.0	21.0
Vegetation removed:					
1959	10.6	10.2	10.3	14.2	11.9
1963	11.4	11.5	12.0	15.9	13.9
1967	12.6	13.4	15.3	19.3	18.7
1971	15.1	17.0	20.7	25.1	25.0

[1] Average of trees living through the period.

on a few trees. As time passed, variation from tree to tree lessened and trees at the wide spacing grew uniformly well. After 12 years, this erratic height response can still be seen at the 6.6- and 9.3-foot spacings with some good trees at the 6.6 spacing making very little height growth and other similar trees making notable height growth.

In the third period, understory vegetation continued to significantly reduce height growth on all spacings although there appears to be some tendency for this effect to diminish in the third period. The trend for understory vegetation to have a greater effect on height growth at the wider spacings during the first and second periods did not continue in the third period, indicating that understory vegetation probably had a uniform effect over the range of spacings.

Cubic Volume Increment

In the third period, volume growth continued to be better where understory vegetation was removed in all but the closest spacing (fig. 5). Also, the trend for understory vegetation to have a greater effect at wider spacings remained.

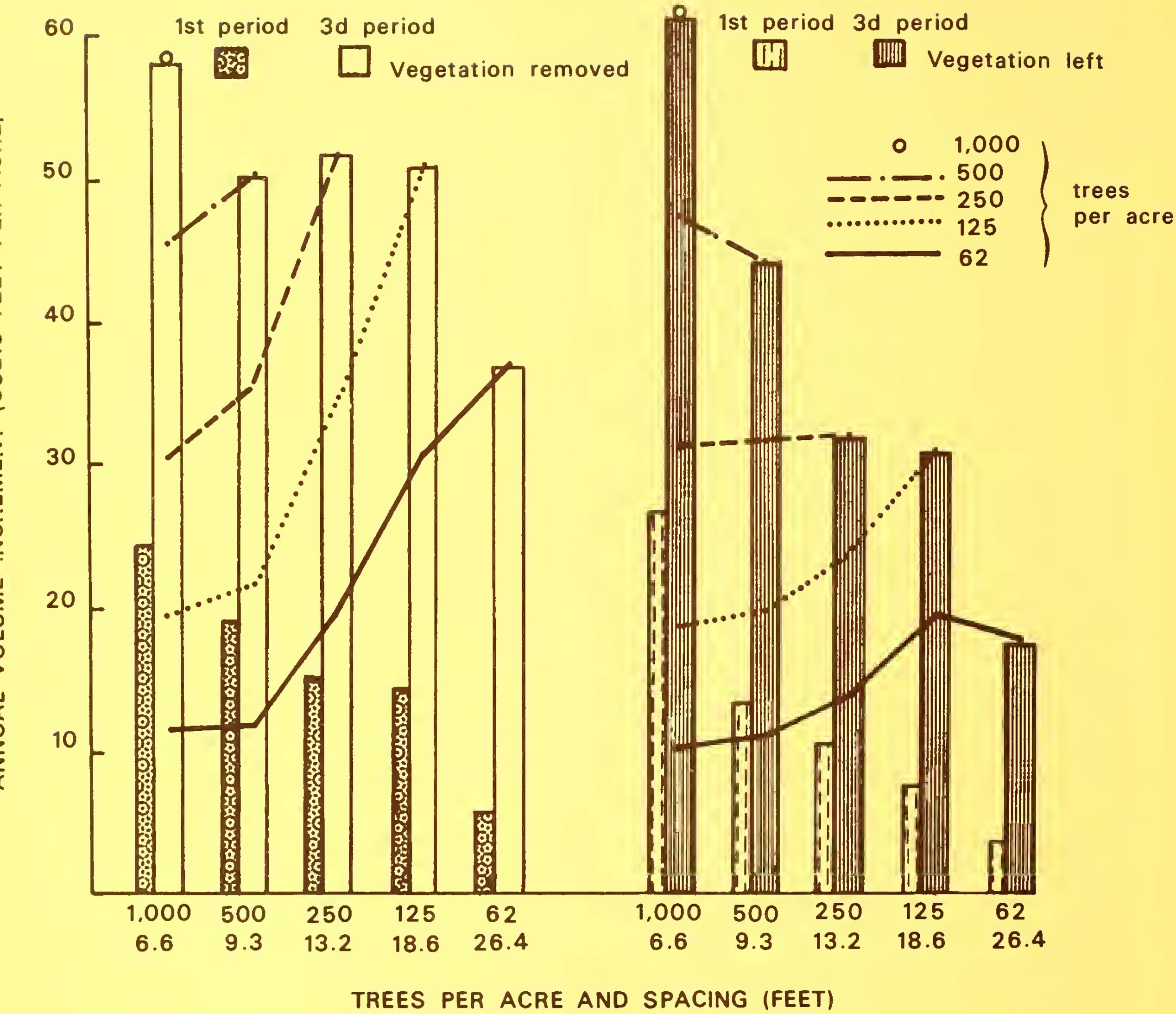

Figure 5.--*Periodic annual volume increment of ponderosa pine saplings thinned to various spacings. Bars show increment for total number of trees at each spacing. Points within bars show increment of the stated number of the largest well-distributed trees within the stand. (First period increments based on pooled equation. See footnote 1 table 4).*

Growth of the largest diameter trees tends to increase with wider spacings. For example, in figure 5 where vegetation was removed, the 125 largest diameters in the 500-tree-per-acre stand produced 21 cubic feet; but where only 125 trees were left, over twice that was produced.

As one might expect, the greatest amount of wood was produced at the highest density where we find many small spindly stems that may never reach merchantability. However, growth per acre may be improving more rapidly at wider spacings than at narrow ones. For example, it is encouraging to note that spacings of 9.3, 13.2, and 18.6 where vegetation was removed produced about the same amount of volume. Although this seems somewhat unrealistic at this early stage in stand growth, it does point out the capacity of only 125 trees per acre to produce wood.

The stand with 1,000 trees per acre with understory vegetation removed contains an average of 602 cubic feet per acre 12 years after thinning (table 4). The 125-tree-per-acre stand where vegetation was removed contains about two-thirds this amount and consists of trees that will surely reach merchantability.

Mortality

Out of a total of 2,232 trees, 23 died in the 12 years following establishment of the study. The 6.6 spacing lost 1.2 percent during this time. The 9.3 and 13.2 spacings lost 0.6 and 2.0 percent, respectively. No trees were lost in the two widest spacings.

Crown Characteristics

Tree crowns at the wider spacing were longer and wider 12 years after thinning and thus contained more spatial volume than crowns of trees at the narrower spacings. As might be expected, crown growth responded to additional growing space and control of vegetation much the same as diameter and height growth. For example, if we compare extremes, crowns of trees at the widest spacing where vegetation was removed contained seven times the volume of a crown of an average tree at the narrowest spacing where vegetation was left. In addition, crown size at the end of the third period was just as sensitive statistically to spacing and understory vegetation as diameter, height, and volume increment. This was also true when only the 62 largest trees per acre at each spacing are considered (fig. 6). Thus, crown development of even the best trees in the higher density stands is affected by density and understory vegetation.

Table 4.--*Net yield of ponderosa pine saplings at the end of the first, second, and third 4-year periods*

Treatment	Trees per acre				
	1,000	500	250	125	62
	Cubic feet				
1st period:					
Vegetation left	185	77	45	25	11
Vegetation removed	133	66	35	32	13
2d period:[1/]					
Vegetation left	409	205	163	117	57
Vegetation removed	370	258	219	200	108
3d period:					
Vegetation left	654	381	291	241	127
Vegetation removed	602	459	426	403	255

[1/] Linear equations expressing volume as a function of height and diameter (diameter squared x height) were used in all three periods. First two period increments as reported in USDA Forest Service Research Paper PNW-106 (James W. Barrett, Ponderosa pine saplings respond to control of spacing and understory vegetation, Pac. Northwest For. & Range Exp. Stn., Portland, Oreg., 1970) were based on pooled measurements from 186 trees. Additional trees on each plot were measured in 1967 making a total of 12 per plot. During the last period, volumes were estimated using a separate equation for each plot. Thus, the difference between second period volumes reported here and in USDA Forest Service Research Paper PNW-106 is accounted for.

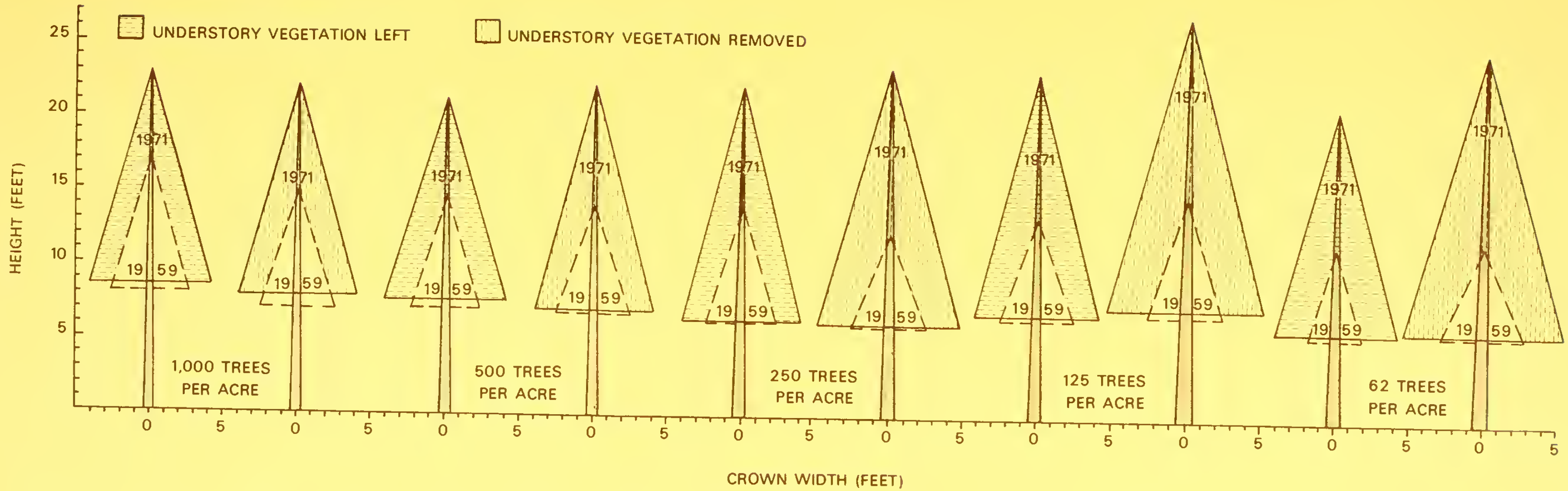

Figure 6.--Average crown dimensions of the 62 largest diameter trees per acre in 1959 and 12 growing seasons later. Crown widths for 1959 were estimated from 1971 regressions of crown width on diameter.

Crown cover probably has a notable influence on the development of understory vegetation. When we consider crown cover in terms of average crown diameter per treatment, it is evident why understory vegetation has not developed to as great an extent as where 1,000 trees per acre were left. Percent of ground covered by crown at the end of the last period is:

Number of trees per acre and spacing (feet)	Understory vegetation left	Understory vegetation removed
	(Percent of ground covered)	
1,000 (6.6)	64	73
500 (9.3)	39	44
250 (13.2)	22	35
125 (18.7)	16	23
62 (26.6)	8	13

Where understory was left, eight times as much ground is canopied by the stand containing 1,000 trees per acre as where 62 trees per acre were left. However, individual crowns on the widest spacing are visibly dense and probably offer more cover per tree than those at the narrowest spacing.

Understory Vegetation

Changes in understory vegetation development from 1967 to 1971 were minor. Essentially the same trends continued. Ground covered by brush was greater at the wider spacings (fig. 7) with 48 percent of the ground covered at the widest spacing and 35 percent at the narrowest spacing. Changes in proportional distribution of species were minor with bitterbrush (*Purshia tridentata*), the principal species occupying 17 to 22 percent of the area 12 years after thinning (fig. 8).

Where understory vegetation was allowed to develop naturally, suppressed ponderosa pine seedlings have also responded to the additional growing space. As shown in figure 9, some seedlings, barely visible below the brush at time of thinning, 12 years after thinning are breast high or higher. These trees will probably offer notable competition to the crop trees within a short time. Herbicide application just after thinning may not eliminate this source of competition, although some seedlings could be destroyed in a first commercial thinning.

Figure 7.--*Ponderosa pine saplings thinned to a wide spacing 12 years earlier. Understory vegetation controlled (left) and allowed to develop naturally (right).*

APPLICATION AND DISCUSSION

This note is a progress report of a study that is gradually providing us with growth information necessary to make timber management decisions. For example, latest diameter and height growth rates may be roughly projected a decade or two to forecast about when a product may be harvestable under a certain initial spacing. Basal area appears to be a poor predictor of diameter increment at this early age and size, and such methods seem risky until trees are larger.

Mature overstory close to this study is growing about 100 board feet per acre per year (between 15 and 20 cubic feet).[7] Understory saplings

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[7] Edwin L. Mowat. Growth after partial cutting of ponderosa pine on permanent sample plots in eastern Oregon. USDA For. Serv. Pac. Northwest For. & Range Exp. Stn. Res. Pap. 44, 23 p., illus., Portland, Oreg. 1961.

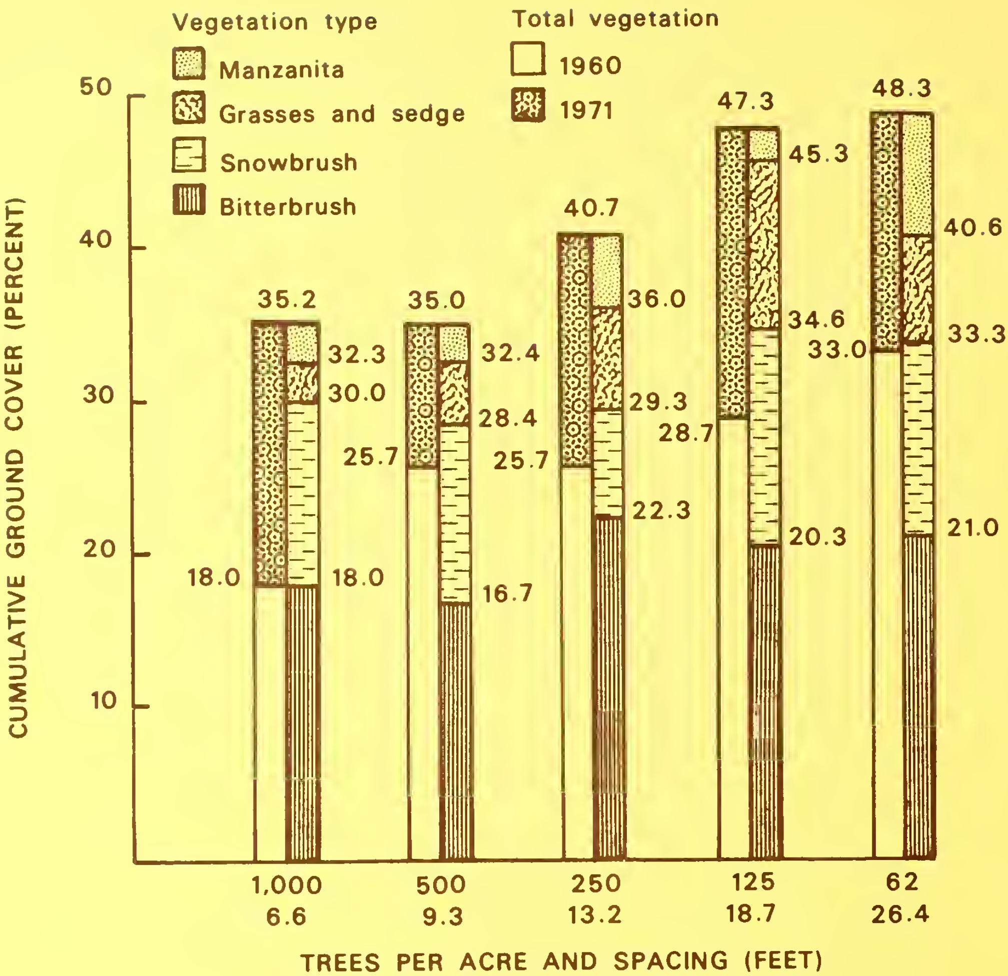

Figure 8.--*Average percent of ground covered by understory vegetation in 1960 and 1971 and percent covered by type of vegetation in 1971. Two growing seasons elapsed between overstory removal and actual measurement of the vegetation in 1960. Thus, enough time probably passed to establish differences between spacing before vegetation cover estimates were made initially.*

Figure 9.--*Plot thinned to a wide spacing, showing development of brushy understory vegetation and young seedling trees that have also taken advantage of additional growing space.*

thinned to 125 trees per acre are, after only 8 years, producing almost three times the cubic wood increment of the old-growth overstory stand. Also, the sapling stand is at the stage where periodic increment is rising rapidly and will soon be producing five to six times that of the overstory (an encouraging outlook for converting old-growth pine stands to second growth).

Forest managers confronted with the obstacles of harvesting overstory and saving the sapling-size understory trees often succumb to the "easy way out" of clearing the land and planting. This "way" will destroy increment that may never be recovered. Although figure 10 is not a direct comparison, it does show the results of planting and not controlling understory vegetation versus saving the existing reproduction and controlling understory vegetation. Trees on the right average 23.8 feet in height and 7 inches in diameter, and those on the left average 9.1 feet high and 1.9 inches in diameter. The planted stand averages slightly less than trees on the right directly after thinning 12 years earlier.

Results here suggest that possibly a decade[8/] of tree growth might be

[8/] Average diameter growth of 125 trees per acre with brush and without brush was projected to a point where both stands contained 125 square feet of basal area (the density assumed to check understory vegetation). The stand where vegetation was controlled "attained" 125 square feet 10 years before the stand where vegetation was allowed to develop naturally.

Figure 10.--*Small pole stand on right was a suppressed sapling stand in this study 12 years earlier. Saplings were thinned to 125 trees per acre and vegetation controlled. Plantation on left was established in a log landing 1 year after thinning stand on right and controlling understory vegetation.*

saved by treating the understory vegetation twice during the early part of the rotation. One might speculate on the possibility of treating the stand described here in the following order:

1. Overstory harvest.
2. Thinning 1 year after overstory removal.
3. Thinning slash disposal.
4. Spray understory vegetation when 15 percent or more of the ground is covered by understory vegetation.
5. Spray understory vegetation when ground cover again reaches 15 percent.
6. Spray no more but allow trees and vegetation to develop naturally.

The time interval between brush treatments will depend largely on the presence or absence of sprouting varieties of brush.[9/]

It should be noted that some degree of discretion needs to be exercised in controlling understory vegetation. Benefits from brush have been recognized for some time.[10/] Bitterbrush and snowbrush ceanothus are both nitrogen fixers and furnish forage and cover for wildlife. Also, they are probably an important link in the soil-plant-water continuum on pumice soils. On the other hand, there is ample evidence in the forests of central Oregon to indicate that some stands can maintain notable productivity for several decades without the presence of brush and without evidence of deterioration of the site. In other instances, stand density has kept brush development in check by crown closure, and trees and brush existed together in an acceptable forest community.

[9/] The long-time effects of keeping the land entirely free of understory vegetation are being studied in a cooperative effort between the Department of Soil Science, Oregon State University, Corvallis, and the Pacific Northwest Forest and Range Experiment Station.

[10/] C. T. Youngberg. Silvicultural benefits from brush. Soc. Am. For. Proc. 1965: 55-59. 1966.

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ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

· USDA FOREST SERVICE RESEARCH NOTE

PNW-210 November 1973

OBSERVATIONS ON THE FORMATION OF ZONE LINES IN WOOD BY *PORIA WEIRII*

by

E. E. Nelson, *Principal Plant Pathologist*

ABSTRACT

The formation of zone lines, based on 8 years' observations in the course of related Poria weirii *(Murr.) Murr. studies, depends upon conditions prior to burial, time, temperature, soil microflora, soil moisture, and stage of decay. Conditions favorable to growth of* P. weirii *are not generally favorable to zone line formation.*

Keywords: *Poria weirii*, root damage, fungi-wood deterioration.

INTRODUCTION

Zone lines are structures formed in wood by several of the higher fungi. Though appearing as lines in cross sections, these structures actually envelop the active fungal colony and allow the fungus forming them to exclude elements of a hostile environment, primarily drought and antagonistic micro-organisms (fig. 1). Many important root pathogens employ this mechanism: *Poria weirii* (Murr.) Murr., *Fomitopsis annosa* (Fr.) Karst. (*Fomes annosus*), and *Armillariella mellea* (Vahl. ex Fr.) Karst. (*Armillaria mellea*).[1/] A thorough

[1/] S. D. Garrett. Pathogenic root-infecting fungi. London, Cambridge University Press, 294 p., 1970.

understanding of the formation of zone lines and conditions conducive to their destruction could be important in the biological control of root disease fungi.

In studies of *P. weirii* survival over the past 8 years, there has been considerable opportunity to observe conditions leading to formation of zone lines. Most of these observations, though related to survival of *P. weirii*, have not been reported. In this paper, an attempt is made to assemble this information as a reference for future work on zone line formation.

OBSERVATIONS

Most observations discussed here originated with studies employing wood cubes cut from trees naturally infected by *P. weirii*. Some of the cubes were buried in soil in the field, but more often in containers held under laboratory conditions. Successful formation of zone lines under study conditions depended upon conditions prior to burial, temperature, time, soil microflora, soil moisture, and extent of decay.

Conditions Prior to Burial

In general, the longer (up to 40 days) colonized wood is stored under conditions favorable for *P. weirii* survival and development ($<5^{\circ}$ C) and humidity (90 percent), the better the chance for zone line formation after burial. This is at least in part because zone line "initials" may be formed in the colonized wood in storage.

Figure 1.--Microscopic section showing composition of *P. weirii* zone line. Cell spaces are filled with dark pigmented, thick-walled hyphae. Adjacent cell walls also appear darker.

Temperature

When buried, colonized wood was incubated at temperatures from $+2^{\circ}$ to $+15^{\circ}$ C; zone lines formed more often at these than at higher temperatures presumably because *P. weirii* was better able to compete with the soil microflora. When higher (20° C) temperatures were used, zone lines formed faster when competition with antagonistic soil micro-organisms was reduced; e.g., when sterile soils were inoculated with micro-organisms which did not exhibit highly antagonistic reactions with *P. weirii* in paired culture on malt agar.

Time

At most temperatures ($+2^{\circ}$ to 20° C), *P. weirii* was able to form noticeable zone lines within a month. Lines formed at higher temperatures were noticeably thicker and appeared darker when colonized substrates were split open.

Soil Microflora

The soil microflora greatly affect formation of zone lines by *P. weirii*. To begin with, antagonistic elements of the microflora under suitable soil conditions can invade the colonized wood and replace *P. weirii* before zone line defenses can be produced. Once zone line formation begins, chances of survival and further development of the barriers are both substantially increased. The ability of *P. weirii* to form lines in the presence of antagonistic soil microflora is strongly influenced by conditions prior to burial and temperature-moisture relationships in the soil. Temperature and moisture strongly influence activity of the soil microflora as well as *P. weirii*.

When *P. weirii* is not in competition with soil microflora (in sterile soil), zone lines rarely form. Often the soil is colonized by *P. weirii* mycelium moving out from the colonized wood. The same has been shown with colonized alder chips in glass tubes. When unsterile soil is added to the tube, zone lines form at the soil-chip interface. If sterile soil is added, it is colonized by *P. weirii* growing from the alder chips. Addition of unsterile soil results in formation of zone lines in the previously sterile soil or at the soil-chip interface. When specific fungi (stain fungi) were added to sterile soil used to bury *Poria*-colonized cubes of wood, zone line formation was stimulated and culminated in a thick dark line. Similar introduction of highly antagonistic fungi (i.e., *Trichoderma viride* Pers. ex S.F. Gray aggr.) overwhelmed *P. weirii* before zone lines could be formed. If a stimulus were present, time did not permit erection of a zone line barrier to exclude the fungus from entry and replacement of *P. weirii*.

Soil Moisture

Stimulation of zone line formation by certain moisture and temperature relationships has been reported elsewhere in the literature for other fungi.[2/] Apparently

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[2/] H. Hopp. The formation of colored zones by wood destroying fungi in culture. Phytopathology 28: 601-620, 1938.

soil moisture as well as aeration and antagonistic fungi may promote zone line formation in colonized buried wood by *P. weirii*. In our studies, soil moisture contents ranged from 29 to 47 percent of dry weight and all were conducive to zone line formation.

Extent of Decay

Nelson[3/] states that although *P. weirii* forms zone lines more consistently in wood in advanced stages of decay, the effectiveness of these lines in excluding antagonistic microflora was no greater than those lines in lesser decayed wood. Numerous later observations have shown that zone lines are much more likely to form in wood in advanced stages of decay.

DISCUSSION AND CONCLUSIONS

The several observations reported here have led to the following conclusions:

1. Visible zone lines can be formed by *P. weirii* in wood in 30 or fewer days at temperatures normally occurring in forest soils over most of the year.

2. At temperatures above 15° C, competition from soil fungi is so great that *P. weirii* is not able to form protective barriers; but, when defensive barriers have already begun, the fungus is able to resist invasion at this or higher temperatures.

3. Where microbial competition is absent (as in sterilized soil) and other factors are favorable for *P. weirii* growth, it does not form zone lines. If fungi with comparatively low competitive abilities (certain "stain" fungi) are introduced, zone lines are formed. If highly antagonistic fungi (such as *Trichoderma viride*) are introduced, zone lines may not be formed in time to resist invasion whether or not the antagonistic fungus provides a stimulus.

