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GROWTH OF YOUNG PONDEROSA PINE STANDS
IN THE INLAND EMPIRE

By

Donald W. Lynch
Forester

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah

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INTRODUCTION

The Inland Empire has been the scene of accelerated logging during and since World War II. Record lumber prices and increased demands for building materials have encouraged large and small operators alike to search out sources of raw material. With virgin stands of timber less and less accessible, the natural trend has been to exploit young second-growth stands that have grown since the early logging days in the region.

The Inland Empire contains approximately one million acres of second-growth ponderosa pine. Even-aged stands of young trees have generally replaced the stands of mature timber that the original settlers found. The first cutting in this region began at an early date, and before the turn of the twentieth century a well-established logging and milling industry was harvesting the virgin timber to meet the needs of a growing empire. Ponderosa pine was the natural choice of species because of its superior lumber quality and its ready accessibility in the valley floors and lower foothills. In those early days, logging was often wasteful. Trees that were not cut were destroyed in the logging process or burned later in slash fires. Conditions were often right for a new crop to seed in from the scattered veterans that happened to escape both axe and fire. Large acreages of these second-growth stands, predominantly in the 40- to 60-year-age class, are today reaching the lower limits of merchantability. Many second-growth stands have already been cut. With pulpwood markets looming on the horizon, these young stands are assuming even greater importance.

Markets for timber products are, of course, essential to good forest management, but ironically enough, markets can likewise be responsible for poor and even destructive cutting if good management principles are not applied. The demand for saw logs, for example, has been an incentive for premature and heavy cutting in many fine young stands of fast-growing trees. When a pulpwood market comes, the pressure for cutting will be even greater; and because of the lower merchantable diameter of pulpwood products, younger stands and smaller trees will be subject to clear cutting. To prevent markets from becoming a curse rather than a boon to good forestry, second-growth stands should be cut wisely. Young stands should not be clear cut at a time when volume growth is most rapid; but rather, a growing stock of well-spaced vigorous trees should be maintained to realize greatest returns from the land. Moderate cutting is often desirable because most young stands need thinning. With markets available, thinning and improvement cutting will yield immediate returns as well as create improved future values.

In order to manage timber wisely and know when and how much to cut, reliable growth information is, of course, essential. Unless a timber owner knows with some degree of certainty how much growth in volume and value his trees will produce if managed wisely, he cannot be expected to hold them in the face of attractive immediate returns. It was for the purpose of providing growth information for young stands of ponderosa pine that the present study was undertaken.

METHODS

Field

The field work for this growth study was conducted during the summer of 1949 in northeastern Washington and northern Idaho. Fifty temporary plots were established in pure ponderosa pine stands ranging from 20 to 100 years of age and on sites ranging from II, very good, to VI, very poor. A few plots contained a small percentage of Douglas-fir or lodgepole pine. Stand densities ranged from open to overstocked. The northern and western limit of the plot locations was in the vicinity of Republic, Washington; the eastern and southern limit was near Potlatch, Idaho; while the southwesterly limit was a short distance south of Cheney, Washington. Plot size varied from 1/10 acre to 1 acre, depending upon tree size; approximately 100 trees were included in each plot. Each tree on the plots was measured and observed in detail as follows:

1. Diameter breast height to 0.1 inch.
2. Bark thickness to 0.1 inch measured by Swedish bark gage.
3. Radial growth of wood for the past 10 years measured on an increment core to 0.01 inch.
4. Crown class.

Heights of approximately 30 trees were measured with an Abney level and tape to provide a height-over-d.b.h. curve for each plot. All dead trees on the plots which were judged, on the basis of condition of needles, branches, and basal rot, to have died within the past 