In general, it appears that conditions favorable for growth of *P. weirii* are not conducive to formation of zone lines. When factors such as soil moisture or microbial competition reach triggering levels, *P. weirii* is stimulated to form zone lines. Whether zone lines are barriers to outward movement of *P. weirii* as well as to invasion by soil fungi is unknown.

The practical interest in zone lines, their formation, and their effectiveness as barriers to competing microflora stems from possibilities of biological control of root diseases. Since zone lines promote the survival of *P. weirii* in wood in soil, site treatments which break up colonized wood and encourage highly antagonistic fungi could be potential control measures for this disease.

[3/] Earl E. Nelson. Factors affecting survival of *Poria weirii* in small buried cubes of Douglas-fir heartwood. Forest Science 13: 78-84, illus., 1967.

GPO 989-588

ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

· USDA FOREST SERVICE RESEARCH NOTE

 PNW-211

November 1973

EMPLOYMENT IMPLICATIONS OF PROJECTED TIMBER OUTPUT IN THE DOUGLAS-FIR REGION, 1970-2000

by

Brian R. Wall, *Economist*

ABSTRACT

The demand for timber in the United States is increasing. Under present levels of timber management, the timber products output in the Douglas-fir region has been projected to decline by the year 2000. Based on these projections and on estimates of changing industry mix and increased labor productivity, employment in the timber-based industries in the Douglas-fir region is projected to drop 45 percent between 1970 and the year 2000. Employment-wood consumption relationships are a major factor influencing employment projections, although declining timber products output and a high level of log exports are also important.

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

INTRODUCTION

This report presents estimates of timber-based employment associated with the level of timber products output projected for the Douglas-fir region in the year 2000. The estimates of timber products output are those prepared for inclusion in the national timber appraisal, "The Outlook for Timber in the United States."[1] The key assumptions behind the projections are an increasing demand for timber products and a continuation of the present level of forest management. Under these assumptions, timber supply is projected to decline in the Douglas-fir region and will be a limiting factor to the development of the timber economy.

The key assumptions behind the estimates of timber-based employment associated with the projected levels of timber products output are changes in industry mix and labor productivity--expressed as changing employment-wood consumption ratios--and increasing log exports.

Because of the particular significance of timber products output expectations, trends in industry mix and labor productivity, and log export assumptions, the sensitivity of the projected level of employment to each of these factors is analyzed in the second part of the report. The alternative assumptions used in the sensitivity analysis are not meant to be used for viable employment alternative projections.

BASIC PROJECTIONS

TIMBER PRODUCTS OUTPUT

The Douglas-fir region timber supply estimates for 1970 and 2000 are a summation of individual projections for lands owned and managed by forest industry, farm and miscellaneous private owners, National Forests, and other public owners. For this analysis the continuation of present levels of forest management was assumed. Thus, the present allowable cut has been projected for public lands. On industrial timber lands, it was assumed that the harvest would gradually decrease until a balance between growth and cut was achieved. On farm and miscellaneous private lands, it was assumed that harvest would gradually increase in the Douglas-fir region, leading to a balance between growth and cut.

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[1] USDA Forest Service. The outlook for timber in the United States. Forest Resource Report No. 20, 367 p., 1973.

The projections of timber products output are as follows:

	1970		2000	
	MM cubic feet	MM board feet (Int. 1/4-inch)	MM cubic feet	MM board feet (Int. 1/4-inch)
Western Washington	1,192.6	7,543.8	954.2	5,342.8
Western Oregon	1,184.7	8,115.5	1,071.8	6,495.5
Total Douglas-fir region	2,377.3	15,659.3	2,026.0	11,838.3

In western Oregon, softwood timber products output from forest industry lands is projected to decline 73 percent during the 1970-2000 period. Softwood production is projected to increase 105 percent from farm and miscellaneous private lands, 22 percent from other public lands, and 16 percent from National Forest lands.

In western Washington, softwood timber products output on forest industry lands is also projected to decrease (58 percent) between 1970 and the year 2000. Declines are projected for farm and miscellaneous private lands (5 percent) and other public lands (2 percent). National Forest timber products output is projected to increase 25 percent by the year 2000.

EMPLOYMENT

Table 1 shows the basic forest-based employment in 1970 and projections for the year 2000 in western Oregon and western Washington. Employment decreases in both States, but the drop is greatest in western Washington. In 1970, an estimated 121,305 persons were employed in the lumber and wood products, paper and allied products, and the log export industries in the Douglas-fir region. Employment is projected to drop 45 percent by the year 2000 to 67,120 employees.

The 1970 data on employment in the lumber and wood products and paper and allied products industries are from the employment departments in the States of Washington and Oregon. Estimates of employment associated with log exports are based on known labor productivity factors.[2]

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[2] Thomas C. Adams and Thomas E. Hamilton. Value and employment associated with Pacific Northwest log exports to Japan. USDA Forest Service Research Paper PNW-27, 15 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1965.

Table 1.--*Average annual forest-based employment in the Douglas-fir region by State and area, 1970 and 2000*

State, area, and industry	Number of employees	
	1970	2000
Western Washington:		
Lumber and wood products; paper and allied products	54,699	23,220
Log exports	1,822	2,630
Total	56,521	25,850
Western Oregon:		
Lumber and wood products; paper and allied products	64,479	40,840
Log exports	305	430
Total	64,784	41,270
Total Douglas-fir region	121,305	67,120

Trends in employment-wood consumption relationships, including labor productivity and industry mix, are developed from a previous study by Wall.[3/] That study projected wood consumption and employment in the forest products industries to the year 2000 by the 12 subregions of the Columbia-North Pacific Region. In that study, historical employment-wood consumption relationships were developed for each industry group. Employment projections for each industry group were added together to obtain regional employment projection totals. These aggregate relationships, adjusted for a different log export projection, are used in this study.

[3/] Brian R. Wall. Projected developments of the timber economy of the Columbia-North Pacific Region. USDA Forest Service Research Paper PNW-84, 87 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1969.

LOG EXPORTS

Log exports are important to the Douglas-fir region; the assumed export levels in this employment analysis come from the new national study. Softwood log exports in the United States were 3.4 billion board feet (International 1/4-inch rule) in 1970. Under the assumption of constant relative prices, softwood log exports in the Nation are projected to be 4.5 billion board feet in the year 2000. For the purposes of this analysis, it has been assumed that the Douglas-fir region will maintain its 1970 share of the national log export market in the year 2000, with about 85 percent of the Nation's log exports originating in the Douglas-fir region. Under this assumption, log exports in the year 2000 from timber grown in western Washington would amount to 3.29 billion board feet (International 1/4-inch rule), and exports from western Oregon would be 535 million board feet. Under these assumptions, a substantial proportion of the harvest in western Washington would be bound for the log export market, having a substantial impact on domestic forest-based employment.

SENSITIVITY OF EMPLOYMENT PROJECTIONS

The employment projections have been examined to see how they change with different assumptions about employment-wood consumption relationships, levels of timber products output, and log exports. In the test, one factor has been varied while the others have been held constant. The resulting difference in employment level thus can be attributed to the factor which has been varied.

HOW WOULD EMPLOYMENT BE AFFECTED IF THE WOOD-CONSUMPTION RELATIONSHIP WERE FROZEN OVER TIME?

Labor and wood are two of the inputs into the forest products manufacturing process. Studies show that these relationships for individual industry segments have been changing, reflecting changes in labor productivity, hours worked, etc. Labor productivity has been increasing in sawmills and planing mills, veneer and plywood plants, and pulp and paper plants. This reflects skill levels, technology, substitution of one factor of production for another, utilization of capacity, and managerial ability. Employment-wood consumption ratios change as the industry mix changes and with increasing use of woods and mill residues. The assumptions used in the basic employment projections reflect the declining trends in these aggregate relationships.

If the 1970 employment-wood consumption relationships were frozen but other factors allowed to change as in the basic projection, the analysis shows that in the Douglas-fir region forest employment in the year 2000 would be 47 percent greater than in the basic projection. Increases would occur in both western Washington and western Oregon.

The results of this analysis are:

	Year 2000 employment (Employees)
Western Washington:	
Basic projection	25,850
Projection with constant 1970 employment-wood consumption ratio	40,600
Employment change	+14,750
Western Oregon:	
Basic projection	41,270
Projection with constant 1970 employment-wood consumption ratio	58,260
Employment change	+16,990
Douglas-fir region:	
Employment change with constant employment-wood consumption ratio	+31,740

WHAT IF TIMBER PRODUCTS OUTPUT REMAINED CONSTANT?

This analysis shows that if the output of timber were held at the 1970 level through the year 2000, employment in the year 2000 would be 16 percent above the Douglas-fir region base projection. Western Washington employment would be 25 percent higher than in the base projection, and western Oregon employment would be 9 percent higher.

The results of this analysis are:

	Year 2000 employment (Employees)
Western Washington:	
Basic projection	25,850
Projection with output constant	32,400
Employment change	+6,550
Western Oregon:	
Basic projection	41,270
Projection with output constant	45,210
Employment change	+3,940
Douglas-fir region:	
Employment change associated with constant timber output	+10,490

SENSITIVITY TO LOG EXPORT ASSUMPTIONS TESTED

The effects of log exports on employment were tested with three questions. What are the employment effects: if the log exports remain at 1970 levels; if log exports drop to zero in the year 2000 and all timber is domestically manufactured; and if log exports drop to zero in the year 2000, but the volume which would have been exported is not available for domestic markets?

WHAT IF LOG EXPORTS REMAIN AT 1970 LEVELS?

The analysis reveals that if log exports were limited to the 1970 levels and the extra timber products were manufactured domestically, forest-based employment would be 10 percent greater for the year 2000 than it was for the basic projection where log exports were higher. Western Washington has the largest increase in employment under this assumption.

The results are presented in the following tabulation:

	Year 2000 employment (Employees)
Western Washington:	
Basic projection	25,850
Projection with log exports at 1970 level	31,740
Employment change	+5,890
Western Oregon:	
Basic projection	41,270
Projection with log exports at 1970 level	42,250
Employment change	+980
Douglas-fir region:	
Employment change with log exports held at 1970 level	+6,870

WHAT WOULD HAPPEN IF LOG EXPORTS DROPPED TO ZERO?--TWO EXTREMES EXAMINED

The question is relevant but difficult. The drop in log exports could occur if the international demand for logs in the Douglas-fir region were not as forecast in the new national study or if log exports were restricted by legislation. The impact on employment is uncertain and the subject of debate. For example, in testimony before Congress on the log export issue, the question has been raised as to what would happen to the volume of exportable logs which would not be exported if log exports were banned. This is a matter of conjecture, for nobody knows for sure whether the exportable logs would be processed domestically or not. For the purposes of this sensitivity analysis, two extreme cases of zero log exports are examined--the impact on employment of (1) domestic manufacture of exportable logs, and (2) no use of exportable logs.

WHAT IF LOG EXPORTS DROPPED TO ZERO AND ALL THE TIMBER PRODUCTS OUTPUT WERE PROCESSED DOMESTICALLY IN THE YEAR 2000?

The following tabulation shows this employment impact:

	Year 2000 employment (Employees)
Western Washington:	
Basic projection	25,850
Projection with zero log exports with all logs processed domestically	36,680
Employment change	+10,830
Western Oregon:	
Basic projection	41,270
Projection with zero log exports with all logs processed domestically	43,470
Employment change	+2,200
Douglas-fir region:	
Employment change with all logs processed domestically	+13,030

Under this assumption forest-based employment would be 19 percent greater than the basic projection which assumed increased log exports. Western Washington forest-based employment would be 42 percent greater than it was under the assumptions of the basic projection.

WHAT IF LOG EXPORTS DROPPED TO ZERO BUT THE EXPORTABLE LOGS WERE NOT AVAILABLE FOR DOMESTIC MANUFACTURE IN THE YEAR 2000?

The employment impacts of this assumption are summarized in the following tabulation:

	Year 2000 employment (Employees)
Western Washington:	
Basic projection	25,850
Projection with zero log exports, with logs not available to domestic markets	20,526
Employment change	-5,324
Western Oregon:	
Basic projection	41,272
Projection with zero log exports, with logs not available to domestic markets	40,407
Employment change	-865
Douglas-fir region:	
Employment change with exportable logs not processed or exported	-6,189

Forest-based employment in the Douglas-fir region in this case would be 9 percent lower than the basic projection which assumed increasing log exports. The loss in employment occurs mostly in western Washington and reflects both exporting jobs and logging jobs associated with log exports.

SUMMARY AND DISCUSSION

With continuation of present levels of forest management, the timber products output in the Douglas-fir region will decline by the year 2000. Based on this projection and estimates of changing industry mix and labor productivity, employment in the timber-based industries is projected to drop 45 percent between 1970 and the year 2000 in the Douglas-fir region. These projections reflect a large volume of logs being consumed by the log export market.

Sensitivity analysis reveals that the employment-wood consumption relationship is the major factor accounting for the projected employment decline. Economic forces largely determine the change in industry mix and increasing labor productivity which will act to reduce employment over time. Such changes must continue if Douglas-fir region forest products industries are to remain competitive.

The projected decline in timber products output is an important determinant in the projected drop in employment. This decline and the employment pattern associated with it could be altered by changing the harvesting schedules of old-growth timber, but the possibilities are limited by the supply. In an old-growth timber economy such as we have in the Douglas-fir region, employment is closely related to the rate at which we draw on our reservoir of timber inventory.

Accelerated forest management and forestry employment have not been examined in this study. Management activities are labor intensive, and accelerated management would increase employment in the forestry sector. To the extent that intensive forest management does take place and results in increased output in the year 2000, it could also lessen the indicated decline in employment in the industrial sector.

Analysis suggests that the level of log exports will have an impact on domestic timber-based employment. Log export levels can be altered by economic forces or changes in public policy. If log exports are reduced, the question is how many of the exportable logs will go to domestic manufacture and generate employment. The volume of exportable logs which would be available for domestic manufacture depends on economic forces and landowner decisions. If log exports decline by the year 2000 and the logs which would have been exported were processed in the Douglas-fir region, employment would be higher than under the basic employment projection. If log exports fall to zero and the exportable logs were not domestically manufactured, projected employment would be less than the basic projection for the year 2000.

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PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

 PNW-212 December 1973

WILDFIRES AND THUNDERSTORMS ON ALASKA'S NORTH SLOPES

by

RICHARD J. BARNEY AND ALBERT L. COMISKEY[1/]

ABSTRACT

Existing records show that five wildfires burned more than 1,600 hectares of tundra on Alaska's Arctic Slope. Environmental conditions suitable for lightning, ignition, and burning occur more often than previously recognized at this northern latitude.

Keywords: Wildfires, Alaska, tundra, thunderstorms, lightning.

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Until now, wildfires (free-burning fires occurring on wild lands) on the North Slope tundra of Alaska have been considered almost non-existent. A statistical summary by Hardy and Franks (1963) did not mention any wildfire activity north of the Brooks Range. The same absence of far northern wildfire acknowledgment is evident in other publications (Spetzman 1959; Barney 1969a, 1971). No wildfire activity was reported as occurring at the northern latitudes on Alaska's North Slope. Personal communications with several individuals have pointed out that fires have occurred north of the Brooks Range divide in the past. Spetzman indicated several man-caused fires have burned in the drier tundra sites in years gone by. Others have observed towering cumulus clouds (probably thunderstorms) in the vicinity of the North Slope. Until recently, official records of the Bureau of Land Management, U.S. Department of the Interior, did not indicate fires occurred at such northern locations. This Federal agency has been responsible for fire suppression activities in the area since the early 1940's.

This lack of official Bureau of Land Management information was found to be partly due to their method of data handling. Wildfires occurring at the extreme northern latitudes had apparently heretofore been pooled with data from other administrative management units at lower latitudes, thereby losing specific identity in terms of their location north of the Brooks Range. In reviewing the Bureau of Land Management's official fire reports, five fires were identified as occurring north of the Brooks Range, on Alaska's North Slope.

Figure 1 shows the general fire locations. Table 1 provides more detailed information on the location, date, size, and cause of the fires. It should be noted that none of these fires has been verified on the ground by the authors. However, one of the fires noted in table 1 is one on which fire suppression action was taken. Suppression action was not taken on the others, either because of higher priority fires elsewhere or because the fire was dead when discovered.

Wildfire activity in northern latitude tundra has been documented in both Canada and Russia. Lightning fires have been reported in the Yukon Territory of Canada as far north as approximately 67°20'N. latitude (Requa 1964). In their paper on fire in the Canadian Northwest Territories, Cochrane and Rowe (1969) reported considerable fire activity was apparent in the arctic tundra: "The environment of the Eastern Arctic 'barrens' is one where the complete absence of fire might be expected. The terrain is that of a vast low plain, windswept and treeless. . . . Nevertheless, fires do occur, contributing to the

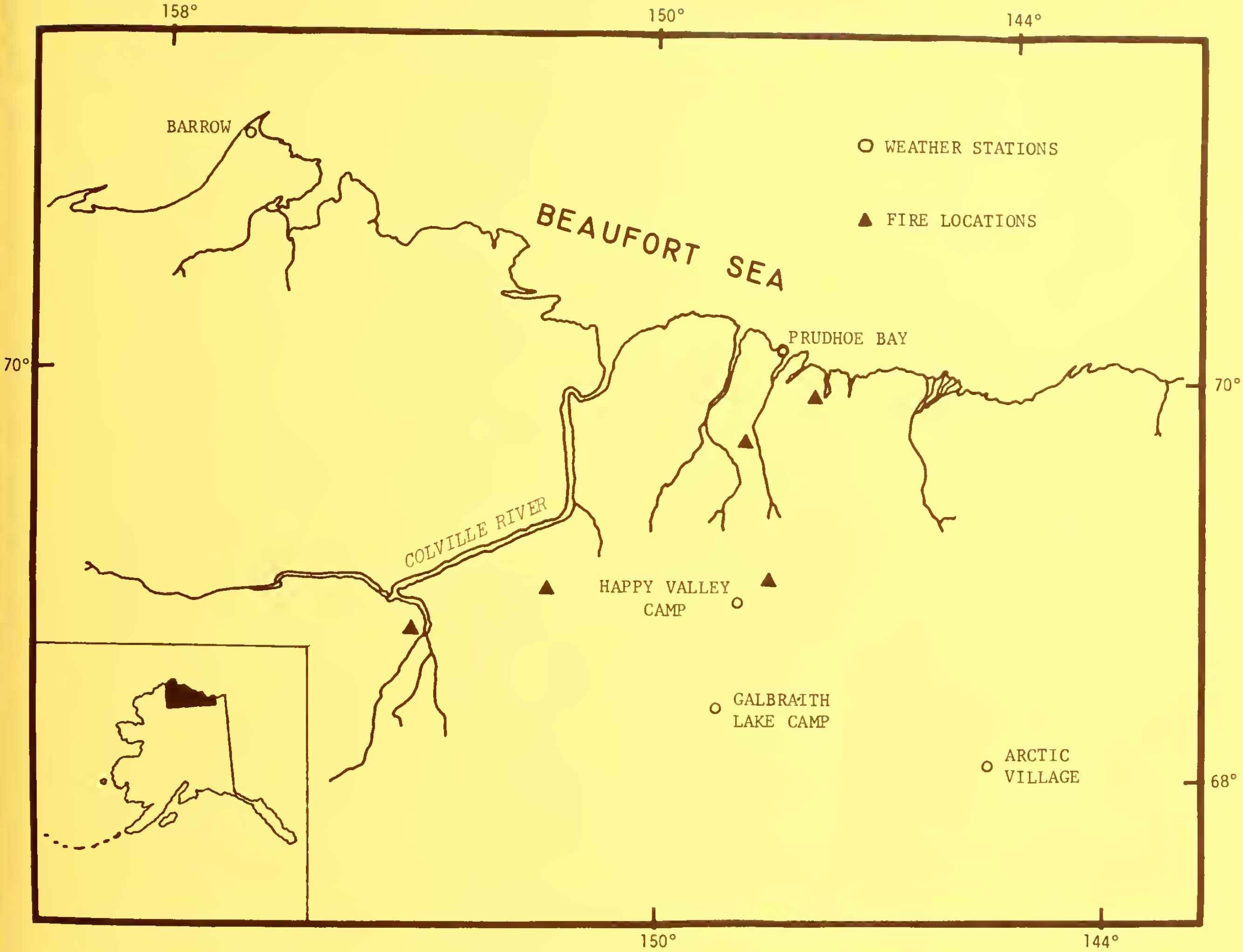

Figure 1.--*Map showing general locations of fires north of the Brooks Range.*

complexity of the tundra ecology." They go on to state that burning is selective and that Labrador tea and ground birch are quite flammable. Wildfires have also been reported in the Minor River and Kugaluk River regions of the Canadian Northwest Territories (Cody 1964). One of these fires was estimated to be 2,124 square kilometers in size. Some of these fires have burned well above the 69°N. latitude line. A forest fire at Inuvic, N.W.T., Canada, burned more than 34,800 hectares (Heginbottom 1971). The Russians have also reported wildfire activity in the Siberian tundra at approximately 70°N. latitude (Kriuchkov 1968). In this paper Kriuchkov discusses pyrogenic tundra. All the above references indicate that tundra can and does burn at far northern latitudes.

Table 1.--*Fires reported north of the Brooks Range, 1969-71.*

Characteristic	Bureau of Land Management fire number				
	9485	9557	9893	8813[1/]	8826
Date of fire discovery[2/]	6/21/69	7/7/69	8/5/70	7/7/71	7/9/71
Reported size (approximate) (hectares)	1,619.4	2.0	28.3	3.6	2.0
Reported cause	Lightning	Lightning	Man	Lightning	Lightning
Latitude	68°49'	70°05'	69°40'	69°02'	69°04'
Longitude	153°33'	147°50'	148°59'	151°55'	148°41'
Approximate elevation (meters)	335	24	122	137	396
Location	W. side Killik River	E. side Sagavanirktok River	E. side Toolik River	E. side Chandler River	N. side Lupine River
Physiographic province	Foothills	Coastal plain	Coastal plain	Foothills	Foothills
Vegetation[3/]	Well-drained tundra ridges	Wet coastal plain tundra	Wet coastal plain tundra	Moraine hills, dry tundra	Moraine hills, dry tundra

[1/] Control action was taken on this fire by 6 men.

[2/] This is the date of discovery and does not necessarily agree with the actual start date.

[3/] Based on map and classifications by Spetzman (1963).

Although wildfires may not be ecologically significant north of the Brooks Range divide, it is certainly important to note that wildfire activity can and does occur there. We suspect that fires have not been reported prior to this time because of poor detection at such northerly latitudes. However, with the increased activity on the North Slope relative to oil exploration and development, more and more fires apparently are being reported. It also seems reasonable that along with the increased activity in the area, man will become a more important cause of fire.

Based on the Alaskan climatological data, there are apparently over 30 days every year on which wildfires can occur at these extreme northern latitudes. Temperatures during June and July reach a high near 20°C. at Arctic Village, Galbraith Lake Camp, and Happy Valley Camp. Temperatures reaching the lower 20's°C. are not uncommon at these locations (U.S. Department of Commerce 1971). High temperatures near 30°C. have been reported in the foothill areas of the North Slope in mid-July (Spetzman 1959). Even Barrow temperatures reach near 21°C. on occasion, and 10°-15°C. maximums are not uncommon there during June and July. A maximum temperature of 23.9°C. has been reported at Prudhoe Bay (Weller and Brown 1971).

With the light, finely divided fuels present in the tundra, it is highly probable that conditions suitable for ignition occur more often than have been previously reported. The abundant low shrubs, grasses, sedges, lichens, and mosses provide ample organic material to sustain combustion. When finely divided dead plant material (0.6-cm diameter and less) is subjected to temperatures in the lower 20's°C. and relative humidities below 70 percent, we calculate that fine-fuel moisture will be about 10 percent and less on an ovendry weight basis (Barney 1969b). Temperature and fuel moisture conditions of this nature are necessary basic ingredients for ignition. When continuous fuels are present and an ignition source is available, fire is certainly possible under such environmental situations.

One ignition source is lightning. During the last 10 or 20 years, there have been random reports of thunderstorms from pilots flying to and from the arctic coast. Since wildfires occurring at lower latitudes are known to have been started by lightning, it seems reasonable that a similar situation undoubtedly occurs at the northern latitudes also.

Because there are few observing stations, climatology of thunderstorm occurrences over the Arctic Slope is nonexistent. However, a significant accumulation of thunderstorm data was obtained during the summer of 1971. During that time, the Bureau of Land Management made numerous thunderstorm patrols in a high-flying aircraft. The plane usually flew at the 12,500-meter level, from which it was possible to see horizontally to a distance of about 320 kilometers. Patrol routes were always restricted to the area between the Brooks Range and the Gulf of Alaska, but it was usually possible to see a portion of the Arctic Slope from the aircraft when it was patrolling the south slopes of the Brooks Range. In this way, numerous sightings were made of huge cumulonimbus clouds (probably thunderstorms) over the Brooks Range and the Arctic Slope.

A record was kept of all probable thunderstorms observed. The first was estimated to be about 80 kilometers east of Sagwon on June 17. On June 18, a line of probable thunderstorms was observed over the highest portion of the Brooks Range from the Canadian border west for a distance of 480 kilometers. On June 22 a line of thunderstorms 640 kilometers long was again observed over the Brooks Range. On June 26 a line of storms about 480 kilometers long was observed over the western portion of the Brooks Range. On the following day, June 27, the line was about 320 kilometers long, and numerous fires were reported in the Noatak River valley. The Noatak River runs generally east to west, empties into Kotzebue Sound, and bisects the western portion of the Brooks Range. On July 20, 24, and 26 the patrol observed thunderstorms over and north of the Brooks Range. It is estimated that during this period a total of 28 probable thunderstorms were observed over or north of the Brooks Range.

Many of the sightings were from a considerable distance, which tends to negate their validity--particularly with respect to location. Thus, many of the storms that were estimated to be over the Brooks Range could well have been over the Arctic Slope. It is reasonably certain that they were not south of the range. It is the opinion of the observers that if the patrol had flown over the Arctic Slope, more thunderstorms would have been sighted, and of course their locations would have been estimated much more precisely.

The summer of 1971 was not a particularly active thunderstorm year for the area between the Brooks Range and the Gulf of Alaska, although the occurrence pattern was unusual. There was almost no thunderstorm activity until about June 20. From June 20 to July 9 there was extensive and vicious thunderstorm activity during which many fires began south of the Brooks Range. Thunderstorm tops measured to an unusually high 12,500 meters. After July 9, there was only random thunderstorm activity.

It is the opinion of the authors that burnable fuel conditions and thunderstorms will occasionally coincide, thereby creating widely spaced potential wildfire conditions over the Arctic Slope. Man and his activities are another potential ignition source. As his access into the area improves, the probability that he will start fires increases.

Although there has been limited formal record of fire previous to this time, we think it is safe to assume that lightning and the associated weather and fuel conditions suitable for fire have been present for many years. It also seems reasonable to assume that fires have not just recently begun occurring north of the Brooks Range. With continued activity in that location, we are certain to receive more and more wildfire reports. Although the North Slope is apparently not a fire-dominated ecosystem, wildfire is not unknown to this arctic environment.

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ALASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

· USDA FOREST SERVICE RESEARCH NOTE

PNW-213 *January 1974*

SEEDING HABITS OF UPPER-SLOPE TREE SPECIES

I. A 12-YEAR RECORD OF CONE PRODUCTION

by

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Richard Carkin, *Forester*

and

Jack Booth, *Forestry Technician*

ABSTRACT

A 12-year study of cone production by noble, Pacific silver, grand, white, subalpine, and Shasta red firs, mountain hemlock, western white pine, and Engelmann spruce shows that upper-slope species produce medium to heavy crops at 2- to 3-year intervals at most locations. The 1968 cone crop was the heaviest observed to date.

Keywords: Cone counting, Coniferae.

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

Production of seed is first in the sequence of events leading to establishment of natural regeneration.[1/] Coniferous species are typically highly periodic in their production of cones and seed, with varying numbers of years between the heavy or very heavy crops which are most important in natural regeneration. Knowledge of patterns of cone production in order to predict the larger cone crops is, therefore, important in managing coniferous forests for natural regeneration.

Cone production by several upper-slope species important in the true fir-hemlock forests of the Pacific Northwest is the subject of this report. This study began in 1961; results from the first 7 years are reported in Franklin.[2/] This note is intended as a brief progress report on cone production over the 12 years of observations now available. The additional years of data also allow us to make some comments on whether the tentative conclusions of 5 years ago are being sustained.

Data from 52 plots scattered over the Cascade Range, Olympic Mountains, and Coast Ranges are tabulated and discussed in this report. Most plots now have been observed 11 years. Species observed included noble fir (*Abies procera*), Pacific silver fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*), western white pine (*Pinus monticola*), grand and white firs[3/] (*Abies grandis* and *A. concolor*), Shasta red fir (*Abies magnifica* var. *shastensis*),[4/] subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*).

1/ Arthur L. Roe, Robert R. Alexander, and Milton D. Andrews. Engelmann spruce regeneration practices in the Rocky Mountains. USDA Production Research Report 115, 32 p., illus., 1970.

2/ Jerry F. Franklin. Cone production by upper-slope conifers. USDA Forest Service Research Paper PNW-60, 21 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 1968.

3/ Grand fir at high elevations in the Oregon Cascade Range is a morphologically variable complex often referred to as white fir. At both Lost Prairie and Bessie Rock where cone plots are located for this species complex elements of both taxons are evident. Due to dominant morphological features, we refer to the plants at Lost Prairie as grand fir and those at Bessie Rock as white fir.

4/ Shasta red fir in southern Oregon is a morphologically variable complex sometimes referred to as noble fir. Populations may constitute hybrid swarms resulting from mingling of noble and California red firs (*Abies magnifica*), in which case none of the present taxonomic designations is correct. However, because of ecological differences between the southern Oregon true fir and the noble fir found in Washington and northern Oregon, and until the identity of the former has been satisfactorily established by taxonomic study, the southern Oregon true fir will be referred to as Shasta red fir.

STUDY AREAS AND METHODS

The location of most of the 52 plots and characteristics of the study trees are tabulated in Franklin (see footnote 2); the general locations are shown in figure 1. With the exception of the Sand Mountain subalpine fir plot, all plots are located in mature to overmature stands of the subject species. Plots added are as follows:

Species	Locale	Ranger District and Forest	Elevation	Number of trees
			(Feet)	
Noble fir	Blue Lake	Wind River, Gifford Pinchot	3,800	18
Engelmann spruce	Lost Prairie	Sweet Home, Willamette	3,325	13
Pacific silver fir	Wildcat Mountain	McKenzie, Willamette	5,000	13
Mountain hemlock	Wildcat Mountain	McKenzie, Willamette	5,000	12
White fir	Bessie Rock	Prospect, Rogue River	4,900	22

Data consist of annual cone counts on dominant and codominant trees of the subject species repeated from the same counting point using high-powered binoculars or a spotting scope. Most of the study plots are along clearcut boundaries or roads where good views of the crowns are available; since annual variations in cone production are the main purpose of the study, edge effects are considered unimportant. For further details on the field methods see Franklin (1968) (footnote 2).

Annual cone production is presented as the median cone count on the plot. This is the middle observation when cone counts are arranged in order of magnitude. We have used medians because they appear more representative of cone production by the "typical" study tree than the average or mean count; one or two trees with large crops in a generally poor year can produce relatively large average plot values even if most trees had few or no cones. The reader interested in means and ranges of cone counts on plots can find them tabulated through 1967 in Franklin (1968) (footnote 2). If a reader wishes to convert the actual counts to total production by a tree, we suggest he use the following admittedly arbitrary multiplication factors:

Noble and Shasta red firs and western white pine	1.5
Pacific silver, grand, and subalpine firs	1.7
Mountain hemlock and Engelmann spruce	2.0

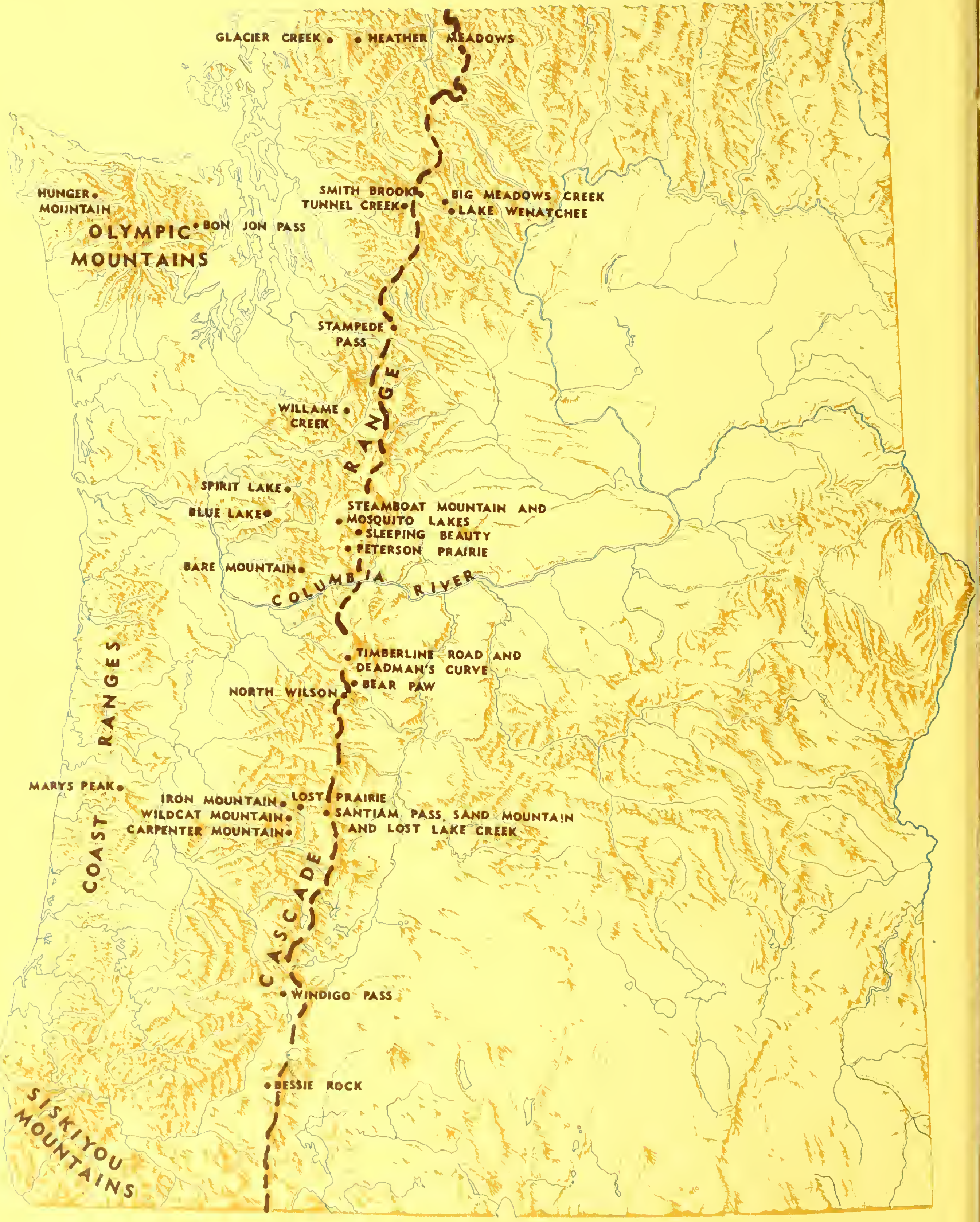

Figure 1.--*Geographic distribution of cone production study plots.*

We have used these factors only in calculating estimated maximum cone and seed yields, not in preparing tables 1 to 6.

For convenience in discussing cone data, we use general categories for cone production--failures, medium crops, very heavy crops, etc. A cone crop rating system based on the median cone count was developed to put the terms used on a quantitative basis (table 1). Considerations of number of seeds per cone and the range in cone production commonly encountered resulted in differences between species in rating definitions. The reader should note the system is based on median cone counts of a sample of dominant trees. It can be applied as well to individual trees.

Table 1.--*Cone crop rating system based on median count of a sample of dominant trees, cone counts to be made from a single observation point per tree*

Species	Crop rating	Number of cones per tree[1/]
Noble, Pacific silver, and Shasta red firs and western white pine	Failure	0
	Very light	1-4
	Light	5-9
	Medium	10-19
	Heavy	20-49
	Very heavy	50+
Grand and subalpine firs	Failure	0
	Very light	1-9
	Light	10-19
	Medium	20-49
	Heavy	50-99
	Very heavy	100+
Engelmann spruce and mountain hemlock	Failure	0-10
	Very light	11-49
	Light	50-99
	Medium	100-199
	Heavy	200-299
	Very heavy	300+

[1/] Median count falls within range shown.

RESULTS

Cone production data from 1961 through 1972 are presented in tables 2 through 6. In discussing these observations, we contrast the productivity over the last 5 years with the earlier data.

One outstanding feature is the consistency in cone production between almost all species and locations since 1968 (tables 2 through 6). Heavy to very heavy crops were produced in 1968 and 1971 with failures or very light crops in 1969 and 1972; at most plots, the 1968 cone crop was the heaviest recorded. Cone crops in 1970 were more variable, but very light to light crops were most common.

CONE PRODUCTION BY SPECIES

Noble fir follows the general pattern of cone production quite closely (table 2). Over an 11-year period, it has now shown itself as a fairly prolific cone producer typically yielding good crops at 3-year intervals within its main range. Trees at the eastern margin of the species' range (Stampede Pass, Sleeping Beauty, and North Wilson plots)

Table 2.--*Median*[1/] *number of cones counted on noble fir trees by location and year*

Location	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Tunnel Creek	18	280	0	8	1	24	0	441	0	4	164	0
Stampede Pass	22	12	0	2	0	0	5	55	0	9	18	0
Willame Creek	--	50	26	2	184	40	2	253	0	34	40	0
Sleeping Beauty	--	18	0	0	0	16	0	78	0	3	18	2
Spirit Lake	--	--	4	--	76	6	0	84	0	2	24	0
Blue Lake	--	--	--	--	--	--	2	149	0	1	35	3
North Wilson	--	1	0	0	0	0	12	40	0	1	35	3
Wildcat Mountain	--	82	9	3	172	0	10	151	0	0	92	0
Marys Peak	--	67	1	1	112	4	4	163	0	12	72	0
Average	20	73	5	2	68	11	4	157	0	7	55	1

NOTE: -- means no measurements were taken.

1/ The median number is the middle observation when cone counts are arranged in order of magnitude.

show somewhat more sporadic patterns of cone production during the first half of the study but have followed the same pattern as the other plots since 1968; there is some indication of lower absolute numbers of cones being produced on these marginal plots. Noble fir at Willame Creek continues to be the most consistently productive plot; we have observed heavy to very heavy cone crops in 7 out of 11 years. Very heavy crops in 1962, 1968, and 1971 have produced the highest total cone count (940) at Tunnel Creek, however; it is interesting that this plot is at the northern limit of the noble fir range.

Pacific silver fir also followed the general pattern of good to excellent cone crops in 1968 and 1971 and few cones in intervening years with only one notable exception (Hunger Mountain, table 3). The

Table 3.--*Median*[1/] *number of cones counted on Pacific silver fir trees by location and year*

Location	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Glacier Creek #1	17	10	0	0	2	0	0	66	0	8	27	0
Glacier Creek #2	--	--	0	0	22	0	0	125	0	21	39	0
Tunnel Creek	--	--	0	0	18	0	0	61	0	0	14	0
Stampede Pass	--	3	0	0	0	0	0	9	0	0	37	0
Mosquito Lakes	--	14	0	0	0	1	0	68	0	0	28	0
Spirit Lake	--	--	0	0	92	0	0	128	0	0	67	0
Bare Mountain	--	18	0	0	2	0	0	87	0	0	23	0
Timberline Road	--	44	0	0	64	0	2	156	0	0	94	0
Santiam Pass	--	12	0	0	1	0	0	62	0	0	34	0
Iron Mountain	--	65	0	0	115	0	1	129	0	0	124	0
Wildcat Mountain	--	--	--	--	--	--	0	42	0	0	26	0
Hunger Mountain	--	8	11	0	40	0	0	207	0	81	0	11
Bon Jon Pass	--	15	0	0	0	0	0	54	0	4	18	0
Average	17	21	1	0	30	0	0	92	0	8	41	1

NOTE: -- means no measurements were taken.

[1/] The median number is the middle observation when cone counts are arranged in order of magnitude.

entire 12-year record strongly suggests a general 3-year periodicity in production of cone crops at a given locale. The absolute numbers of cones produced are largest in 1968 but still well below the numbers recorded for noble fir.

Most mountain hemlock plots had very heavy cone crops in 1968 and medium to heavy crops in 1971 (table 4). In 1969, 1970, and 1972, cone crops were essentially failures on all plots except at Heather Meadows near Mount Baker; this plot had a medium crop in 1970 and followed it with a very heavy crop in 1971. In general, the 11-year record shows good crops at 3-year intervals, but some erratic behavior in the Washington plots in 1965 and 1966 suggests localized climatic effects.

Table 4.--*Median*[1/] *number of cones on mountain hemlock trees by location and year*

Location	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Heather Meadows	300	0	5	37	120	0	429	2	175	300	0
Stampede Pass	255	0	0	30	95	0	288	0	14	80	0
Steamboat Mountain	192	0	0	198	96	0	300	2	0	225	12
Deadman's Curve	265	0	0	265	6	0	1,200	0	0	150	1
Santiam Pass	600	0	0	26	8	0	750	0	0	188	0
Wildcat Mountain	--	--	--	--	--	0	410	0	0	125	0
Carpenter Mountain	380	0	3	420	1	0	620	0	0	150	0
Windigo Pass	300	0	25	130	0	0	650	0	0	125	0
Average	327	0	5	158	47	0	581	0	24	168	2

NOTE: -- means no measurements were taken.

1/ The median number is the middle observation when cone counts are arranged in order of magnitude.

Western white pine continued to be the most consistent cone producer of the species studied (table 5). However, more cone crop failures were recorded on plots in 1969 and 1972 than had been previously noted in a single year. Interestingly, the very heavy crops of 1968 and 1971 were synchronous with those of the other species; prior to 1968, good crop years for western white pine typically were not synchronized with those for other species.

Engelmann spruce and grand and white firs, which had previously shown considerable variation in peak years of cone production between plots and in relation to other species, also followed the general

Table 5.--*Median*[1/] *number of cones counted on western white pine trees by location and year*

Location	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Lake Wenatchee	0	0	--	--	--	--	--	--	--	--	--
Big Meadows Creek	--	0	114	1	0	0	42	0	--	--	--
Smithbrook	--	--	16	10	10	0	22	0	39	22	26
Peterson Prairie	50	2	113	14	17	87	88	0	51	63	0
Bear Paw	34	3	77	14	2	13	40	--	--	--	--
Santiam Pass	41	12	54	11	2	70	58	0	0	58	0
Lost Prairie	--	0	8	35	0	21	189	4	8	37	0
Windigo Pass	62	1	38	39	2	4	109	0	0	57	0
Bessie Rock	--	--	--	--	59	9	144	0	27	70	4
Average	37	3	60	18	12	26	86	1	21	51	5

NOTE: -- means no measurements were taken.

[1/] The median number is the middle observation when cone counts are arranged in order of magnitude.

pattern of heavy crops in 1968 and 1971 and poor crops during 1969, 1970, and 1972 (table 6). Results now suggest good crops at intervals of 2 to 3 years for these species. Subalpine fir had a very heavy crop in 1968 and, at three of four plots, medium to very heavy crops in 1971 (table 6). An average interval of 2 to 3 years is also indicated for this species by the 11-year record of cone production. Finally, the limited data for Shasta red fir show a consistency with cone production in noble fir for at least the last 5 years, i.e., good crops in 1968 and 1971.

Table 6.--*Median*[1/] *number of cones counted on subalpine fir, grand and white firs, Shasta red fir, and Engelmann spruce by location and year*

Location and species	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Subalpine fir:											
Smithbrook	--	--	45	10	0	0	182	0	0	97	0
Big Meadows Creek	--	0	126	0	63	0	118	0	22	4	0
Steamboat Mountain	53	0	3	31	3	1	84	0	0	26	0
Sand Mountain	15	0	1	44	0	0	153	0	0	78	0
Average	34	0	44	42	33	0	134	0	6	51	0
Grand and white firs:											
Big Meadows Creek	--	0	342	0	252	0	227	0	28	140	0
Peterson Prairie	--	1	148	1	302	0	184	0	8	160	0
Lost Prairie	--	0	50	36	16	11	151	0	7	136	0
Bessie Rock	--	--	--	--	--	13	326	0	0	232	0
Average	--	0	180	12	190	6	222	0	11	167	0
Shasta red fir:											
Windigo Pass	7	0	7	22	0	1	76	0	0	36	0
Bessie Rock	--	--	--	--	0	6	91	0	0	132	0
Average	7	0	7	22	0	4	84	0	0	84	0
Engelmann spruce:											
Big Meadows Creek	--	0	290	145	120	0	625	0	50	112	0
Lost Creek	--	170	0	570	12	160	1,600	0	0	600	0
Lost Prairie	--	--	--	--	--	1	750	0	10	225	0
Average	--	85	145	358	66	80	992	0	20	312	0

NOTE: -- means no measurements were taken.

[1/] The median number is the middle observation when cone counts are arranged in order of magnitude.

RECORD CROPS OF INDIVIDUAL TREES

Because of the very heavy cone crop in 1968, almost all of the earlier records of production by individual trees were shattered; only the subalpine fir record (510 cones counted) stood.

Species	Plot	Cones counted	Conversion factor	Estimated total cones	Total seeds per cone[5]	Estimated total seeds
Noble fir	Tunnel creek	2,000	1.5	3,000	500	1,500,000
Pacific silver fir	Hunger Mountain	609	1.7	1,035	400	414,000
Mountain hemlock	Deadman's Curve	2,500	2.0	5,000	100	500,000
Western white pine	Bessie Rock	426	1.5	639	120	77,000
Grand and white fir	Bessie Rock	1,000	1.7	1,700	250	425,000
Shasta red fir	Bessie Rock	412	1.5	618	450	278,000
Engelmann spruce	Lost Lake Creek	5,000	2.0	10,000	100	1,000,000

These are, of course, only estimated values, but the quantities of seed a single tree can produce are obviously prodigious. The production of the noble fir tree approximates 100 pounds of cleaned seed and that of the Shasta red fir and Pacific silver firs 32 and 35 pounds, respectively.

CONE PRODUCTION IN MIXED SPECIES STANDS

Franklin (see footnote 2) examined cone production by different species occurring in the same locale and concluded that some seed can be expected from at least one species almost every year, i.e., all species rarely fail simultaneously. The data from 1968 to 1972 show a much greater synchrony in cone crops than from 1962 to 1967, however (table 7). In the areas shown in table 7, all species failed in 1969 and 1972, and the three Oregon locales show consistent failure of all species in 1970. This is clearly a consequence of western white pine, grand and white firs, and Engelmann spruce following the same patterns as the other species from 1968 to 1972, whereas they show considerable independence from 1962 to 1967. Our 11-year record suggests that very heavy and failure cone years for different species are as likely to be in phase as complimentary in a given locale.

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[5] Based on cone scale counts; data on file at U.S. Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon.

Table 7.--*Yearly comparison of cone crop ratings*[1] *between species as observed in the same general locality*

Location and species	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Big Meadows Creek:											
Western white pine	0	0	5	0	0	0	4	0	--	--	--
Subalpine fir	--	0	5	2	0	0	5	0	3	1	0
Engelmann spruce	--	0	5	3	3	0	5	0	2	3	0
Grand fir	--	0	5	0	5	0	5	0	3	5	0
Mount Adams:											
Noble fir	3	0	0	0	3	3	5	0	1	3	1
Pacific silver fir	3	0	0	0	0	0	5	0	0	4	0
Subalpine fir	4	0	1	3	1	1	4	0	0	3	0
Grand fir	--	1	5	1	5	0	5	0	1	5	0
Mountain hemlock	3	0	0	3	2	0	5	0	0	4	1
Western white pine	5	1	5	3	3	5	5	0	5	5	0
Douglas-fir[2]	--	--	--	--	--	2	5	0	0	3	0
Western hemlock[2]	--	--	--	--	--	1	5	1	2	4	0
Santiam Pass:											
Pacific silver fir	3	0	0	1	0	0	5	0	0	4	0
Mountain hemlock	5	0	0	1	0	0	5	0	0	3	0
Western white pine	4	3	5	3	1	5	5	0	0	5	0
Subalpine fir	2	0	0	3	0	0	5	0	0	4	0
Engelmann spruce	--	4	0	5	1	3	5	0	0	5	0
Willamette Province:											
Pacific silver fir	5	0	0	5	0	1	5	0	0	5	0
Noble fir	5	3	1	5	0	3	5	0	0	5	0
Grand fir	0	0	4	3	2	2	5	0	1	5	0
Mountain hemlock	5	0	0	5	0	0	5	0	0	3	0
Western white pine	--	2	2	4	0	4	5	1	2	4	0
Engelmann spruce	--	--	--	--	--	--	5	0	0	5	0
Southern Oregon Cascades:											
Shasta red fir	2	0	2	4	0	0	5	0	0	5	0
White fir	--	--	--	--	--	2	5	0	0	5	0
Western white pine	5	0	4	4	1	2	5	0	0	5	0
Mountain hemlock	5	0	0	3	0	0	5	0	0	3	0

NOTE: -- means no measurements were taken.

[1] Crop ratings are 0 = failure, 1 = very light, 2 = light, 3 = medium, 4 = heavy, and 5 = very heavy.

[2] Estimated from collections of material in seedtraps.

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ALASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-214 *January 1974*

SEEDING HABITS OF UPPER-SLOPE TREE SPECIES

II. DISPERSAL OF A MOUNTAIN HEMLOCK SEEDCROP ON A CLEARCUT

by

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and

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ABSTRACT

Mountain hemlock seedfall declined rapidly beyond one tree height from the stand edge (125 feet). Central portions of the 30-acre clearcut still received 50,000 to 100,000 sound seeds per acre during a very heavy seed year. Therefore, seedling germination or establishment appears to be the major problem in regenerating mountain hemlock on clearcuts.

Keywords: Seed dispersal, seedling survival, mountain hemlock, *Tsuga mertensiana*.

Seed supply is a key element in natural regeneration of forest stands. Consequently, seeding habits received early attention in a research program on natural regeneration of upper-slope forests begun in 1961. An initial long-term study involves cone production by selected species (Franklin 1968, Franklin et al. 1974). In 1967, research was extended to measurements of seedfall to relate the cone production data to viable seed production and measure dissemination on partially cut and clearcut areas. These and other studies of upper-slope seeding habits continue. Rather than waiting until all are completed, we will report results of small but self-contained study segments which are valuable in providing foresters with guidelines for selection of silvicultural techniques.

Dissemination of a bumper 1968 mountain hemlock (*Tsuga mertensiana*) seed crop on a clearcut in the southern Oregon Cascade Range is the subject of this report. Most data concern relationships between seedfall and distance from seed source. Although based on a single case history, this report provides information useful in evaluating seed supply as a limiting factor in natural regeneration and in selecting clearcut sizes suitable for mountain hemlock forests. Data from a somewhat smaller seed crop in 1971 confirm the 1968 results.

STUDY METHODS

The clearcut studied is located on gently sloping topography at about 5,400-foot elevation near Diamond Lake in the Crater Lake Province, Oregon High Cascades (Franklin 1965). The 31-acre tract was logged in 1961 as part of the Windigo Pass Timber Sale, and there has been very little revegetation since then. The surrounding stand is dominated by mountain hemlock (92 percent of the stems) with lesser amounts of Shasta red fir (*Abies magnifica* var. *shastensis*) and western white pine (*Pinus monticola*). Characteristics of the mountain hemlock stand component adjacent to the four seed trap transects are as follows (height is average of two dominant trees, and basal area and trees per acre are for trees over 5-inch d.b.h. on a 1-acre plot):

Clearcut edge	Tree height (Feet)	Basal area (Ft^2/acre)	Trees (Number/acre)
North	70	149	277
South	97	410	357
West	140[1/]	258	380
East	77	240	324

Dominants averaged 225 years in age based on stump counts; the stand adjacent to the north transect appeared somewhat younger than the remainder of the bordering forest.

[1/] Based on Shasta red fir trees; mountain hemlock dominants averaged 25 to 35 feet shorter.

Seed production and dissemination were measured using four groups of four-seed-trap transects extending at right angles from each of the timber edges toward the center of the clearcut (fig. 1). Sixteen traps

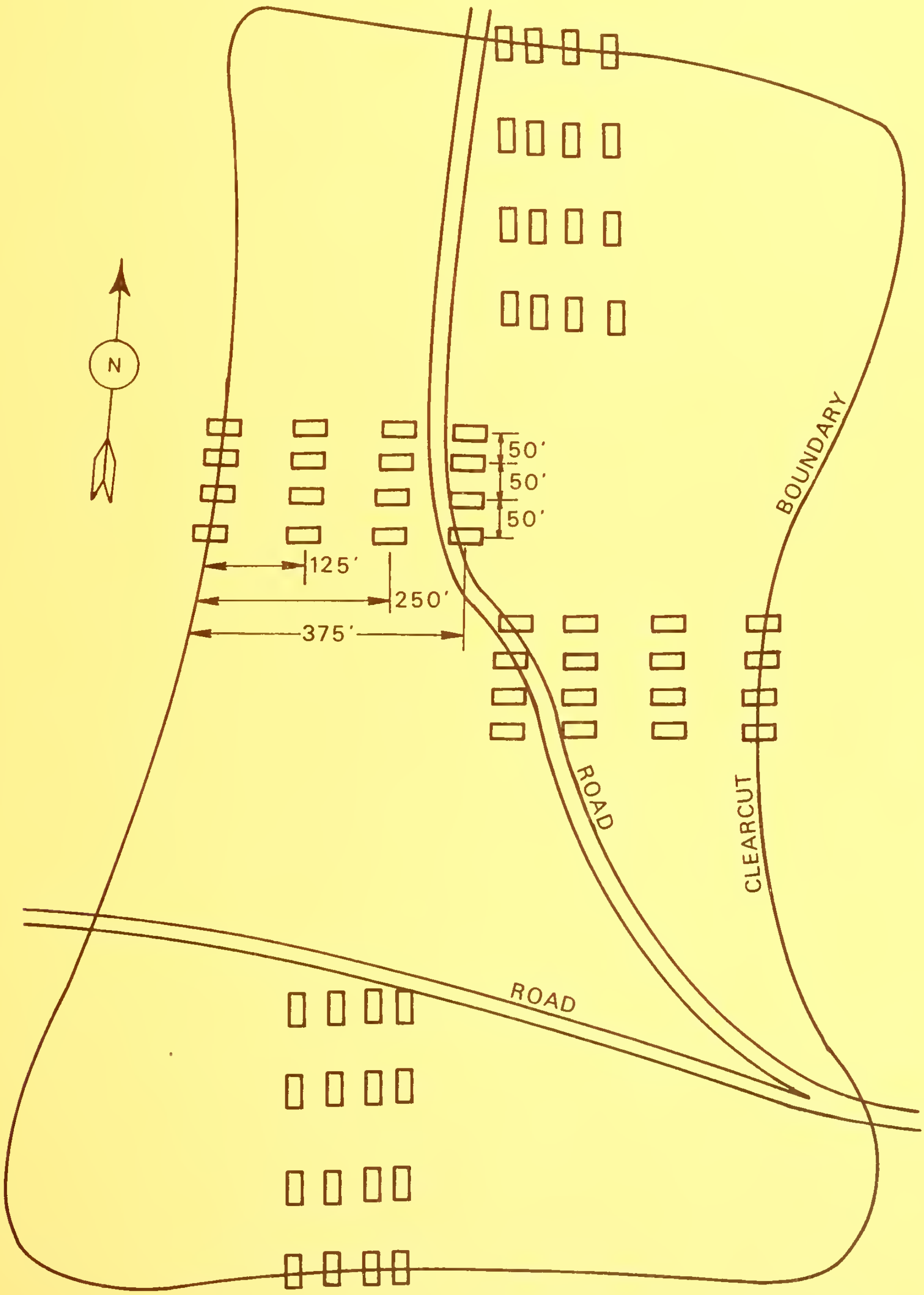

Figure 1.--Arrangement of seed traps and transects on clearcut.

were used in each transect group with four traps placed at 0, 125, 250, and 375 feet from the stand edge. One transect group was located on each side of the essentially rectangular clearcut for a total of 64 traps. The 1- by 2-foot seed traps used followed Herman's (1963) design with an additional crossmember in the top half of the trap to support heavy snow loads.

Trapping began during the 1967 seed year, but the mountain hemlock seed crop was insufficient for statistical analysis. In 1968, mountain hemlock produced a very heavy cone crop which provided the seedfall data reported here. Seeds were collected from the traps on about October 1 and November 1 and again the following spring as soon as snow conditions permitted. Seed soundness was determined by a cutting test. Mountain hemlock, which apparently produces medium to heavy cone crops at approximately 3-year intervals (Franklin 1968, Franklin et al. 1973), produced a medium crop in 1971. Collections were repeated for the 1971 seed crop following the same procedures.

STATISTICAL ANALYSES

Regression analyses were conducted to determine the relationship between distance from stand edge and both total and sound seedfall for each transect and the combined data. The regression model was of the form

$$log_e\ (y+1) = a + b\ (\frac{1}{x})$$

where y = number of seed and x = distance from stand edge. Covariance analyses were conducted to determine whether the regression surfaces (slopes and intercepts) for each transect were significantly different. Finally, regression of the ratio of sound to total seed on distance was carried out to determine whether the ratio varied with distance; this allowed us to draw inferences as to whether empty and sound seed differ in flight distance.

RESULTS

Not surprisingly, mountain hemlock seedfall is strongly correlated with distance from stand edge (fig. 2, table 1). Regression analyses of seedfall on distance are significant for all transects or cutting margins. The rapidity with which seedfall declines with increasing distance from stand edge was unexpected, however, for the small, winged mountain hemlock seeds. Sound seeds declined by about two-thirds from the amount at the stand edge in the distance of one-tree height (i.e., 125 feet) into the clearcut, generally falling to a level of less than 10 percent at 250 feet and beyond. The regression equations predict a somewhat more rapid decline in seedfall in the first 125 feet than the actual data indicate (table 1).

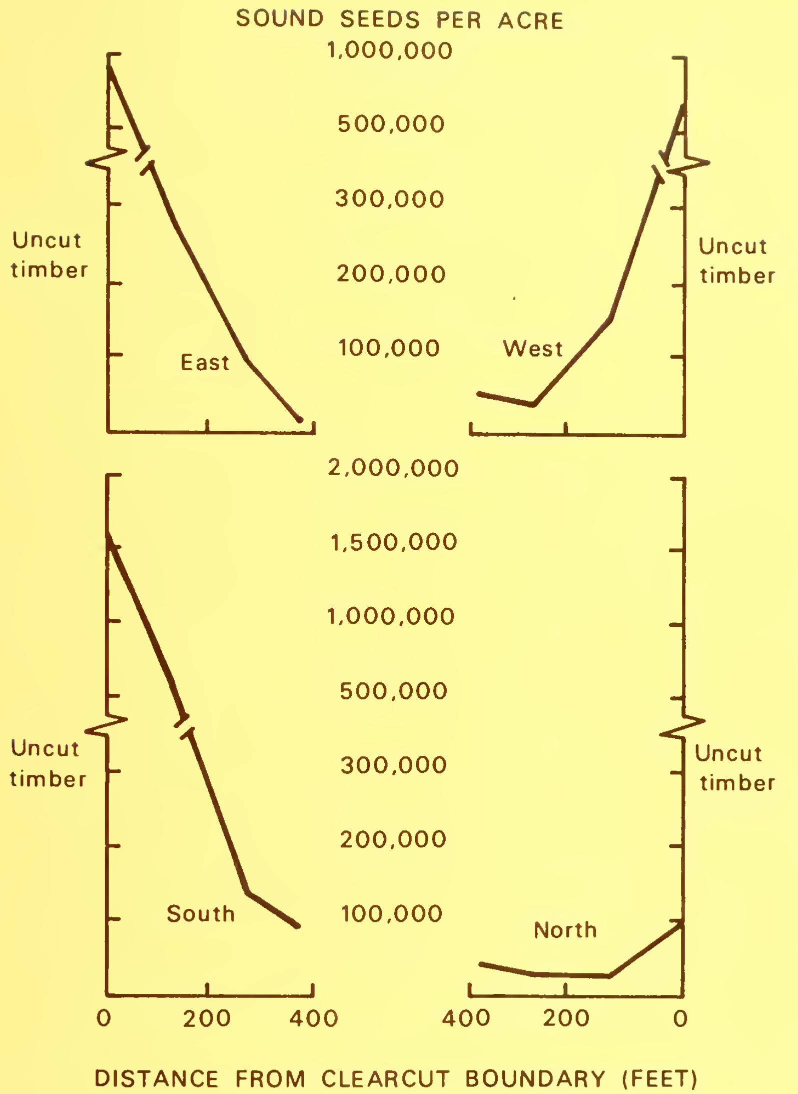

Figure 2.--Average mountain hemlock seedfall from the 1968 cone crop by clearcut boundary and distance from the stand edge.

Table 1.--*Numbers of sound mountain hemlock seed per acre from the 1968 seed crop by distance from stand edge and clearcut boundary*[1/]

Clearcut margin	Distance from stand edge (feet)			
	0	125	250	375
	-------------------*Thousand seeds*-------------------			
North	87	27	33	49
South	1,677	506	142	93
West	659	163	38	51
East	888	283	98	16
Average, all transects	828	245	78	52
Values predicted by regression analysis[2/]	[3/] 524	77	77	77

[1/] Each figure (except for the "average" row) is based on sound seed collected in four 1- by 2-foot traps, converted to a per-acre basis, and rounded to the nearest thousand. Standard errors were calculated for each four-trap set; one standard deviation ranged from 340 to 6,806 sound seeds per acre (±) for the sets of traps at 375 feet, which had the greatest variation.

[2/] Based on the pooled data. Since there were significant differences in the regression coefficients, we are not justified in using the regression equation for the pooled data. We have included it simply to show the general form of the curves predicted by the individual regression equations.

[3/] Predicted value 1 foot from the stand edge.

Level of seedfall varies with transect or clearcut margin; covariance analyses indicated statistically significant differences between the regression coefficients for the four transects. Inspection of the data strongly suggests that the absolute amounts of seedfall as well as the slope of the regression line (regression coefficients) vary significantly with transect. A major factor affecting absolute numbers of seed (and possibly responsible for a part of the significant variation in regression coefficients as well) would seem to be the nature of the marginal stand. The transect with the highest seedfall is on the south margin which has the largest basal area of the four marginal stands; the north transect has the lowest seedfall per acre and by far the lowest basal area and trees per acre.

Initially it was hoped that use of four transects extending from different stand margins would enable us to draw some tentative conclusions about the major wind direction for dispersal, i.e., dry east winds versus winter storm winds from the southwest. No such inferences seem possible because of the large differences in stand density and total seedfall on each side of the clearcut. The statistically significant difference in regression coefficients does suggest the possibility of at least small differences in dispersal patterns from different stand margins, however.

Results have been presented and discussed in terms of sound seed only rather than total seed since analyses of both give essentially the same results. The ratio of sound to total seed did not vary significantly with distance from stand edge; this suggests that differences in seed flight distances of sound and empty seed are of no importance on small clearcuts of the type studied here. Our data do show some interesting seasonal variations in percent of sound seed, however.

Collection date	Sound	Total	Percent sound
October 1, 1968	104	158	65.8
November 1, 1968	667	961	69.4
Spring 1969	109	269	40.5
Total	880	1,388	63.4

The results of the seedfall study in 1971-72 were similar, although total seedfall was only about one-third as much as in 1968-69 (444 seeds collected). The proportion of sound seed was slightly higher--74.8 percent. Seeds collected on October 1 were much poorer (35.7 percent sound) than those collected in the spring (76.0 percent). The relationship between seedfall and distance from seed source was the same. The various clearcut boundaries again differed in total seedfall with the same ranking; the largest number of seed were collected in the transect adjacent to the southern boundary, fewest in the northern transect, and the east and west transects intermediate.

DISCUSSION AND CONCLUSIONS

Dispersal patterns on this 31-acre clearcut show a rapid decline in seedfall with distance from stand edge. Seedfall (in a bumper seed year) tends to plateau at a level of 50,000 to 100,000 sound seeds per acre (1 to 2 pounds) beyond one tree height and up to 375 feet from the stand edge, the maximum distance possible on this small cutting. Marginal stand conditions (number and size of seed-bearing trees) appear to strongly influence absolute amounts in the adjacent clearcut.

It might be logical to expect further decreases in seedfall beyond 375 feet, i.e., in central portions of larger clearcuts. Results of similar studies with other light-seeded species--Engelmann spruce (Roe 1967; Roe et al. 1970) and lodgepole pine (Dahms 1963)--suggest that further decreases in seedfall beyond 375 feet from the stand edge are very gradual. These studies also confirm the extremely rapid decline in seedfall between the stand edge and one tree-height distance into a cutting. The question as to what might happen to seedfall on a larger clearcut is probably academic in any case since few foresters would recommend clearcutting more than 30 acres of mountain hemlock forest in a single patch.

Larger mountain hemlock clearcuts (including the one studied here) have failed to restock adequately with postlogging natural regeneration of mountain hemlock even with the substantial seedfall reported here. This appears to confirm our suspicions that factors other than seed supply (such as frost and drought) are limiting natural regeneration on larger clearcuts. This is clearly the situation on some of the small (less than 10 acres), poorly stocked mountain hemlock clearcuts.

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PACIFIC NORTH WEST
FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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SEEDING HABITS OF UPPER-SLOPE TREE SPECIES III. DISPERSAL OF WHITE AND SHASTA RED FIR SEEDS ON A CLEARCUT

by

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ABSTRACT

Seedfall from the very heavy white and Shasta red fir seed crops in 1968 and 1971 declined very rapidly with increasing distance from the stand edge on a 40-acre clearcut. Southwesterly winds appear to be most important in dispersal. Strip clearcuts elongated northwest-southeast or shelterwoods provide the best assurance of adequate seed supply and favorable conditions for seedling establishment.

Keywords: Seed dispersal, seedling survival, *Abies magnifica* var. *shastensis*, white fir, *Abies concolor*.

Seed supply is a key factor in natural regeneration of forest stands. Consequently, seeding habits received early attention in a research program on natural regeneration of upper-slope forests begun in 1961. An initial long-term study involved cone production by selected species (Franklin 1968, Franklin et al. 1974). In 1967, research was extended to measurements of seedfall to relate the cone data to viable seed production and measure dissemination on partially cut and clearcut areas. These and other studies of upper-slope seeding habits continue. Rather than waiting until all are completed, we will report results of small but self-contained study segments which are valuable in providing foresters with guidelines for selection of silvicultural techniques.

Dissemination of very heavy 1968 and 1971 Shasta red fir (*Abies magnifica* var. *shastensis*) and white fir (*Abies concolor*) cone crops on a clearcut in the southern Oregon Cascade Range is the subject of this report. Most data concern relationships between seedfall and distance from seed source. Although based on a single case history, this report provides information useful in selecting clearcut sizes suitable for upper-slope true fir forests.

STUDY METHODS

The clearcut studied is located at about 5,100-foot elevation near Bessie Rock on the Prospect Ranger District, Rogue River National Forest. This is within the Crater Lake Province of the Oregon High Cascades (Franklin 1965). The 40-acre tract was logged in 1961. The gently sloping area is in a midslope position with highest elevations to the north; exposure is southerly. The surrounding stand is composed of Shasta red fir (53 percent of basal area), white fir (21 percent), western white pine (*Pinus monticola*) (18 percent), Douglas-fir (*Pseudotsuga menziesii*), and mountain hemlock (*Tsuga mertensiana*) (4 percent each). Dominant Shasta red firs were some 123 to 137 years of age. Characteristics of only the true fir stand components adjacent to the four seed trap transects are as follows (height is average of two dominant Shasta red fir trees, and basal area and trees per acre are for trees over 5-inch d.b.h. based on a 1-acre plot):

Clearcut edge	Tree height (Feet)	Basal area (Ft^2/acre)	Trees (No./acre)	Red fir (Percent of true fir basal area)	White fir (Percent of true fir basal area)
North	176	41	65	79	21
South	161	56	98	82	18
West	123	27	90	66	34
East	150	32	71	63	37

White firs average 10 to 20 feet shorter than the Shasta red firs on this site.

Seed production and dissemination were measured using four groups of seed trap transects extending at right angles from each timber edge toward the center of the essentially rectangular clearcut (fig. 1).

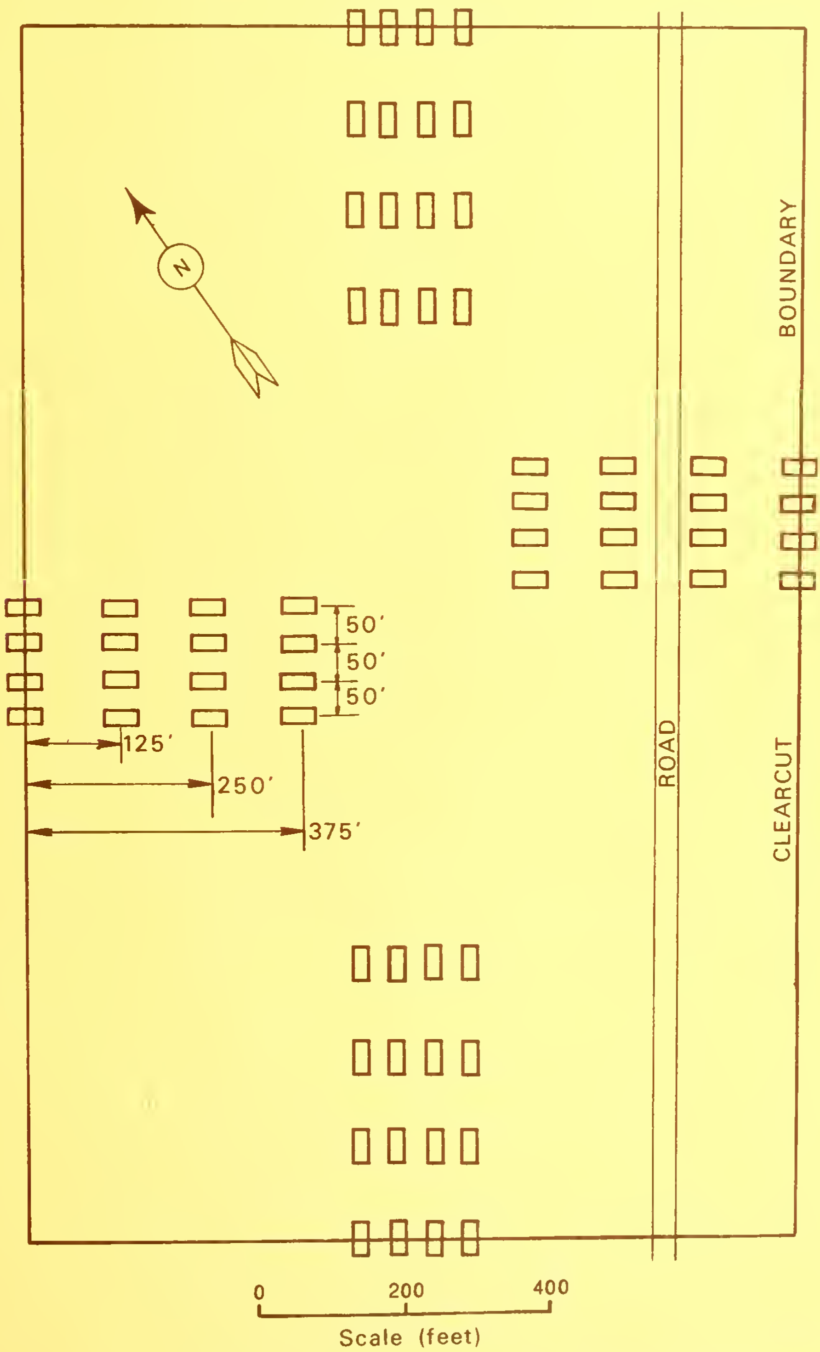

Figure 1.--Layout of seed traps on clearcut area.

Sixteen traps were used in each transect group, with four traps placed at 0, 125, 250, and 375 feet from the stand edge for a total of 64 traps. The 1- by 2-foot seed traps were constructed as described by Herman (1963) with an additional crossmember in the top half of the trap to support heavy snow loads.

Trapping began during the 1967 seed year, but the true fir seed crop was insufficient for statistical analysis. In 1968, true firs produced a very heavy cone crop which provided the seedfall data reported here. Seeds were collected from the traps on about October 1, November 1, and again the following spring as soon as snow conditions permitted. Seed soundness was determined by a cutting test. Collections were repeated for the very heavy true fir cone crop in 1971 using the same procedures.

STATISTICAL ANALYSES

A variety of regression analyses were conducted to determine the relationship between distance from stand edge and:

- sound Shasta red fir seed,
- sound white fir seed,
- sound true fir seed (Shasta red and white),
- total true fir seed,
- ratio of sound true fir to total true fir seed, and
- ratio of Shasta red fir to total true fir seed.

These analyses were conducted separately for all four transects or clearcut margins. The regression model was of the form

$$\log_e (y+1) = a + b \left(\frac{1}{x}\right)$$

where y = number of seed (trap counts) and x = distance from stand edge. Covariance analyses were conducted for each set of four equations to determine whether the regression surfaces (slopes and intercepts) were significantly different.

RESULTS

The 1968 and 1971 seed crops are compared in table 1. Total seedfall was higher in 1968, but numbers of sound seed were greater in 1971 because seed quality (percent filled seed) was substantially better in 1971. The proportion of white fir seed was also greater in 1971 than in 1968 (32.4 versus 15.4 percent of all true fir seed collected).

Seedfall thins out very rapidly with distance from the stand edge (table 2, fig. 2). The pattern is very similar for both years. In 1968, seedfall at the clearcut margins varied between about 200,000 and 400,000 sound white and Shasta red fir seeds per acre. At 125 feet, seedfall is down to about 25 percent of the stand-edge value; and it averages about 10 percent (30,000 sound seeds per acre) at

Table 1.--*Characteristics of the seedtrap collections from 1968 and 1971 true fir seed crops*

Seed characteristic	Seed crop year	
	1968	1971
Shasta red fir:		
Number of seed	1,544	1,048
Number of sound seed	192	348
Percent of sound seed	12.4	33.2
White fir:		
Number of seed	280	503
Number of sound seed	137	99
Percent of sound seed	48.9	19.7
All true firs:		
Number of seed	1,824	1,551
Number of sound seed	329	447
Percent of sound seed	18.0	28.8

375 feet. In 1971, the stand edge values were somewhat higher, with seedfall decreasing by about two-thirds in the first 125 feet from the stand edge and almost 90 percent at 375 feet.

The various regression analyses confirm what is obvious from inspection of the data--seedfall is significantly correlated with distance from stand edge. This is true regardless of the measure used, i.e., sound Shasta red fir, sound true fir, total true fir seed, etc. The analyses allow us to draw some additional inferences, however. The analyses of sound true fir seedfall in 1968 are our example (essentially all analyses showed the same result). (1) All four transects (north, south, east, and west) have highly significant correlations between seedfall and distance from stand edge. (2) The regression coefficients are not significantly different (i.e., the slope of the regression line is the same for all four transects) but the means are significantly different (i.e., the absolute amounts of seedfall vary significantly between transects). (3) The common regression line is strongly curvilinear and predicts a more rapid decrease in seedfall during the first 125 feet and a flatter relationship beyond than is apparent in the data (273,000 sound seeds per acre at 1 foot from the stand edge and 38,000 at 125, 250, and 375 feet).

Table 2.--*Numbers of sound white and Shasta red fir seed per acre from the 1968 and 1971 seed years by distance from stand edge and clearcut margin*[1/]

Clearcut margin	Distance from stand edge in feet			
	0	125	250	375
	Thousand seeds			
1968 seed year:				
North	381	136	54	38
South	229	82	44	38
West	250	49	33	33
East	343	49	27	11
Average, all transects	301	79	40	30
1971 seed year:				
North	234	101	58	32
South	542	228	90	74
West	303	74	117	48
East	276	96	74	21
Average, all transects	339	125	85	44

1/ Each figure (except for the "average" row) is based on sound seed collected in four 1- by 2-foot traps converted to a per-acre basis and rounded to the nearest thousand.

There was no consistent relationship between stand edge and the amount of seedfall even though there were significant differences. In 1968, the northern boundary had the highest seedfall and the southern the lowest; in 1971, this relationship was reversed (table 2). In 1971, amount of seedfall at the various clearcut boundaries did have the same ranking as the number of true fir trees per acre--south, west, east, and north--but this was not so in 1968.

Neither the ratio of sound to total true fir seed nor the ratio of total red fir to total true fir seed varies significantly with distance from stand edge. From these analyses, we can infer that sound and empty seeds and white and Shasta red fir seeds were showing no significant differences in flight distance.

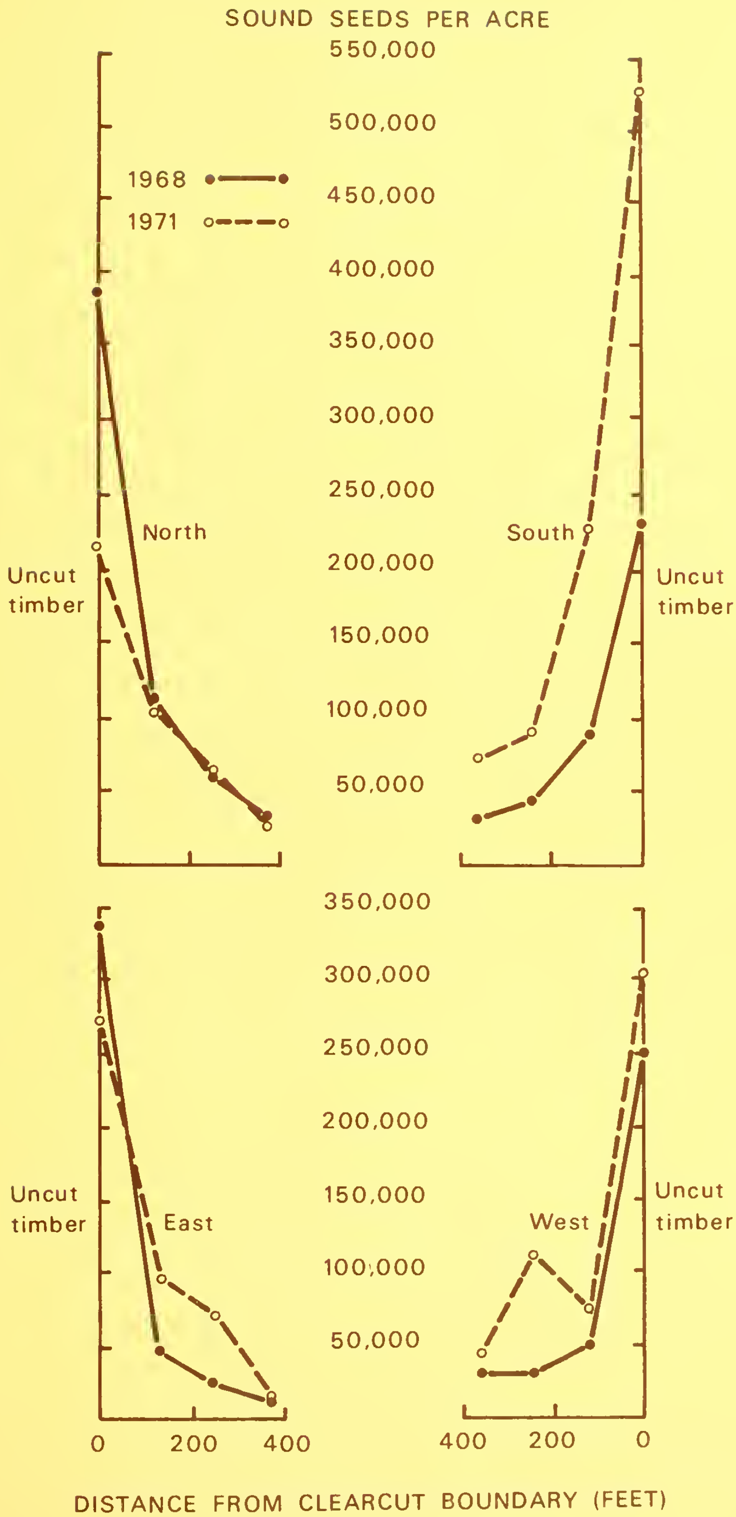

Figure 2.--Average white and Shasta red fir seedfall from the 1968 and 1971 seed crops by clearcut boundary and distance from the stand edge.

DISCUSSION AND CONCLUSIONS

If seed were disseminated primarily by winds from one direction, such as the storm winds from the southwest, we would expect significant differences in regression coefficients for the various transects or clearcut boundaries. We might expect seed to fly farther from the southern and western clearcut boundaries, for example. The statistical analyses do not show such differences.

Nevertheless, there is some indication that seed is disseminated farther from the southern and western clearcut boundaries. In 1968, seedfall 375 feet from the eastern boundary of the clearcut was only 3 percent of the value at the stand edge whereas it was 16 and 14 percent at the same distance from the southern and western boundaries, respectively (table 2). The situation is not as marked in 1971, although the percent of stand-edge seedfall at 375 feet is still substantially lower (8 percent) on the eastern transect than on the remainder (14 to 16 percent).

These observations, which are not supported by the statistical analyses, would confirm those of Gratkowski (1958) and Gordon (1970) who found much heavier true fir seedfall on southwest sides of cuttings than on northeast margins. This tendency for dispersal on strong southwesterly storm winds does have a very logical basis as indicated by Gordon (1970, p. 7).

Large amounts of seed fell in 1968 and 1971 even on central portions of this 40-acre clearcut. It will be more than adequate for regeneration, provided 1 percent of the sound seed produces established seedlings. If the established seedling to sound seed ratio falls much below 1 percent, seed supply will quickly become critical beyond 125 feet from the edge, however. This points out the importance of providing the most favorable environmental conditions for seedling establishment--mineral soil seed beds and some shade.

Cutting methods recommended for red and white fir forests are strip clearcut and shelterwood which will provide abundant seed and favorable conditions for seedling establishment (Gordon 1970, 1973). Our data suggest that clearcuts should be kept well below 40 acres in size and elongated in a northwest-southeast direction to favor seed dispersal by the southwesterly winds.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of personnel from Prospect Ranger District, Rogue River National Forest, especially Mel Hornbuckle, in making periodic collections of seed trap contents. U.S. Forest Service Region 6 provided the seed traps used in the study.

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

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DOMINANT DOUGLAS-FIR RESPOND TO FERTILIZING AND THINNING IN SOUTHWEST OREGON

by

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ABSTRACT

In 30-year-old, Site IV Douglas-fir in southwest Oregon, fertilizing increased average 4-year basal area growth of dominant trees by 57 and 28 percent on clay loam and sandy loam soils, respectively. Fertilizing with thinning increased growth by 94 and 132 percent over untreated growth. Thinning on clay loam soil increased growth by 53 percent. Treatment did not affect height growth on either soil.

Keywords: Douglas-fir, thinnings, fertilizer response (forest tree), forest management, soil management, basal area increment, southwest Oregon.

INTRODUCTION

To increase tree growth and wood production, fertilizing and thinning are being tested by several organizations in southwestern Oregon. We report the growth-stimulating effects of these treatments during the 4 years after their application to 30-year-old, Site IV Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) near Tiller, Oregon.

STUDY AREA

Location.--The study area is located 7 miles southeast of Tiller, Oregon, between the 2,500- and 3,000-foot elevations. Topography is relatively uniform with northeast aspect and slopes ranging from 20 to 35 percent. Soils in the study area are derived from volcanic tuffs and breccias but are unnamed. In the lower and major part of the study area, the soil is a moderately deep, well-drained clay loam overlying loamy clay subsoil; at higher elevations, the soil is a shallow, well-drained, sandy loam over sandy clay loam subsoil.[1/]

Stand.--The stand originated from natural seed fall about 10 years after a wildfire in 1929. When this study was established in spring 1969, dominant trees on the clay loam soil averaged 29 years old and approximately 58 feet tall; site quality was estimated at site index 120 (100-year index age). Average initial basal area (118 square feet per acre) was near normal standards; however, stand density (995 stems per acre) was about 76 percent of normal. On the sandy loam soil, site quality was slightly lower, site index 95; no direct measure of initial stand basal area and density was made; however, the stand was similar to the one on the clay loam.

Climate.-- Based on 10-year records (1963 through 1972) from two locations 9 to 10 miles northeast of the study area and also at the 2,400- to 2,500-foot elevation, annual precipitation averaged 43.5 inches with 9.4 inches (22 percent) falling during the April-through-September period.[2/] Evaporation greatly exceeds precipitation during the summer months, so trees in the study area are subjected to summer moisture stress characteristic of western Washington and Oregon.

Design and treatment.--The experimental design differed on the two soils. On the more extensive clay loam soil, it was a 2 x 2 completely random factorial with seven replications; thus, both fertilizing and thinning were compared with untreated controls as separate or combined treatments. On the less prevalent sandy loam soil, two treatments, fertilizing and fertilizing plus thinning, were compared with controls; stand and soil conditions permitted only three replications.

[1/] L. D. Herman. Detailed soil survey of Levels-of-Growing-Stock Study Area in Stampede Creek, Umpqua National Forest. Unpublished report on file, Forestry Sciences Laboratory, Olympia, Washington, 16 p.

[2/] Records provided by Jack Rothacher, Research Hydrologist, Forestry Sciences Laboratory, Corvallis, Oregon, August 1973.

Each study tree is a dominant Douglas-fir, located within or immediately outside a levels-of-growing-stock (LOGS) trial. This trial is part of a regional cooperative test of eight[3] thinning regimes located on the clay loam soil. Control and thinned trees on that soil were randomly selected from nearby control or thinned plots of the LOGS trial. No trees were fertilized on the LOGS plots; therefore, trees outside LOGS plots were randomly assigned to a fertilizing or fertilizing and thinning treatment. On both soils, these treatments were applied within 0.05-acre circular plots centered on the chosen trees.

Treatments were applied prior to the 1969 growing season. Thinning removed approximately 70 percent of the initial number of trees and 40 percent of the initial basal area. Fertilizers containing N, P, K, and S were uniformly broadcast by hand at the rates of 300, 150, 100, and 50 pounds of element per acre, respectively. Sources of nutrient elements were as follows:

ELEMENT	SOURCE
N	Urea (46-0-0-0)
P and S	Sulfated-superphosphate (0-30-0-20)
	Triple superphosphate (0-45-0-0)
K	Potassium chloride (0-0-60-0)

Measurements.--Diameter at breast height was measured prior to treatment in spring 1969 and annually through the 1972 growing season. Total heights as of fall 1963 and 1968 were measured after the 1969 growing season; total height as of 1971 was measured in 1971. Thus, height growth data for a 5-year period before and a 3-year period after treatment were available.

[3] LOGS = 8 thinning regimes vs. 1 unthinned (control).

RESULTS

Height growth.--There is no strong evidence that treatment affected height growth on either soil during the 3 years after treatment (table 1). On the clay loam, posttreatment growth ranged only between 5.4 and 6.1 feet among the treatment means. These differences were not statistically significant.[4] On the sandy loam soil, both pretreatment and posttreatment growth varied more than on the clay loam. Posttreatment growth ranged between 4.0 and 6.7 feet. These differences among treatment means were not statistically significant, although they indicated that fertilizing may have reduced height growth on the sandy loam soil.

Basal area growth.--On both soils, average basal area growth of treated trees exceeded that of untreated in all years (table 2). On the clay loam soil, basal area growth was positively and significantly related to initial tree size. The seven replications on that soil permitted covariance adjustment of average posttreatment growth to a common, average d.b.h. at the start of all treatments. Orthogonal

[4] In this paper, when differences are statistically significant, $p = 0.05$; when highly significant, $p = 0.01$.

Table 1.--*Average initial height and 3-year height growth before and after treatment of 30-year-old, Site IV Douglas-fir near Tiller, Oregon*

Treatment	Initial height, 1968	Height growth, 1964-68		Height growth, 1969-71		Ratio after/before
		Mean	S.D.[1]	Mean	S.D.	
	- - - - - - - -	- - - - - *Feet* - - - - -				
CLAY LOAM SOIL						
No treatment	57.7	8.9	1.4	5.4	1.3	0.61
Thinning	60.0	8.4	1.1	5.4	1.0	.64
Fertilizing	55.6	8.0	1.6	6.1	1.6	.76
Fertilizing plus thinning	57.7	[2]8.7	1.6	[2]5.8	1.6	.72
SANDY LOAM SOIL						
No treatment	47.7	[3]7.5	.5	4.7	.5	.63
Fertilizing	47.7	8.7	1.7	4.0	1.7	.46
Fertilizing plus thinning	48.7	10.7	1.5	6.7	1.5	.64

1/ S.D. = standard deviation.

2/ Based on 6 not 7 trees as with other entries.

3/ Based on 2 not 3 trees as with other entries.

comparisons of these adjusted means confirmed that there was no statistically significant interaction in any year, indicating that the effect of thinning or fertilizing probably held at either level of the other treatment. The main effect of thinning (average for fertilized and unfertilized trees) was highly significant in each year (table 2) and in the total 4-year period (table 3). The statistical significance of the fertilizer effect, however, gradually decreased from highly significant in years 1 and 2 to nonsignificant in year 4. The main effect of fertilizing was highly significant in the 4-year period (table 3).

For the 4-year period, percentage gain in basal area growth on the clay loam soil averaged 53 percent from thinning, 57 percent from fertilizing, and 94 percent from the combined treatments (table 2). These percentage gains are for trees having an initial d.b.h. equal to the average for all study trees on the clay loam soil, or 8.9 inches. Percentage gains for trees of smaller diameter will be larger and those for trees with initially larger than average diameter will be somewhat smaller than these. Based on growth during the fourth growing season after treatment, continued response is predictable for all treatments.

Table 2.--*Average basal area growth per tree and relative gains over growth of untreated trees, 30-year-old, Site IV Douglas-fir near Tiller, Oregon*

Treatment	First year		Second year		Third year		Fourth year		All years	
	Growth	Gain	Growth	Gain	Growth	Gain	Growth	Gain	Growth	Gain
	Square feet	*Percent*	*Square feet*	*Percent*	*Square feet*	*Percent*	*Square feet*	*Percent*	*Square feet*	*Percent*
CLAY LOAM SOIL[1/]										
No treatment	0.030	--	0.040	--	0.016	--	0.024	--	0.109	--
Thinning	.038	27	.061	53	.029	81	.040	67	.167	53
Fertilizing	.043	43	.067	67	.028	75	.032	33	.171	57
Fertilizing plus thinning	.055	83	.078	95	.034	112	.045	88	.211	94
		[2/](28)		(17)		(21)		(41)		(23)
SANDY LOAM SOIL										
No treatment	.017	--	.020	--	.013	--	.016	--	.065	--
Fertilizing	.021	24	.029	45	.016	23	.017	6	.083	28
Fertilizing plus thinning	.036	112	.052	160	.029	123	.034	112	.151	132
		(71)		(79)		(81)		(100)		(82)

1/ Growth adjusted by covariance techniques for differences in initial average d.b.h. among treatments.

2/ Figures in parentheses show percentage gain with fertilizing and thinning over fertilizing alone.

Table 3.--*Average basal area growth per tree on clay loam soil during 4 years after treatment of 30-year-old, Site IV Douglas-fir near Tiller, Oregon*[1/]

(In square feet)

Treatment	Treatment		Average[2/]
	Unfertilized	Fertilized	
Unthinned	0.109	0.171	0.140
Thinned	.167	.211	.189
Average[2/]	.138	.191	.165

[1/] Growth adjusted by covariance techniques for differences in initial average d.b.h. among treatments.

[2/] The differences between the thinned and fertilized treatments and their 99-percent confidence intervals are 0.049±0.007 and 0.053±0.007, respectively. The main effects for fertilizing and thinning were each significant at the 1-percent probability level.

On the sandy loam soil, basal area growth of dominant trees was consistently less than that of control or comparably treated trees on the clay loam soil (table 2). Fertilized trees showed only slight and statistically nonsignificant gains over control trees. However, growth of fertilized and thinned trees exceeded that of control or fertilized trees in all periods, and these differences were significant in all but the fourth year (table 2).

The combination of fertilizing and thinning was much more effective than fertilizer alone, especially on the sandy loam soil. For the 4-year period, percentage gain in basal area growth of the combined treatment over the single treatment was 82 percent on the sandy loam compared with 23 percent on the clay loam. Based on growth during the fourth growing season after treatment, future additional gains on the sandy loam from the combined treatment will be substantial and those from fertilizing will be minimal.

Regardless of treatment, dominant trees on both soils showed similar yearly trends in basal area increment (table 2). Average basal area growth for all trees was depressed in the third year, 1971. This growth depression is not related to less precipitation during the growing season; in fact, both total and growing season precipitation were second highest recorded at two nearby weather stations during the most recent 10-year period. Some reduction in basal area growth by treated trees may be explained by a heavy cone crop on some of these trees; in contrast, no control trees had cones in 1971. On the clay loam soil, the difference in growth between treated and untreated trees was greatest in the third year. On the sandy loam soil, apparent gain was greatest in the second year after treatment (table 2).

DISCUSSION AND CONCLUSIONS

This study in southwestern Oregon, like numerous field trials in western Washington and northwestern Oregon, demonstrates that fertilizing or thinning or both significantly increase growth of Douglas-fir. Since response has not yet ended, a longer period of observation is necessary before the final benefits or gain from treatment can be measured and evaluated.

Increased growth resulted from combining several fertilizers supplying N, P, K, and S at rates of 300, 150, 100, and 50 pounds per acre, respectively. We do not know which of the nutrient elements or combinations corrected the growth-limiting shortage at this site. Since supplying nitrogen in a complete fertilizer more than doubles the cost of comparable urea treatment, choice of fertilizer has practical significance to the land manager. In addition to continuing growth measurements in the study area, we plan chemical analysis of foliage from fertilized and unfertilized trees to indicate gross nutrient shortages or imbalances among the nutrient elements tested.

Fertilizer tests in a nearby area suggest that nitrogen is probably the nutrient element that most limits growth. In a thinned stand 11 miles north and with similar stand and site conditions, 5-year basal area growth of dominant trees treated with 200 pounds of N was 96 percent of that of trees treated with equal amounts of N but with additions of P, K, and S. This difference was statistically nonsignificant.[5]

Initial trends of basal area growth suggest that the long-term effect of thinning on diameter growth of dominant trees may exceed that of fertilizing in our study area. On both soils, the stimulating effect of the fertilizer-only treatment declined rapidly after the third growing season. In contrast, growth of fertilized and thinned trees or thinned-only trees (on the clay loam soil) was maintained at much higher levels. The apparent shorter duration of the fertilizer effect could indicate that nutritional levels for the subject trees are returning to their original levels. Alternatively or additionally, the fertilizer treatment may have stimulated the growth of nearby trees so that increased competition is more rapidly reducing the diameter growth of fertilized but unthinned subject trees.

There is considerable practical interest in determining if and where the effects of the combined treatment, thinning plus fertilizing, will provide a larger increase in growth than the theoretical addition of their separate effects. In this study, the average increase in basal area growth on clay loam soil during the first year after

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

the combined treatment was 83 percent; yet the sum of the separate effects of thinning (27 percent) and fertilizing (43 percent) was 70 percent (table 2). This suggests a more-than-additive or synergistic effect when the treatments are actually combined. However, in each of the following 3 years and in the total period, the effect of the combined treatment was less-than-additive or antagonistic. These comparisons suggest initial positive and subsequent negative interaction between the thinning and fertilizing treatments at this location. However, our statistical analyses indicated that these apparent interactions, thus far, are likely due to chance.

Additional time and data are necessary before making further comparisons of thinning and fertilizing as single or combined treatments. Most important to the local land manager thus far is the direct evidence that growth of crop trees can be increased by these silvicultural treatments.

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ASKA OREGON WASHINGTON PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-217 *January 1974*

CHEMICAL CHARACTERISTICS OF SOME FOREST AND GRASSLAND SOILS OF NORTHEASTERN OREGON

II. Progress in Defining Variability in Tolo and Klicker Soils

by

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ABSTRACT

Comparisons of Tolo and Klicker soil fertility indicated that Tolo soils have lower overall nutrient concentration levels. Organic matter, total nitrogen, and available phosphorus concentrations decrease sharply from upper to lower depths in all soil profiles, while certain other chemical characteristics increase. Variability in chemical properties differs by depth increment and specific chemical characteristic in both soils.

Grouping of soils according to overstory dominant vegetation showed that differences in several chemical properties were associated with these groups. Such results imply possible nutrient cycling differences among these plant communities which may have bearing on their ecological dynamics. Many similar chemical changes with depth gradient were noted between soil series and vegetative groupings.

Topsoil conservation practices should be stressed in heavy equipment use on both Tolo and Klicker soils. The data indicate that precautions are necessary in soil sampling, particularly if fertilization guides are to be developed. The results will also be useful in determining effects of forest management on soil chemical systems.

Keywords: Soil fertility, soil properties, soil management, Oregon.

INTRODUCTION

This paper reports progress in defining soil chemical properties and their variation for soils mapped within the Tolo and Klicker series. The data are part of a continuing effort to characterize upland soils in eastern Oregon. This information provides a reference base for measuring effects of overstory removal or other vegetative management, information on present fertility levels, and a basis for determining sampling requirements for resource inventory and future research studies. An earlier report contained results from single profile analyses of several forest and grassland soils but lacked information about variation of the properties determined (Geist and Strickler 1970).

The data may not characterize all Tolo and Klicker soils of the study area because the sampling locations were restricted to occurrences of soils supporting relatively uniform forest vegetation. The dominant trees encountered on these soils included ponderosa pine (*Pinus ponderosa* Laws.), grand fir (*Abies grandis* (Dougl.) Lindl.), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Biessn.) Franco), lodgepole pine (*Pinus contorta* Dougl.), and western larch (*Larix occidentalis* Nutt.).

Sampling was performed in the northern portion of the Starkey Experimental Forest and Range, 30 miles southwest of La Grande, Oregon. The soils were mapped earlier in a soil survey[1/] and associated vegetation was described by Strickler (1965). Starkey is in the central Blue Mountains, a faulted, uplifted, and dissected tertiary basalt formation. A volcanic ash mantle of varying thickness (20-90 centimeters) overlies portions of the area, generally on moderately sloping plateaus, north and east slopes, and some toe slopes of other exposures. Starkey contains 29,000 acres, of which 21,000 acres are forested and include 19,500 acres mapped as Tolo or Klicker series and closely related complexes.

Klicker soils have developed principally on south and west exposures from basalt residuum with some surface influence of ash and loess. They have medium surface textures, moderately fine to fine subsoil textures, and are influenced by rock and gravel throughout the profile.

Tolo soils are generally found on north and east exposures and are derived from volcanic ash which overlies older loess and residuum from basalt. Surface textures are medium, and little change occurs through the profile until the older material is encountered which has medium to fine textures. Rock and gravel influence is generally less than in Klicker soils. The two soils

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[1/] Soil Survey, Starkey Experimental Forest and Range, Union and Umatilla Counties, Oregon. Unpublished report issued by Soil Conservation Service and Pacific Northwest Forest and Range Experiment Station, USDA Forest Service, 32 p., 1960.

are associated together geographically and with the Rock Creek, Albee, and Couse series. Both Tolo and Klicker soils can occur in nearly all topographic positions.

Precipitation averages 20 inches and is principally distributed over late fall, winter, and spring; a pronounced summer drought is characteristic. Hence the soils are usually moist but are dry in the 10- to 30-centimeter depth for 60-80 consecutive days during summer and fall. Elevation ranges from 3,800 to 5,000 feet, the mean annual temperature is about 6°-7°C (42°-45°F), and the growing season varies from 60 to 120 days.

METHODS

Sample locations were established within homogeneous vegetation units in conjunction with research being conducted near Bally Mountain and on the upper Smith Creek watershed (secs. 16, 17, 18, 19, 20, 21, 28, 29 of T. 3 S., R. 34 E., Willamette prime meridian). Analytical samples were composites of the same depth obtained in increments from five random points along a 30-meter transect. Each point increment had equal volume in the composite. The depth increments used were 0-15, 15-30, 30-60, and 60-90 centimeters. Sample materials were air-dried and sieved (less than 2 millimeters) for subsequent chemical analysis.

Soil analyses included organic matter by the Walkley-Black method (Jackson 1958, p. 219-221), total nitrogen by Kjeldahl method (Jackson 1958, p. 187-190), extractable sodium and potassium by flame photometer, and extractable calcium and magnesium by versenate titration (U.S. Salinity Laboratory Staff 1954, p. 100-101). Available phosphorus was determined by the sodium bicarbonate extraction technique (Watanabe and Olsen 1965), and soil reaction was measured in 0.01 M calcium chloride. Carbon-nitrogen ratios were computed, assuming organic matter averages 58-percent carbon content. Calcium-magnesium ratios were calculated from exchangeable quantities of each.

RESULTS

Means with a 95-percent confidence interval, ranges, and coefficients of variation of properties of Klicker and Tolo soil groups were determined (tables 1 and 2). The confidence interval offers an index of precision of the estimated mean. Values of zero for coefficients of variation and for confidence intervals occurred when the rounded results of analyses or calculations were less than the level of precision used for the means. Shallow soil and associated subsoil rock precluded sampling to 90 centimeters at some locations, so fewer observations are available for the two deepest sampling increments.

The least variable property measured in both soils was pH, which averaged from 5.4 in surface soils to 5.6 in subsoils. Earlier pH measurements at other locations of study soils and of additional forest and grassland soils were similar to these values (Geist and Strickler 1970).

Table 1.--Klicker soil chemical properties

Soil depth (cm)	Number of observa-tions	pH	Organic matter	Total nitrogen	C:N	Avail-able P	Extractable cations					Ca:Mg
							K	Na	Ca	Mg	Total	
			----------Percent---------			P/m	------------------------Meq/100 g--------------------------					
						Means[1/]						
0-15	17	5.4 ± 0.1	4.12 ± 0.57	0.11 ± 0.01	21 ± 1	47 ± 7	1.5 ± 0.2	0.1 ± 0.0	11.3 ± 1.1	2.6 ± 0.4	15.5 ± 1.4	5 ± 1
15-30	17	5.5 ± .1	2.28 ± .42	.07 ± .01	18 ± 2	34 ± 8	1.2 ± .2	.1 ± 0	10.8 ± 1.1	3.0 ± .4	15.1 ± 1.2	4 ± 1
30-60	13	5.5 ± .1	1.47 ± .37	.05 ± .01	16 ± 2	27 ± 6	1.0 ± .2	.2 ± 0	12.0 ± 2.0	4.4 ± .9	17.6 ± 2.5	3 ± 1
60-90	5	5.6 ± .1	.81 ± .34	.04 ± .01	14 ± 5	14 ± 7	.8 ± .3	.2 ± .1	14.3 ± 6.6	7.0 ± 3.7	22.3 ± 10.2	2 ± 1
						Ranges						
0-15	17	5.0-5.7	2.66-6.83	0.08-0.17	17-24	26-70	0.7-2.2	0.1-0.1	8.3-15.7	1.4-3.9	12.5-21.1	3-7
15-30	17	5.3-5.7	1.31-4.26	.05- .11	13-24	17-68	.6-1.5	.1- .2	7.8-14.8	2.1-4.4	11.8-18.6	2-7
30-60	13	5.3-5.7	1.08-3.23	.04- .10	13-21	15-44	.7-1.6	.1- .2	8.3-17.1	2.6-6.7	12.4-24.4	2-5
60-90	5	5.5-5.7	.47-1.23	.02- .04	11-20	7-21	.5-1.1	.1- .3	8.8-22.1	3.6-10.7	13.7-34.0	2-3
						Coefficients of variation (percent)						
0-15	17	3	27	24	9	29	27	0	19	27	17	29
15-30	17	2	36	25	19	43	25	35	20	24	15	33
30-60	13	2	42	33	16	38	26	31	27	33	24	33
60-90	5	2	34	25	26	42	29	37	37	43	37	23

1/ ± 95-percent confidence interval.

Table 2.--Tolo soil chemical properties

Soil depth (cm)	Number of observa-tions	pH	Organic matter	Total nitrogen	C:N	Avail-able P	Extractable cations					Ca:Mg
							K	Na	Ca	Mg	Total	
			-----------*Percent*--------			*P/m*	------------------------*Meq/100 g*----------------------------					
						Means[1/]						
0-15	24	5.4 ± 0.1	3.37 ± 0.36	0.09 ± 0.01	22 ± 1	63 ± 9	1.1 ± 0.2	0.1 ± 0.0	6.2 ± 0.9	1.2 ± 0.1	8.6 ± 1.2	5 ± 1
15-30	24	5.5 + .1	1.74 ± .21	.06 ± .01	18 ± 1	36 ± 7	1.0 ± .1	.1 ± 0	5.2 ± .6	1.1 ± .2	7.4 ± .8	5 ± 1
30-60	24	5.5 ± .1	1.12 ± .17	.04 ± 0	18 ± 2	20 ± 4	.9 ± .1	.2 ± 0	6.8 ± .9	1.8 ± .6	9.7 ± 1.6	5 ± 1
60-90	20	5.5 + .2	.60 ± .06	.03 ± 0	12 + 1	12 ± 2	.8 ± .1	.3 ± .1	10.6 ± 1.6	3.8 ± 1.0	15.5 ± 2.7	3 ± 1
						Ranges						
0-15	24	5.1-5.9	1.73-5.00	0.05-0.12	17-32	30-111	0.6-1.9	0.1-0.1	3.5-9.8	0.8-1.8	5.1-13.5	3-10
15-30	24	5.1-5.8	1.14-3.45	.04- .09	14-32	16-76	.5-1.5	.1- .2	3.2-8.3	.6-2.7	4.3-11.5	3-9
30-60	24	4.7-5.8	.72-2.29	.03- .06	12-33	5-47	.5-1.3	.1- .4	4.3-14.8	.6-8.7	5.6-24.6	2-7
60-90	20	4.7-6.6	.39- .86	.02- .04	9-16	3-21	.6-1.1	.1- .7	7.8-25.0	1.4-12.0	11.7-38.7	2-7
						Coefficients of variation (percent)						
0-15	24	4	25	22	15	34	35	0	35	21	32	32
15-30	24	3	28	21	19	48	29	26	28	41	27	28
30-60	24	5	37	22	25	51	22	38	32	85	38	33
60-90	20	7	21	21	18	37	16	48	33	56	37	36

1/ ± 95-percent confidence interval.

Average organic matter and total nitrogen levels were higher in Klicker soils for all depths and also more variable than in Tolo soils. These mean levels were moderate and low, respectively, for the Klicker and Tolo soils. Concentrations declined rapidly with increasing soil depth in both soils. Ranges of organic matter contents extended rather high in both soil groups, up to the upper 6-percent level for the Klicker and the 5-percent level for the Tolo.

Average carbon-nitrogen ratios were similar for both soils; however, the Tolo soils showed wider ranges and more variable values than the Klicker. Both groups showed a consistent narrowing of the ratio from the surface depth down. This might be expected since the upper levels of the profile are most affected by root proliferation and organic matter deposition.

Available phosphorus averaged higher in the upper profile of the Tolo group and higher in the lower profile of the Klicker group, although levels in both soils declined with increasing soil depth. The variability of available P was generally higher and ranges were wider in the Tolo soils.

Both individual and total extractable cations, with two exceptions, averaged higher at all depths in the Klicker soils. In both soil groups, the calcium and magnesium levels commonly decreased slightly, then increased with depth as did the total cations. This trend was more pronounced for calcium. Sodium levels increased with increasing depth, while potassium decreased. The abrupt increase in extractable Ca, Mg, and total cations in the Tolo group is associated with the ash-basalt residuum lithologic discontinuity which occurred near the 60-centimeter depth. The percentages of individual cations of the totals for a given depth were similar between the two groups and showed similar trends, although trends appeared more pronounced in the Klicker soil group (table 3). Percentages gave a

Table 3.--Individual cation percentages of mean total extractable cations for Klicker and Tolo soils

Soil depth (cm)	Extractable cation			
	K	Na	Ca	Mg
	Percent			
Klicker soils:				
0-15	9	1	73	17
15-30	8	1	71	20
30-60	6	1	68	25
60-90	4	1	64	31
Tolo soils:				
0-15	13	1	72	14
15-30	14	1	70	15
30-60	9	2	70	19
60-90	5	2	68	25

different perspective of cation dynamics and indicated reverse trends to analytical values for calcium. Calcium and potassium percentages generally decreased with depth, whereas magnesium increased and sodium remained the same or increased slightly.

Calcium-magnesium ratios averaged slightly higher in the Tolo group and held at about a 5:1 level except at the 60- to 90-centimeter depth. This may reflect the influence of more clay in the lower profile. In contrast, Ca:Mg ratios in the Klicker soils steadily declined. A ratio between 1:1 and 5:1 is considered most desirable (Black 1965, p. 919).

At this point, the data were regrouped on the basis of dominant overstory species to see if analyses would reflect vegetative influences, and to provide a better opportunity for associating soils with the landscape. Three categories of dominant trees resulted: lodgepole pine, ponderosa pine, and mixed conifer (tables 4-7). The ponderosa pine group of soils was composed of one Tolo and 14 Klicker soils. The lodgepole pine group contained only Tolo soils, and the mixed conifer group contained three Klicker and 13 Tolo soils.

Because of the strong association of soil series and vegetation, many data for the vegetative groups were similar to those discussed above, not only in analytical trends but also in cation percentage trends. Differences among the new group means did occur, although the ranges associated with those means overlapped as noted with previous group means.

Soil reaction increased under lodgepole and ponderosa pine but decreased under mixed conifer with increasing soil depth.

Organic matter levels generally were higher in the ponderosa group, but less than 1-percent average difference occurred by depth among the three vegetative groups. Total N was also highest under ponderosa pine and lowest under lodgepole. Both total N and organic matter declined rapidly with depth. Calculated C:N ratios were very similar and declined with increasing depth.

Higher and more variable surface values were noted in available phosphorus under mixed conifer, while the other two groups were quite similar to each other. Rapid declines were noted in all three groups with increasing depth.

The lodgepole pine group was consistently lowest in mean extractable K, even though ranges overlapped. The average spread of 0.7 milliequivalents at the surface narrowed to 0.1 milliequivalents/100 grams at 60-90 centimeters. The mixed conifer and ponderosa group means were nearly identical. Extractable Ca was also lowest under lodgepole pine in the upper two depths.

Among the other extractable

Table 4.--Ponderosa pine group soil chemical properties

Soil depth (cm)	Number of observations	pH	Organic matter	Total nitrogen	C:N	Available P	Extractable cations K	Na	Ca	Mg	Total	Ca:Mg
			-----------Percent	--------		P/m	-----------------------	-------	Meq/100 g	-------	-------------------	
						Means[1/]						
0-15	15	5.4 ± 0.1	4.04 ± 0.60	0.11 ± 0.01	22 ± 1	44 ± 7	1.5 ± 0.2	0.1 ± 0.0	10.6 ± 0.9	2.5 ± 0.4	14.7 ± 1.1	5 ± 1
15-30	15	5.4 ± .1	2.32 ± .48	.07 ± .01	20 ± 3	31 ± 7	1.2 ± .2	.1 ± 0	10.0 ± 1.0	3.1 ± .4	14.4 ± 1.3	3 ± 0
30-60	11	5.4 ± .1	1.34 ± .25	.04 ± 0	17 ± 3	25 ± 6	1.0 ± .2	.2 ± 0	11.1 ± 2.5	4.5 ± 1.1	16.8 ± 3.5	3 ± 0
60-90	4	5.6 ± .2	.82 ± .50	.04 ± .02	15 ± 6	15 ± 11	.9 ± .4	.3 ± .2	14.9 ± 9.2	7.7 ± 4.9	23.8 ± 14.0	2 ± 1
						Ranges						
0-15	15	5.0-5.7	2.66-6.83	0.08-0.17	19-24	26-68	0.7-1.9	0.1-0.1	8.3-14.0	1.2- 3.9	12.3-19.3	3-7
15-30	15	5.2-5.7	1.31-4.26	.05- .10	13-32	17-68	.6-1.6	.1- .2	7.8-12.7	1.6- 4.4	10.9-17.8	2-5
30-60	11	4.9-5.7	1.08-2.29	.04- .05	13-26	15-42	.7-1.4	.1- .2	7.0-17.1	2.1- 6.7	10.1-24.4	2-3
60-90	4	5.5-5.7	.47-1.23	.02- .04	12-20	7-21	.5-1.1	.1- .3	8.8-22.1	3.6-10.7	13.7-34.0	2-3
						Coefficients of variation (percent)						
0-15	15	3	27	23	7	29	24	0	16	32	14	31
15-30	15	2	37	23	24	43	25	46	18	26	16	25
30-60	11	4	28	11	23	38	23	23	33	35	31	17
60-90	4	2	38	25	25	44	29	33	39	40	37	25

1/ ± 95-percent confidence interval.

Table 5.--Lodgepole pine group soil chemical properties

Soil depth (cm)	Number of observa-tions	pH	Organic matter	Total nitrogen	C:N	Avail-able P	Extractable cations					Ca:Mg
							K	Na	Ca	Mg	Total	
			----------Percent--------			P/m	------------Meq/100 g------------					
						Means[1/]						
0-15	10	5.3 ± 0.1	3.62 ± 0.62	0.09 ± 0.01	24 ± 3	53 ± 9	0.8 ± 0.1	0.1 ± 0.0	4.4 ± 0.5	1.1 ± 0.1	6.4 ± 0.6	4 ± 0
15-30	10	5.5 ± .1	1.61 ± .20	.05 ± .01	18 ± 1	31 ± 7	.7 ± .1	.1 ± 0	4.6 ± .9	1.1 ± .4	6.5 ± 1.3	5 ± 1
30-60	10	5.6 ± .1	.90 ± .08	.03 ± 0	16 ± 2	16 ± 5	.8 ± .1	.2 ± .1	7.0 ± 2.0	1.9 ± 1.7	9.9 ± 3.9	5 ± 1
60-90	10	5.7 ± .3	.60 ± .11	.03 ± 0	13 ± 2	10 ± 2	.8 ± .1	.3 ± .1	11.3 ± 3.6	3.8 ± 2.1	16.2 ± 5.8	3 ± 1
						Ranges						
0-15	10	5.1-5.4	2.29-5.00	0.06-0.11	20-32	37-70	0.6-1.0	0.1-0.1	3.5-5.8	0.8-1.4	5.1- 8.0	3-5
15-30	10	5.3-5.7	1.17-2.11	.04- .07	14-21	18-48	.5-1.0	.1- .2	3.2-7.5	.6-2.7	4.3-11.0	3-6
30-60	10	5.4-5.8	.72-1.10	.03- .04	12-20	5-27	.5-1.1	.1- .4	4.3-14.8	.6-8.7	5.6-24.6	2-7
60-90	10	5.1-6.6	.39- .86	.02- .04	9-16	3-14	.6-1.0	.1- .7	7.8-25.0	1.4-12.0	11.7-38.7	2-7
				Coefficients of variation (percent)								
0-15	10	3	24	16	15	24	15	0	15	17	13	14
15-30	10	2	17	15	11	32	22	32	26	54	28	24
30-60	10	2	13	11	16	40	22	46	39	127	55	31
60-90	10	7	25	21	17	30	18	55	44	79	50	48

1/ ± 95-percent confidence interval.

Table 6.--Mixed conifer group soil chemical properties

Soil depth (cm)	Number of observa-tions	pH	Organic matter	Total nitrogen	C:N	Avail-able P	Extractable cations					Ca:Mg
							K	Na	Ca	Mg	Total	
			----------Percent--------			P/m	-------------Meq/100 g-------------					
						Means[1/]						
0-15	16	5.6 ± 0.1	3.38 ± 0.52	0.10 ± 0.01	20 ± 1	70 ± 11	1.5 ± 0.2	0.1 ± 0.0	8.7 ± 1.8	1.5 ± 0.4	11.8 ± 2.3	6 ± 1
15-30	16	5.5 ± .1	1.86 ± .31	.06 ± .01	18 ± 1	41 ± 10	1.2 ± .1	.1 ± 0	7.0 ± 1.9	1.3 ± .3	9.6 ± 2.3	5 ± 1
30-60	16	5.4 ± .1	1.38 ± .35	.05 ± .01	18 ± 3	24 ± 7	1.0 ± .1	.2 ± 0	8.0 ± 1.7	2.0 ± .4	11.2 ± 2.0	4 ± 1
60-90	11	5.4 ± .2	.61 ± .07	.03 ± 0	11 ± 1	13 ± 3	.8 ± .1	.3 ± .1	10.1 ± .8	3.9 ± .4	15.1 ± 1.0	3 ± 0
						Ranges						
0-15	16	5.4-5.9	1.73-5.43	0.05-0.16	17-25	30-111	1.0-2.2	0.1-0.1	4.6-15.7	0.9-3.2	6.7-21.1	4-10
15-30	16	5.1-5.8	1.14-3.48	.04- .11	13-21	16-76	.9-1.6	.1- .2	3.5-14.8	.7-2.6	5.4-18.6	4-9
30-60	16	4.7-5.7	.79-3.23	.03- .10	13-33	11-47	.8-1.6	.1- .3	4.4-14.4	1.1-3.4	7.4-18.9	2-7
60-90	11	4.7-5.7	.44- .75	.03- .04	9-15	7-21	.7-1.1	.2- .4	8.5-11.6	3.1-5.1	12.8-17.7	2-4
						Coefficients of variation (percent)						
0-15	16	2	29	28	10	31	27	0	39	51	37	29
15-30	16	3	31	28	13	48	19	24	51	45	45	32
30-60	16	5	47	34	27	51	21	31	39	37	34	30
60-90	11	6	17	15	16	37	14	26	12	15	10	20

1/ ± 95-percent confidence interval.

Table 7.--Individual cation percentages of mean total extractable cations according to plant community divisions

Soil depth (cm)	Extractable cation			
	K	Na	Ca	Mg
	Percent			
Ponderosa pine:				
0-15	10	1	72	17
15-30	8	1	69	22
30-60	6	1	66	27
60-90	4	1	63	32
Lodgepole pine:				
0-15	12	1	70	17
15-30	11	1	71	17
30-60	8	2	71	19
60-90	5	2	70	23
Mixed conifer:				
0-15	13	1	73	13
15-30	12	1	73	14
30-60	9	2	71	18
60-90	5	2	67	26

cations, sodium values differed little among soils in both level and profile trends. Extractable Mg and total cations showed some similar trends among the three groups. However, a decline and rise in cations did not occur in the lodgepole group and differed in degree in the others. Mean values were generally lower under lodgepole and higher under ponderosa pine. Little difference was noted in Ca:Mg values. Percentages of the total cations for Ca and K decreased with depth whereas Mg increased. The latter values may reflect relative mobilities of these exchangeable ions.

DISCUSSION

Data reported for the Klicker and Tolo soils indicated considerable overlapping in the ranges of all properties at all depths. There were differences between calculated means of certain chemical characteristics; the larger differences were associated with organic matter, total nitrogen, available phosphorus, extractable calcium, magnesium, and total extractable cations. Overlapping between soil groups for a given soil property and depth is partially explained by the fact that soils are not distinct entities but are a part of a continuum of gradual change upon which classification boundaries are superimposed. Further, where soils are associated geographically, some similarities would be expected.

It appears advantageous to try grouping soils by means other than classification criteria, since soil-vegetation relationships may be revealed. For example, mean pH decreased with increasing soil depth in the mixed conifer group but increased in other soil and vegetative groups. Also, organic matter and total N levels declined faster with depth in the lodgepole pine group than in other vegetative groupings considered. This latter trend and the seemingly lower nutrient status reflected in many of the analyses suggest that these lodgepole pine plant communities may be either low cyclers of certain nutrients and organic matter or are adapted to low fertility sites. (The possible role of fire cannot be ignored, although all soils examined in this study contained charcoal.) Nutrient concentrations in the ponderosa pine group averaged highest in most cases.

Considerable variability in soil properties within overstory strata suggested that differences in the understory vegetation might affect soil chemical properties. Future studies should investigate this aspect of soil-plant relations. Knowledge of conditions favoring key wildlife habitat or recreation species, as well as general ecological knowledge, should accrue from such a study.

Topsoil of both Tolo and Klicker soils is of management concern; analytical data illustrate why. Organic matter, total nitrogen, and available phosphorus levels declined rapidly from surface to subsoil depths in all cases. Hence, the topsoil represents the major source of N and P and other nutrients present mainly in organic matter. Topsoil losses due to accelerated surface erosion, machine slash piling, road building, landing construction, etc., could certainly reduce site productivity.

General fertility levels in the Tolo soils were lower than in the Klicker soils. This observation is based on expressions of nutrient concentration rather than quantity, and since Tolo soils are generally deeper they may, in contrast, contain total amounts similar to the Klicker soils. The relative importance of amounts as opposed to concentrations of nutrients is associated with root distribution and abundance for a given plant in a particular profile section. These factors are unknown, although many grasses and forbs root primarily in the surface soil. Hence nutrient concentrations may be more important in understanding production, quality, ecology, etc., of these species than others with widely distributed root systems.

All carbon-nitrogen ratios fell within a range where nitrogen mineralization would exceed immobilization during decomposition of existing organic matter. Incorporating new organic residues with high C:N ratios would immobilize mineral nitrogen during decomposition until the ratio of the residue is lowered to about 30:1. The amount and rate of immobilization and its impact on the soil-plant nutritional system depends on size, amount, degree of mixing, and nature of the residue as well as the residue C:N ratio. Woody residues (C:N = 100+) are relatively resistant to microbial attack; hence the amount of N immobilized per amount of residue is considerably less than readily decomposable plant residues, particularly at first (Bartholomew 1965). Lignin in woody matter apparently retards decomposition of cellulosic materials through both its resistance to degradation and its close structural linkage with cellulose in the cell wall (Alexander 1961). The influence of slash from thinned trees and root decomposition on soil nitrogen has been considered in detail by Cochran (1968).

We do not have fertilizer guides for perennial vegetation in the Blue Mountains. Thus, the manager must depend on tissue symptoms of nutrient deficiency or past fertilization experience. Where nitrogen deficiencies are observed and fertilizer nitrogen is added to Tolo or Klicker soils to augment native N supply, nutrient responses on topsoils have shown that sulfur should be included in the fertilizer material. The sulfur prevents a nutrient imbalance and increases the efficiency of fertilizer N use. Phosphorus analyses indicated adequate levels in the surface soils studied; however, in degraded or severely disturbed situations where exposed subsoils require rehabilitation, application of N, S, and P may be valid (Geist 1971). Calcium, magnesium and potassium appeared adequate, although K may be limiting at the 0.5 meq/100 g level in Tolo soils under intensive production of high base-requiring crops such as grasses.

The variability noted in chemical properties is a signal to those working with Tolo and Klicker soils that visually selecting sampling locations is difficult because wide fertility differences may exist and should be accounted for. The rapid change in chemical soil properties from the surface down should also alert the sampler to carefully control penetration of the sampling device. Such chemical changes are frequently associated with changes in physical properties as well.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Nutrient concentration levels were generally lower in Tolo soils (volcanic ash-derived) than in Klicker soils (basalt-derived). Coefficients of variation of nutrient levels were fairly similar between soils and fluctuated with the chemical characteristic and soil depth considered.

Maintaining topsoil is important for nutrient supply in both soils but appears more critical in Tolo soils, particularly under lodgepole pine overstory. Stockpiling and subsequently restoring topsoil should be beneficial in rehabilitating heavily disturbed sites (log landings, slash piling areas, etc.).

Stratification of data according to overstory vegetation types appeared advantageous in terms of better understanding of soil-plant relationships including possible nutrient cycling differences. This also offers greater ease in relating soils data to vegetative mapping units. Study of understory vegetation relationships to soil chemical properties was indicated.

Rapid changes in chemical

characteristics within the soil profile showed the need for rather precise control of sampling depth. This will be of specific importance to soil surveyors and engineering personnel.

In developing fertilization guides, sampling procedures must account not only for inherent nutrient variation among soils, but also for the contrasting distribution patterns among nutrients with soil depth (e.g., as N and P decreased, K, Ca, and Mg increased). Differences in rate of change as well as direction of change were noted.

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ALASKA OREGON WASHINGTON

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-218 January 1974

LABORATORY REACTIVATION OF DIAPAUSING LARCH CASEBEARER LARVAE FOLLOWING DIFFERENT LENGTHS OF WINTER EXPOSURE

by

R. B. Ryan, *Principal Entomologist*

ABSTRACT

Batches of field-collected diapausing larvae were transferred to 20° C between November and April. Before larvae became active, the elapsed time varied depending on date of collection. The number of days until 50 percent of the larvae reactivated decreased from 28 to less than 1 between November and May. This relationship is useful in predicting reactivation of larvae for use in a laboratory rearing program.

Keywords: Larch casebearer, *Coleophora laricella*.

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

The larch casebearer, *Coleophora laricella* (Hbn.) (Lepidoptera: Coleophoridae), is the object of a biological control program in the Pacific Northwest where parasites are being reared in the laboratory for study and release in infested larch stands.[1/] The larch casebearer can be reared throughout the year on potted larch seedlings. However, from November through April larvae are more easily obtained from the field by gathering branches on which the cases of the diapausing larvae are firmly attached.

When moved to room temperature, larvae exhibit a period of apparent inactivity, following which they free their cases from the twigs and resume feeding and growth. During this preliminary period of apparent inactivity, internal physiological changes are proceeding. The length of the period is variable depending upon the duration of the chilling period previously experienced. Eidmann,[2/] in extensive experiments in Sweden, recorded reactivation of larvae of *C. laricella* over a wide range of temperatures. I recorded and am reporting here the reactivation of larvae collected in Oregon during the winter of 1972-73 to serve as a basis on which to predict reactivation of casebearer larvae for use in the laboratory rearing program.

MATERIALS AND METHODS

Twigs were cut from November to April from infested western larch (*Larix occidentalis* Nutt.) trees at an elevation of about 1200 m, 35 km northwest of Elgin in the Blue Mountains of Oregon. Twigs were placed in polyethylene bags closed with a rubber band and transported back to the laboratory. Some were stored temporarily at 2° C. In the laboratory, twigs were placed in one of two types of emergence containers to facilitate collection of reactivated larvae: (1) a 35-cm length of 10.2-cm-diameter black plastic pipe closed on each end with a piece of nylon chiffon or (2) a 15.8 by 30.2 by 7.6-cm clear polystyrene box with one of the 15.8 by 30.2-cm sides closed with nylon chiffon. Ambient conditions were maintained at 20 ± 1° C and 68±5 percent relative humidity. Fluorescent lights in the laboratory were controlled by time switches to give a daily regimen of 18 hours light and 6 hours dark.

Emergence containers were inspected every 1-2 days; any larvae which had completed diapause, as evidenced by the freeing of the case from the twig, were removed and counted. Containers were inspected until reactivated larvae ceased to appear. Cases still attached to twigs after this period were not

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[1/] R. B. Ryan and R. E. Denton. Initial releases of *Chrysocharis laricinellae* and *Dicladocerus westwoodii* for biological control of the larch casebearer in the Western United States. USDA Forest Service Research Note PNW-200, 4 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 1973.

[2/] H. H. Eidmann. Ökologische und physiologische Studien über die Larchenminiermotte, *Coleophora laricella* Hbn. Studia Forestalia Suecica, Nr. 32, 222 p. 1965.

examined to determine if any larvae still remained in diapause or whether larvae had died.

The daily numbers of reactivated larvae were plotted as a cumulative percentage of the total numbers reactivated. The regression of the number of days until 50 percent were reactivated over the date the batch was transferred to 20° C was calculated to establish the relationship between duration of winter exposure and time for reactivation.

RESULTS AND DISCUSSION

Results are presented in figures 1 and 2. Reactivation in the November 21 collection was delayed and took place over a considerable timespan, the 11th to the 53d day. It was almost a month before the 50-percent point on the reactivation curve was reached. Reactivation in successive batches grew progressively more rapid. For example, the 50-percent point for the April 3 batch was reached within 2 days after transfer to 20° C. When larvae

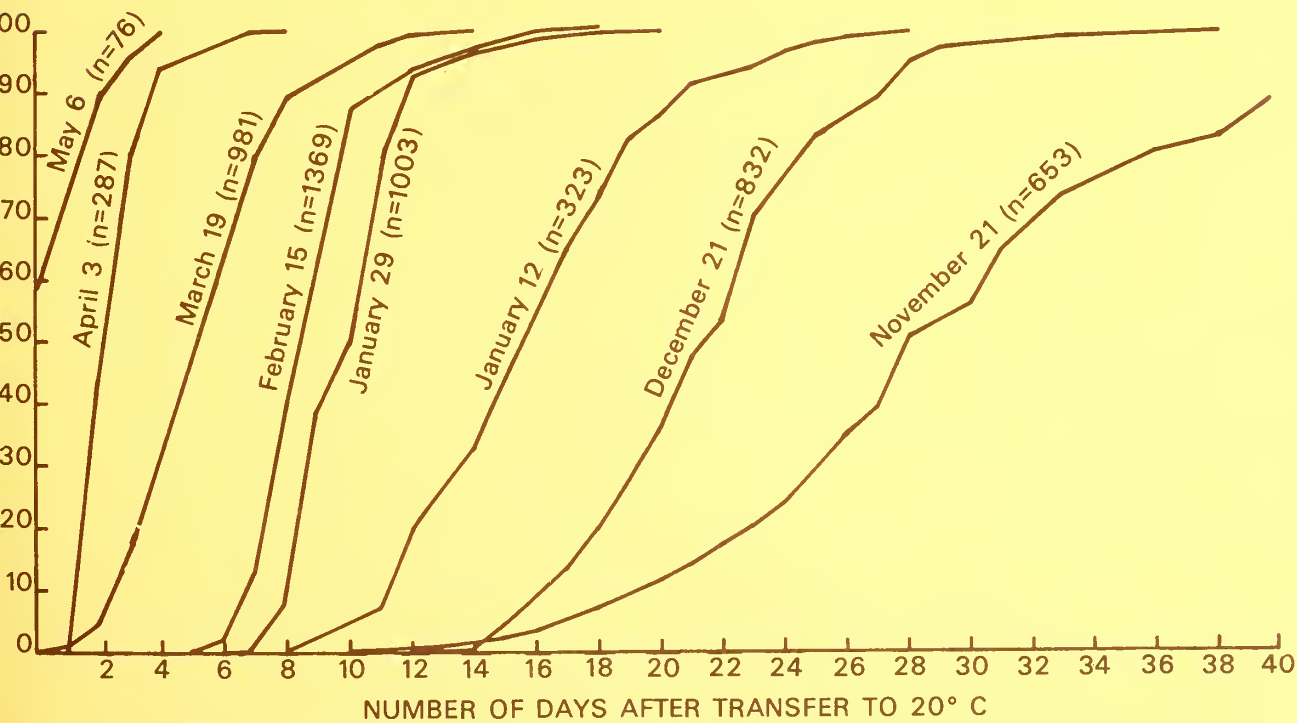

Figure 1.--Reactivation of overwintering *Coleophora laricella* transferred to 20° C on various dates from November 1972 to May 1973.

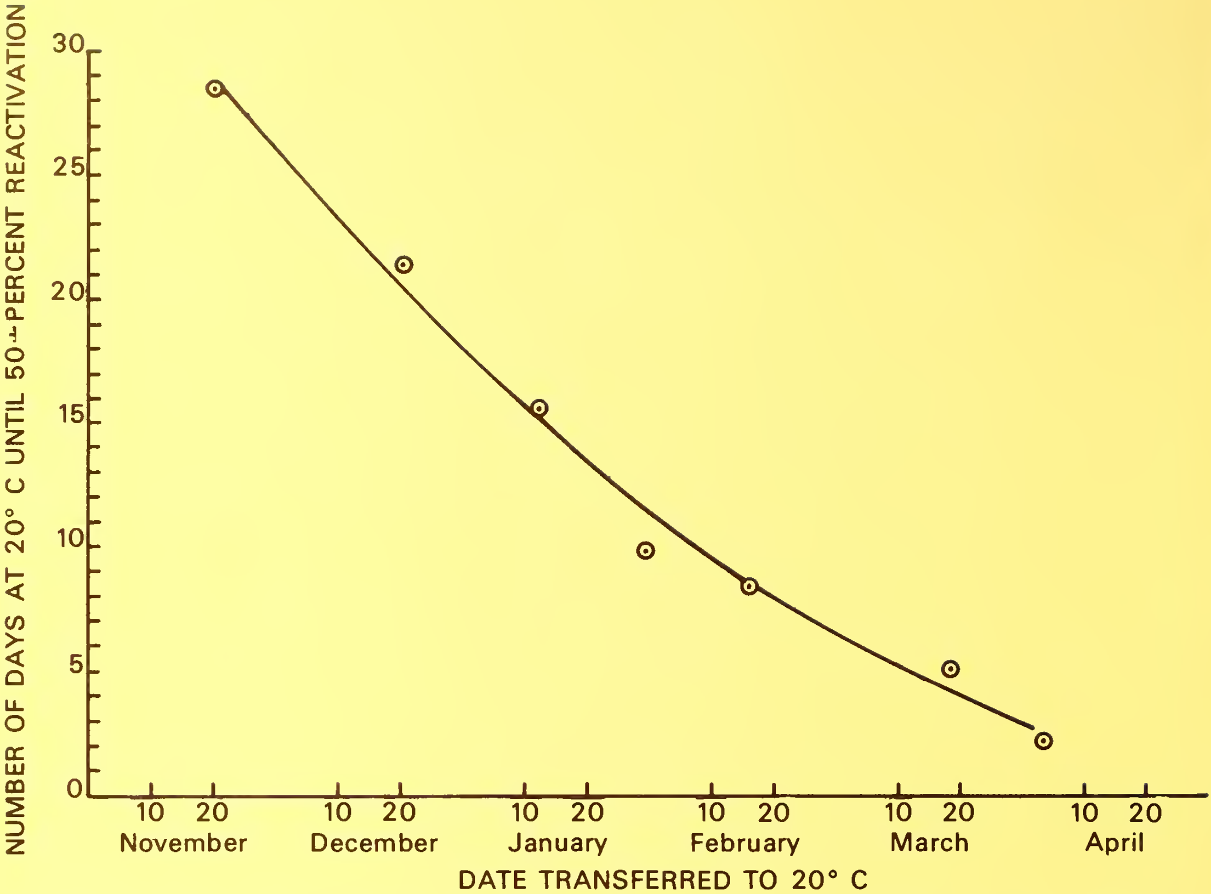

Figure 2.--The relationship between duration of winter exposure and reactivation time at 20° C for overwintering *Coleophora laricella* larvae.

which had been stored at 2° C were transferred to 20° C on May 6, many larvae became active immediately, indicating that diapause had already been terminated.

In the field, active, feeding larvae can be found as early as mid-April at lower elevations, but at higher elevations some larvae do not become active until mid- to late May.

The relationship between reactivation time and date for the period November 21 to April 3 (fig. 2) can be described by the equation:

$$Y = 35.56 - 0.3465X + .00085X^2$$

(where Y = number of days until 50-percent reactivation and X = number of days after November 1) ($r^2 = 0.989$).

A knowledge of this relationship is useful in predicting reactivation of larvae for use in a laboratory rearing program.

GPO 989-999

ALASKA OREGON WASHINGTON

PACIFIC NORTH WEST FOREST AND RANGE EXPERIMENT STATION

USDA FOREST SERVICE RESEARCH NOTE

PNW-219 February 1974

ENDRIN IN FOREST STREAMS AFTER AERIAL SEEDING WITH ENDRIN-COATED DOUGLAS-FIR SEED

by

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ABSTRACT

Extent and duration of endrin contamination in streamwater were determined after aerial seeding of two western Oregon watersheds with treated Douglas-fir seed. Detectable residues of endrin were found in a steep gradient stream for a period of less than 5 hours and in a slower flowing stream for 11 days. Endrin was again detected in the low gradient stream during the high flow of a winter storm 23 days after seeding. Maximum concentrations measured were well below reported 96-hour median tolerance limits for important fish species.

Keywords: Repellents (- animal damage control, water quality, endrin, seeding (direct), Douglas-fir, *Pseudotsuga menziesii*.

This paper is also issued as Technical Paper No. 3709 of the Oregon Agricultural Experiment Station.

INTRODUCTION

Endrin,[1] a chlorinated hydrocarbon insecticide, has been extensively used in the Pacific Northwest for the past 15 years to protect directly sown Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seed from seed-eating rodents. Seed is coated with endrin at a rate of 0.5 to 1 percent by weight (Radwan et al. 1970). Standard practice is to aerially sow treated seed at 0.56 to 1.12 kilograms per hectare.

Amounts of endrin thus introduced into the forest environment are very small (2.5 to 10 grams per hectare). However, endrin-treated seed may enter small streams flowing through seeded areas, and endrin is one of the most toxic pesticides to fish (Tarzwell 1963, Henderson et al. 1959, 1960). The 96-hour median tolerance limit (TL_m) of coho salmon (*Oncorhynchus kisutch*) is 0.27 part per billion (p/b) endrin (Katz 1961, Katz and Chadwick 1961). Hence, there is concern about the potential hazard to aquatic organisms from the use of endrin-coated seed near forest streams.

Uptake of endrin and other chlorinated insecticides is very rapid (Johnson et al. 1971, Naqvi 1973, Wilkes and Weiss 1971), but Johnson et al. (1971) noted that degradation of the accumulated residues also starts during the same period. Biological magnification, stepwise food chain concentration, of endrin by aquatic invertebrates has not been reported. Bridges (1961) found that endrin applied to a pond disappeared rapidly from water, plants, bottom mud, and fish.

Rates of application and the total amounts of endrin introduced into forests by direct-seeding programs suggest that impact on the aquatic environment will be small, but firm knowledge of endrin residue levels is required. In the present study, we determined the extent and duration of endrin contamination in streamwater after aerial seeding of two western Oregon watersheds with treated Douglas-fir seed. Residue levels in aquatic insects, salmon eggs, and fish were monitored at one location.

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[1] 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4,5,8-endo-endo-dimethanonaphthalene.

MATERIALS AND METHODS

FIELD SAMPLING

Aerial seeding of two experimental watersheds in 1967 provided a unique opportunity to compare the extent and duration of streamwater contamination under different streamflow conditions. The watersheds are about the same size, and the length of stream channel covered by the seeding was similar (table 1). However, runoff characteristics differ greatly between the two streams, and these differences may influence maximum endrin concentrations measured and the length of time endrin can be detected in the water.

Watershed No. 1 at the H. J. Andrews Experimental Forest was aerially seeded on October 30, 1967, with 0.56 kilogram of 0.5-percent endrin-coated Douglas-fir seed per hectare. Needle Branch Watershed in the Alsea River Basin was seeded with 0.84 kilogram per hectare of 1.0-percent endrin-coated seed on December 18 and 26, 1967. The Needle Branch Watershed had been aerially seeded in January 1967 at this same rate (Marston et al. 1969); because of inadequate stocking with Douglas-fir, it was reseeded in December 1967.

Table 1.--*Characteristics of two experimental watersheds in western Oregon: Watershed No. 1, H. J. Andrews Experimental Forest; and Needle Branch Watershed, Alsea Basin*

Item	Watershed No. 1[1/]	Needle Branch Watershed[2/]
Area (hectares)	96	71
Area seeded (hectares)	82	66
Aspect	WNW	SSW
Topography (average slope percent)	63	37
Elevation:		
Minimum (meters)	442	131
Maximum (meters)	1,013	366
Stream channel:		
Length (meters)	1,510	1,525
Elevation change (meters)	426	11

1/ From Rothacher et al. (1967).

2/ From Williams (1964).

Both experimental watersheds are equipped for streamflow measurements. Grab samples of water for endrin analysis were collected at the gaging stations before, during, and after seeding. Samples were taken in 4-liter metal containers, stored in ice, transported to the laboratory as soon as possible, and placed in a 2° C coldroom.

Water sampling for endrin residues began 30 minutes before seeding at each site and continued at 15-minute intervals for 2 hours after seeding started. The sampling interval then widened to one sample every 30 minutes for 1 hour, one 1-hour interval, and one sample every 2 hours for 4 hours, one 4-hour interval, one every 12 hours for 36 hours, one every 24 hours for 72 hours, and one sample at the end of the first week. Additional samples were taken at 2 weeks and 3 weeks after seeding and at 3-hour intervals during winter storms for 1 month.

A limited number of biological samples were collected at the Needle Branch site. About 1 week before seeding, eyed coho salmon eggs were obtained from the Fall Creek Salmon Hatchery and planted in separate chambers about 25 centimeters deep in the stream gravels to simulate the position of naturally deposited eggs. Small samples of two species of fish (coho salmon and the reticulate sculpin, *Cottus perplexus*) and several samples of aquatic insects were collected on several dates after seeding. The size and number of samples that could be collected were limited by the small size of the stream and the midwinter date of the seeding operation. Additional samples of coho salmon were obtained from Needle Branch and from adjacent untreated streams (Deer Creek and Flynn Creek) in January 1969, and samples of both fish and aquatic insects were obtained in July 1970. Aquatic biological samples were frozen as soon after collection as possible. Samples of the treated Douglas-fir seed were collected at the time of seeding and from 0.5-square-meter litterfall boxes about 1 month after seeding.

SAMPLE ANALYSIS

Water samples were analyzed for endrin by extracting the total volume collected (up to 4 liters) with *n*-hexane for 16 hours in a batch liquid-liquid partitioning extracting apparatus. Hexane extracts were dried with sodium sulfate, evaporated to 5 to 10 milliliters using a stream of nitrogen, and eluted through a 0.7-percent water-deactivated florisil column (Wood 1966). Eluate volumes were adjusted to 10 milliliters and analyzed by electron capture, gas-liquid chromatography (EC-GLC).

Biological samples were extracted by grinding with silica sand and 10 to 15 milliliters of hexane:isopropyl alcohol (4:1) in a glass mortar (volumes are for a 1- to 2-gram sample and are adjusted according to sample size). The solvent was decanted and filtered and the grinding repeated with seven aliquots of fresh solvent. The residue and the filter paper were extracted with hexane in a soxhlet extractor for 20 hours. All extracts were combined, saponified, cooled, diluted with an equal volume of water, and extracted with hexane. The hexane extract was washed with water until the washings were neutral, dried with sodium sulfate, evaporated to 5 to 10 milliliters, and transferred to a 15-gram florisil column (Wood 1966). Columns were washed with 50 milliliters of benzene:hexane (30:70) followed by 75 milliliters of benzene:hexane (70:30) which eluted the endrin. The volume of eluate was adjusted with hexane for EC-GLC analysis.

A Microtek[2/] model GC-2000MF gas chromatograph with a 130-millicurie tritium electron capture detector and a 1.5-meter by 2-millimeter inside diameter glass column packed with 3-percent SE-30 on 80/100 mesh Gas Chrom Q was used for analysis of endrin. Inlet, column, and detector temperatures were 200°, 175°, and 195° C, respectively. Nitrogen carrier gas flowed at 40 milliliters per minute. Endrin was quantified by peak height, but data obtained were not corrected for recovery efficiencies. Average recoveries, based on analysis of spiked samples, were 97 percent for water samples, 94 percent for treated seed, and 92 percent for other biological material. Confirmation of the identity of endrin was by microcoulometric titration and by treatment with heat and hydrochloric acid to form the aldehyde and ketone isomers as reported by Phillips et al. (1962).

RESULTS AND DISCUSSION

ENDRIN RESIDUES IN STREAMWATER

Instantaneous concentrations of endrin in samples from the two streams are shown in figure 1. The steep gradient of the stream channel in Watershed 1 resulted in the highest concentration of endrin (0.070 p/b) being measured 15 minutes after seeding started. Concentrations of endrin in the water changed rapidly, and the peaks coincide with the flight pattern of the helicopter. All detectable quantities of endrin in the stream were found in the first 5 hours after seeding began. Douglas-fir seed float, and seeds falling directly into the stream channel were carried downstream by the current. No seeds were found on the stream bottom.

In sharp contrast to Watershed No. 1, endrin was not detected in samples from Needle Branch until 6 hours after seeding started (fig. 1). The peak concentration of 0.013 p/b was reached in 21 hours, and residues remained near that level for 3 days. Concentrations then dropped to 0.002 to 0.004 p/b

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[2/] Mention of product or company does not imply endorsement by U.S. Department of Agriculture.

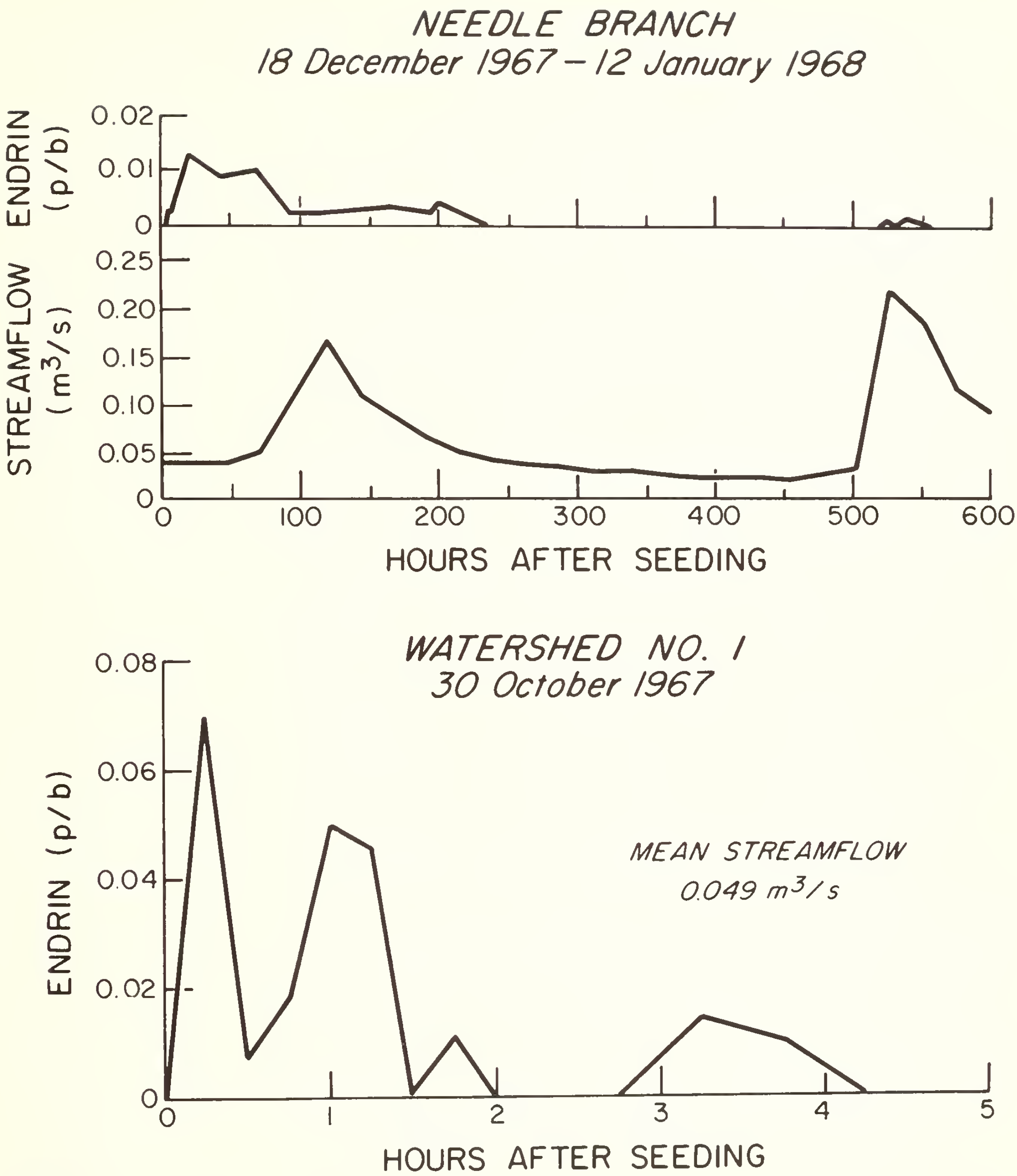

Figure 1.--Concentration of endrin in streamflow after aerial seeding with endrin-coated Douglas-fir seed: Needle Branch Watershed--seed treated with 1.0-percent endrin and sown at 0.84 kilograms per hectare; Watershed No. 1--seed treated at 0.5-percent endrin and sown at 0.56 kilograms per hectare.

for the next 5 days. Measurable amounts of endrin were again detected during the high flow of a winter freshet 3 weeks after seeding.

Half the treated seed was sown on December 18, and the other half on December 26, 1967. Unfortunately, too few samples were taken during the first several days after the second application to detect levels comparable to those measured earlier.

Residues were found in the Needle Branch stream during a winter freshet 3 weeks after seeding probably because of the relatively flat gradient of the stream channel. Fndrin-treated seed falling into open water was not carried downstream as quickly as at Watershed No. 1, and some fir seed was undoubtedly trapped in small, quiet pools. Peak concentrations were lower at Needle Branch; one possible explanation is that, even though more time was available to dissolve endrin from the seed coating, more time was also available for adsorption of the residues on bottom and suspended sediments in the streams (Ferguson et al. 1965). Endrin leached from seed floating downstream was diluted by increased flow volumes in progressively larger streams, and concentrations in solution would be further decreased by adsorption on stream sediment.

The pattern of endrin concentration we found at Needle Branch is different from that reported by Marston et al. (1969) for a similar study of the same watershed a year earlier. They found endrin for only 2 hours after seeding started and again during a storm 6 days later. The maximum concentration found, 0.1 p/b, was in the second sample taken after seeding started. Stream discharge during that seeding operation, however, was about four times greater than in the present study. Higher streamflow reduced the influence of the flat stream gradient; thus their pattern of endrin outflow for Needle Branch closely resembles ours for Watershed No. 1.

Stream discharge data were used to calculate the total amount of endrin in runoff from each watershed (table 2). The endrin load was low and considerably less than the total amount applied directly to the stream channel. For example, the area of the stream channel in Watershed No. 1 is 0.14 hectare, and the amount of endrin applied to this surface area on treated fir seed was approximately 0.38 gram. Thus, the amount of endrin measured in the stream (0.011 gram) represents only about 3 percent of the potential load. Because of the steep gradient of this stream, we assume that the remainder of the applied endrin was carried from the watershed on floating seed. Amounts of endrin measured in Needle Branch samples were considerably higher because of the extended period of time over which detectable residues were present in the stream. Although stream contamination was extremely low, aquatic organisms were exposed to detectable residues for about 3 weeks.

Table 2.--*Grams of endrin in streams of aerially seeded watersheds in western Oregon based on water samples collected between January 23, 1967, and January 10, 1968*

Experimental watershed	Total applied to watershed	Total recovered in stream	Total in stream as percent of total applied to watershed
	-------*Grams*-------		----*Percent*----
Watershed No. 1, H. J. Andrews Experimental Forest[1/]	230	0.011	0.005
Needle Branch Watershed, Alsea Basin:[2/]			
January 1967[3/]	558	.697	.125
December 1967	336	.190	.057

[1/] Douglas-fir seed treated with 0.5-percent endrin and sown at 0.56 kilogram per hectare.

[2/] Douglas-fir seed treated with 0.6-percent endrin and sown at 0.84 kilogram per hectare.

[3/] Calculated from data of Marston et al. (1969).

ENDRIN RESIDUES IN BIOLOGICAL SAMPLES

Data are not presented for samples of aquatic insects, fish, and planted salmon eggs collected before and during the first 4 weeks after aerial seeding of the Needle Branch Watershed. These samples had been frozen as collected and were all processed through the laboratory for residue analysis at the same time. Several, and perhaps all, of these samples were apparently contaminated before or during analysis. All pretreatment samples contained otherwise unexplainable endrin residues, since it is doubtful that any residues from the January 1967 seeding would have persisted through the spring and fall storms. Posttreatment data were extremely variable and exhibited unexplained temporal relationships.

Although inadvertent contamination of these biological samples makes it impossible to draw specific conclusions, a few general observations can be made. Endrin residues were present in all biological materials sampled. In general, residue concentrations increased and then gradually declined after seeding, but it is not possible to quantify actual maximum residue levels resulting from treatment. Even with sample contamination, however, maximum levels of endrin residues in fish did not reach 100 p/b. Residue levels well above 100 p/b endrin did not result in mortality of steelhead fingerlings in a live-box test conducted in California (California Department of Fish and Game 1967).

Additional biological samples were collected 12 and 30 months after treatment to determine whether any detectable residues had persisted from the application of endrin-coated Douglas-fir seed in December 1967. Wild adult coho salmon were obtained from Needle Branch and Deer Creek, and a sample of retained eggs was taken from the Deer Creek fish in January 1969. Coho fingerlings and aquatic insects were collected from Needle Branch and Flynn Creek in July 1970. No endrin was detected in any of these samples.

POSSIBLE HAZARD TO AQUATIC ENVIRONMENT

Cope (1966) and Hunt (1966) conducted laboratory bioassay tests to determine the toxicity of endrin-treated conifer seed to fish and wildlife. Two endrin-treated Monterey pine seeds (0.655-percent endrin) in a 20-liter aquarium were fatal to rainbow trout. Douglas-fir seed containing 200 micrograms endrin per seed caused complete mortality of five rainbow trout in 1 day when 21 seeds were added to 15 liters of aquarium water. Endrin leached from six seeds caused complete mortality in 3 days.

Field studies, however, conducted in California and Oregon have indicated that application of endrin-coated conifer seeds to Pacific slope watersheds may not pose a serious hazard to aquatic organisms (Morton 1967, California Department of Fish and Game 1967). In bioassay tests, fingerling steelhead were placed in live-cars in a flowing stream, and treated pine seed was put in cheesecloth bags and placed in the stream above each live-car. A safety factor for fish was demonstrated of greater than 26 times the amount of endrin that would fall into the stream at the prescribed application rate of 0.84 kilogram per hectare (California Department of Fish and Game 1967). Other studies carried out cooperatively by the Bureau of Commercial Fisheries and the California Department of Fish and Game (1967) indicate that endrin residues are not accumulating in shellfish in bays and estuaries of central and northern California.

CONCLUSIONS

Aerial application of endrin-coated Douglas-fir to reforest harvested or burned watersheds as previously practiced in the Pacific Northwest does not appear to constitute a serious hazard to aquatic habitats. Although rates of seed treatment and dissemination are very low, endrin concentrations known to be toxic to several important species of anadromous fish can result if treated seed fall directly into open ponded water. Static water bioassay tests show that treated fir seed can release sufficient endrin to cause mortality. However, adsorption of endrin residues on stream sediments and continuous dilution in rapidly moving waters of forest streams prevent the development of hazardous exposure conditions.

Data obtained in the present study indicate that direct seeding does result in detectable residues of endrin in streamwater and that the level and duration of contamination depend on the profile of the stream channel. Aquatic organisms normally will not be exposed to chemical residues for more than a few hours in streams with steep gradients or more than several days in slower flowing streams. The maximum concentrations measured are well below reported 96-hour median tolerance limits for important fish species. Detectable levels of endrin were found in the Needle Branch stream up to 23 days after seeding, probably because high flow during a winter storm picked up additional treated seed from along the stream banks. However, actual exposure of fish and aquatic insects amounted to only 3 days to 0.010 p/b endrin and another 8 days to an average of 0.002 p/b.

Endrin residues were found in all biological samples collected during the first month after seeding. Unfortunately, many of these samples were contaminated during analysis, but maximum residue levels in fish were still less than 100 p/b endrin. In general, residues in the aquatic organisms began to dissipate as soon as detectable levels disappeared from the surrounding water. Similar results have been reported by Bridges (1961) and Ferguson et al. (1966).

Although endrin applied at high rates can persist in soils for many years (Nash and Woolson 1967), residues did not appear to accumulate or persist in the aquatic ecosystems of the treated watersheds. Stream bottom sediments were not sampled, but these streams are subject to frequent flushing during the high flow of winter storms, and it is reasonable to assume that adsorbed endrin would soon be carried downstream. Biological samples collected from treated and untreated streams 12 and 30 months after treatment contained no endrin residues. Stream contamination which did occur in the present study, even though small, might be minimized or eliminated by leaving appropriate buffer strips and avoiding direct application to open water and streambanks.

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HIGH YIELDS FROM 100-YEAR-OLD PONDEROSA PINE

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ABSTRACT

A 100-year-old stand of ponderosa pine on a good site responded in diameter growth to a thinning from above that removed 20 percent of the volume or 16 percent of the basal area. Impressive periodic annual volume increments were produced in both thinned and unthinned stands during the 30 years of observation. Total net yield of thinned and unthinned stands at 126 years was 62,500 board feet (International 1/8-inch) per acre. Mortality, caused by mountain pine beetle in small merchantable trees, suggests that similar stands should be thinned lightly and frequently from below.

Keywords: Ponderosa pine, *Pinus ponderosa*, yield (forest), growth response, thinnings (stand volume).

Ponderosa pine (*Pinus ponderosa*) growth east of the Cascades is regarded by most laymen and some foresters as slow. This is due largely to observations of vast areas of old mature timber growing at minimal rates. This note reports some impressive growth in a 100-year-old stand on a good site where tree numbers had been reduced to low-density levels by repeated ground fires and a thinning from above. Such information hints at production possibilities under management and gives us insight as to when and how to manage these highly productive stands. In addition we also have an opportunity to compare actual stand growth with Meyer's normal yield tables, Technical Bulletin 630.[1/] For direct comparison with Meyer, we have used International 1/8-inch board-foot rule and total cubic feet.

THE TIMBER STAND

The stand (fig. 1) is located on the Lookout Mountain Unit of the Pringle Falls Experimental Forest 35 miles southwest of Bend in central Oregon. Study plots are on an east slope at an elevation of about 4,600 feet. The *Pinus ponderosa/Ceanothus velutinus* plant community[2/] (in an *Abies concolor/Ceanothus velutinus* climax association) covers extensive areas on the mountainside. In the study area, snowbrush ceanothus (*Ceanothus velutinus*) predominates with an occasional golden chinkapin (*Castanopsis chrysophylla*). Western prince's pine (*Chimaphila umbellata*) is abundant.

Soil consists of a Mount Mazama pumice mantle 3 to 4 feet deep underlain by a sandy loam Paleosol developed in older volcanic ash. Average annual precipitation is estimated between 25 and 35 inches.

Seedlings became established following a hot fire about 1840. Repeated ground fires thereafter and intermittent beetle activity reduced density to around 280 trees per acre when the study was established. At this time trees averaged a little over 12 inches in diameter and 80 feet tall. About half the trees were from 9 to 15 inches in diameter at breast height, 30 percent were less than 9 inches, and 20 percent were 15 to 25 inches.

The plots to be thinned contained about 6,500 cubic feet and 37,000 board feet (International 1/8-inch, 6.6-inch and larger d.b.h. to a 6-inch top d.i.b.)

1/ Walter H. Meyer. Yield of even-aged stands of ponderosa pine. U.S. Department of Agriculture Technical Bulletin 630 (revised), 59 p., illus. 1961.

2/ Jerry F. Franklin and C. T. Dyrness. Natural vegetation of Oregon and Washington. USDA Forest Service Technical Report PNW-8, p. 176-177. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg., 1973.

Figure 1.--The timber on Lookout Mountain adjacent to the study area. Stand is about 100 years old.

(table 1). The plots left unthinned contained slightly more volume. Basal area and cubic volume on the thinned and unthinned plots were about 6 percent above Meyer's normal before thinning.

Although no crown measurements were made, several observers thought that tree crowns were short and narrow relative to tree height.

The stand consists almost entirely of ponderosa pine, with an occasional lodgepole pine. Some loss from suppression and beetle attack is evident, although the stand is free of serious diseases.

THE STUDY

In 1938 a 40-acre portion of the 94-year-old stand was thinned from above. Just before thinning, all trees were measured and a stand table constructed. Some heights were measured and volume estimates made to aid in applying thinning treatment. However, trees left after thinning were not tagged until 1940. Thus, the 30-year period of detailed growth observation did not start until two growing seasons after thinning.

Cutting in the thinned area removed an average of 23 trees per acre or 20 percent of an original volume of 6,500 cubic feet per acre, leaving 5,200 cubic feet (table 1). About 9,300 board feet were removed from an original volume of 37,000 board feet. Dominants and codominants removed in this thinning averaged about 17.0 inches in diameter. There was notable variation between plots, although plots were reasonably uniform within

Table 1.--*Stand characteristics before and after thinning and amount removed in thinning*

[Per acre. Derived from stand tally information made at time of cutting]

Plot number	Number of trees			Basal area			Average diameter[1]			Cubic volume[2]			International volume[3]		
	Before	Removed	After	Before	Removed	After	Before	Removed[4]	After	Before	Removed	After	Before	Removed	After
				----*Square feet*----			--------*Inches*--------			------*Cubic feet*------			--------*Board feet*--------		
Thinned:															
2	266	18	248	212	31	181	12.1	17.7	11.6	6,111	1,002	5,109	33,187	6,674	26,513
3	184	32	152	214	57	157	14.6	18.1	13.7	6,824	2,051	4,733	44,317	16,142	28,175
4	370	12	358	226	18	208	10.6	16.6	10.3	6,008	568	5,440	29,770	3,831	25,939
5	258	22	236	223	36	187	12.6	17.2	12.1	6,665	1,210	5,455	40,270	9,650	30,620
6	276	30	246	228	41	187	12.3	15.8	11.8	6,864	1,508	5,356	38,506	9,970	28,536
Average	271	23	248	219	35	184	12.2	16.8	11.6	6,494	1,268	5,219	37,210	9,253	27,957
Unthinned:															
7	390	--	--	275	--	--	11.4	--	--	7,993	--	--	42,913	--	--
8	184	--	--	186	--	--	13.6	--	--	5,694	--	--	35,119	--	--
Average	287	--	--	230	--	--	12.5	--	--	6,844	--	--	39,016	--	--

1/ Quadratic mean.

2/ Total volume of entire stem inside bark, trees 2.6-inch d.b.h. and larger.

3/ International 1/8-inch rule (to convert to 1/4-inch, multiply by 0.90476); trees 6.6-inch d.b.h. and larger to a 6-inch top d.i.b.

4/ Removed tree measurements as of 1938 when thinning was made.

themselves. Although early records did not indicate any intent to sample extremes in stand density, this may have been the intent.

Seven permanent plots were established (table 2), five in the thinned and two in an unthinned portion. Three of the thinned plots were 0.5 acre and the rest 1 acre. At the beginning of the detailed growth study in 1940, diameters of all trees were measured at breast height to the nearest 0.1 inch. Heights of about 45 trees per plot representing the complete range of diameters were measured with an abney. Plot volumes were calculated using equations of the form $\log_e$ volume = a + b $\log_e$ diameter fitted to the sample tree values of diameter and corresponding volumes as estimated by table 32 (total cubic) and table 33 (International 1/8-inch rule) in Technical Bulletin 630.

Estimates of 1938 volumes of cut trees were calculated from a stand table made at the time of cutting. The volume equation developed for each plot during the first period was used to estimate 1938 volumes. No attempt was made to measure growth from 1938 to 1940, because measurements in 1938 were not made with the same precision as those in 1940. Volume estimates differ slightly from those published in 1947[3/] because of the method of volume computation.

At the time of thinning, stump ring counts of 121 dominant and codominant trees indicated the stand to be an average of 94 years old. Apparently variation in age from tree to tree was small. This age was further substantiated in 1973 from recently logged trees adjacent to study plots. Except for one tree which exhibited a core of six closely spaced rings in the center, there was little evidence of severe competition for space in early years.

3/ Edwin L. Mowat. High yields from young-growth ponderosa pine. USDA Forest Service Pacific Northwest Forest and Range Experiment Station Research Note 37, 3 p. Portland, Oreg., 1947.

Table 2.--*Stand characteristics 2 years after thinning and three periodic intervals thereafter*

[Per acre]

Plot number	Age	Site index[1]	Number of trees	D.b.h. average[2]	Height average[3]	Basal area	Cubic volume[4]	International volume[5]
	Years			*Inches*	*--Feet--*	*Square feet*	*Cubic feet*	*Board feet*
Thinned:								
2	96	86	248	11.6	79	181	5,303	28,083
	107		225	12.8	84	202	6,302	36,554
	117		212	13.7	89	218	7,291	44,406
	126		197	14.6	94	228	8,084	51,335
3	96	91	152	13.7	84	156	4,925	29,755
	107		136	15.2	92	171	5,884	38,097
	117		126	16.3	99	183	6,759	45,222
	126		122	17.1	104	194	7,572	51,721
4	96	79	358	10.4	70	209	5,681	27,871
	107		284	12.0	79	223	6,820	38,162
	117		262	13.0	86	241	8,006	47,781
	126		236	14.1	92	255	8,930	56,157
5	96	88	236	12.1	80	188	5,657	32,346
	107		208	13.4	87	203	6,648	41,445
	117		186	14.5	92	214	7,434	49,119
	126		168	15.5	97	220	8,044	54,854
6	96	88	246	11.8	76	186	5,539	29,970
	107		205	13.3	84	197	6,384	37,999
	117		178	14.6	90	208	7,227	45,359
	126		165	15.6	96	220	8,125	52,823
Average	96	86	248	11.9	78	184	5,421	29,605
	107		212	13.3	85	199	6,408	38,451
	117		193	14.4	91	213	7,343	46,377
	126		178	15.4	96	224	8,151	53,378
Unthinned:								
7	96	88	390	11.4	76	275	8,233	44,913
	107		308	12.9	84	281	9,261	55,493
	117		262	14.1	92	286	10,178	64,438
	126		204	15.3	99	261	9,811	64,567
8	96	94	184	13.6	84	186	5,948	37,149
	107		164	15.1	95	204	7,295	48,236
	117		137	16.6	103	206	7,944	54,225
	126		129	17.5	108	215	8,708	60,472
Average	96	91	287	12.5	80	231	7,090	41,031
	107		236	14.0	89	242	8,278	51,864
	117		199	15.4	97	246	9,061	59,332
	126		166	16.4	104	238	9,260	62,520

1/ Technical Bulletin 630.

2/ Quadratic mean.

3/ Average height corresponding to quadratic mean diameter.

4/ Cubic volume of trees 2.6-inch d.b.h. and larger.

5/ International 1/8-inch scale; trees 6.6-inch d.b.h. and larger to a 6-inch top d.i.b.

RESULTS

DIAMETER GROWTH

Even though these trees were approaching 100 years, they did respond to thinning. Average annual diameter increment per surviving tree was as follows:

Period	Thinned	Unthinned	Difference
	Inches		
1940-51	0.0734	0.0610	0.0124
1951-61	.0622	.0545	.0077
1961-70	.0580	.0510	.0070

Response to release was greatest during the first growth period. Diameter increment averaged about 17 percent better on the thinned plots the first period and only 12 percent the last two periods. Many small trees had no measurable increment from one period to another. Some large trees, with full crowns and ample growing space, grew 2.5 inches per decade. On the other hand, not all large trees grew fast. Each plot contained a few 15- to 20-inch trees that did not add any detectable increment from one period to the next. A typical average range of increments with tree diameter is shown by the linear regressions in figure 2 (r^2 values ranged from 51 to 59 percent). No direct relationship between diameter growth and the amount of release a given tree received could be established during the first growth period.[4/]

MORTALITY

Almost all mortality could be attributed to mountain pine beetle (*Dendroctonus ponderosae*). In the last period, volume of mortality increased to about 77 percent more in the unthinned plots than in the thinned (table 3). Evidently unthinned density increased to a point ideal for beetle development. Mortality was consistently lower in the thinned than the unthinned plot throughout the 30-year period of growth observation.

Mortality often occurred in dense tree groups. Usually, suppressed or intermediate trees from 4 to 10 inches in diameter were the most susceptible. Occasionally trees over 20 inches would succumb to attack of the insect. This occurred in one of the unthinned plots during the last period

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[4/] Unpublished progress report on file at the Pacific Northwest Forest and Range Experiment Station, Silviculture Laboratory, Bend, Oreg.

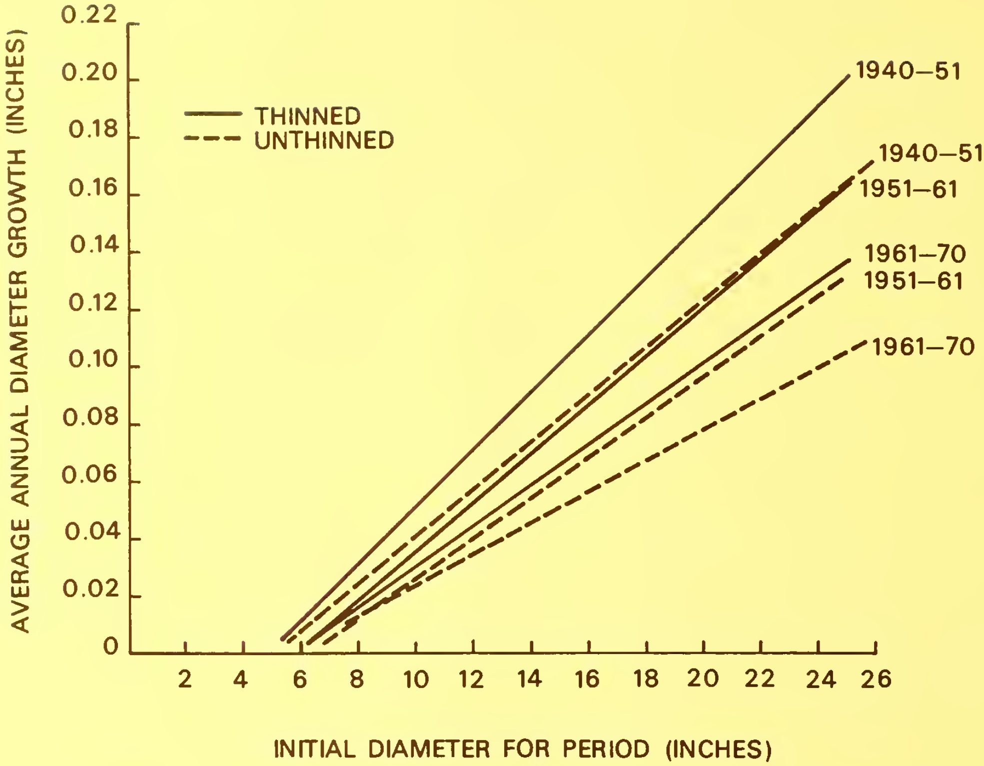

Figure 2.--Average annual diameter increment of trees of given diameter in thinned and unthinned plots.

Table 3.--*Periodic annual net and gross increments and mortality during the 30 years of growth observation*

[Per acre]

Treatment	Growth period	Periodic annual net volume increment		Periodic annual mortality		Periodic annual gross volume increment	
		Board feet	*Cubic feet*	*Board feet*	*Cubic feet*	*Board feet*	*Cubic feet*
Thinned	1940-51	804	90	62	22	866	112
	1951-61	793	94	57	16	850	110
	1961-70	778	90	76	19	854	109
Unthinned	1940-51	985	108	102	30	1,087	138
	1951-61	747	78	220	44	967	122
	1961-70	354	22	489	84	843	106

where there were 262 trees and basal area was over 280 square feet per acre. Of 58 trees that died in this plot during the last period, 60 percent had no measurable increment the previous period and 95 percent were growing at rates less than 0.8 inch per decade. Fifty-three percent of these trees were merchantable (10-inch or more diameter breast height) and could have been harvested.

VOLUME INCREMENT

Gross periodic annual volume increment averaged greater on the unthinned plots during the first and second periods (table 3 and figs. 3 and 4). During the last period, thinned and unthinned plots were about equal. Net increment, on the other hand, was higher on the unthinned plots only during the first period. Mortality increased during the second and third periods; on one unthinned plot, mortality was so high that no net yield resulted. Total net yield of the thinned (including volume removed in thinning) and unthinned plots at 126 years (1970) was about 62,500 board feet per acre.

On a tree-by-tree basis,large dominants are growing 10 to 18 board feet per year. And, in many instances about half the total board-foot volume produced was grown on only the 40 largest diameter trees per acre. This is contrasted to many small but merchantable trees growing less than a board foot a year. For example, plot 6 (table 2) had 36 trees in this category in the last period, 22 of which would be merchantable under present day standards in central Oregon. This suggests that a thinning from below, removing many small unproductive trees, may not reduce growth appreciably, yet it will permit utilization of mortality that is likely to occur within the

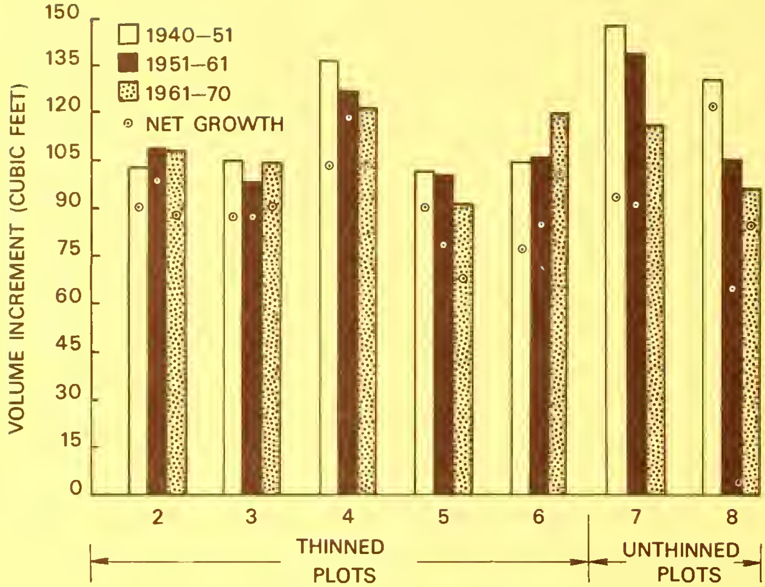

Figure 3.--Periodic annual net and gross cubic volume increment per acre.

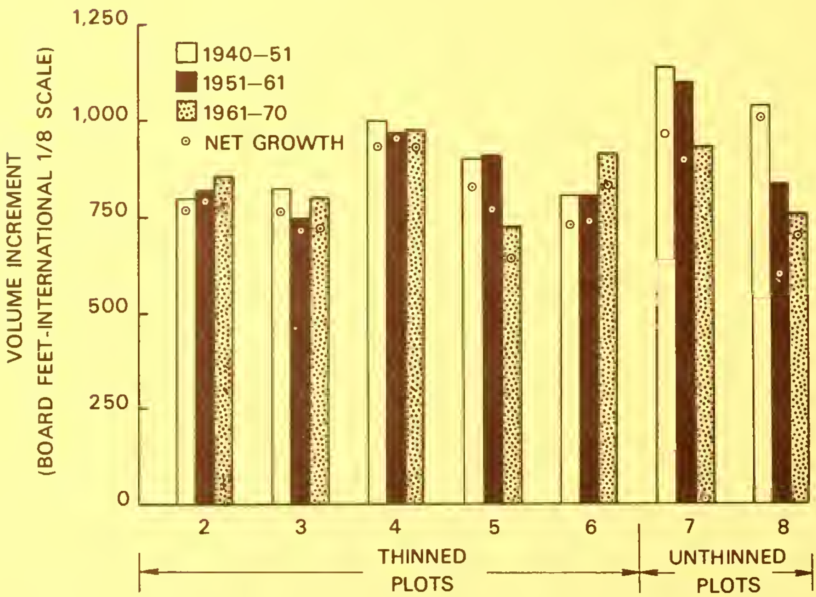

Figure 4.--Periodic annual net and gross board-foot volume increment per acre (International 1/8-inch rule).

decade. Also, the few large trees that are not adding any increment could be cut if detectable at the time of marking.

During the 30 years of observation, annual growth of the thinned plots averaged 857 board feet per acre gross and 791 net (table 3), increments that are far above normal stand values. An average increase in site index of 2.5 points took place during the 30 years of observation. This in itself would account for an annual increment of about 85 board feet per acre in the yield table but does not account for increment values far above normal in this study. In terms of cubic volume, net increment was over 250 percent of normal yield table growth in the thinned area (table 4), even though cubic stand volume was cut 12 percent below normal. One is tempted to suspect that the height growth characteristics of this stand may be quite different from those reflected in Technical Bulletin 630.

Table 4.--*Comparison of total cubic volume, basal area, and net cubic volume increment with Meyer's normal yield table (Technical Bulletin 630)*

Plot	Stand volume		Basal area		Periodic annual increment	
	1940	1970	1940	1970	1940-51	1961-70
	Percent of normal stand values					
Average, thinned	88	115	89	108	257	321
Average, unthinned	105	120	108	111	258	73

DISCUSSION AND CONCLUSIONS

Even though this stand may be rotation age, it is producing impressive amounts of wood annually that are far in excess of what might be anticipated from Meyer's yield table. Because of age and poor crown ratios, most trees in this stand do not have the capacity to respond dramatically to thinning. Even so, this unmanaged stand, thinned late in the rotation, responded to thinning. Evidently small increases on large tall trees resulted in substantial growth per acre.

Thirty-year growth in the thinned plots remained nearly constant, while that in the unthinned declined. Over the 30 years, thinned plots grew less gross cubic wood than unthinned. However, net increment of thinned plots averaged considerably higher than unthinned.

Although this stand is growing above normal, we probably should not conclude that all similar stands are going to perform as well as this one. For some reason the productivity potential for this area is high for the measured site index. The capacity of a site index class to have more than one productivity potential has been recognized for some time,[5/] and this may be what has happened in this stand.

Although this stand was thinned from above, the pattern of mortality during the 30 years of observation would suggest that light thinnings from below with removal of an occasional poor tree from above would maintain the productive capacity of the stand and permit utilization of mortality that is likely to occur.

The public land manager with large acreages of low-producing, overmature, and diseased timber often faces a difficult decision. Should he concentrate all of his allowable cut in old-growth stands to convert them more quickly to fast-growing, young stands? Or should he do some commercial thinning in stands such as described in this note? Obviously the major portion of the cut should come from old-growth stands. However, if a minimum of effort can be expended in thinning these 100-year-old stands gently but frequently, it is possible to avoid wasting wood through mortality and thus increase the total amount available for cutting. Excessive cutting in these 100-year-old stands to forestall mortality would slow down old-growth conversion efforts and would ultimately result in an overall loss in productivity.

On the other hand, private landowners without a large reserve of old growth may wish to liquidate a large portion of the growing stock in a stand of this type.

[5/] E. Assmann. The principles of forest yield study. New York: Pergamon Press, 506 p., illus., 1970.

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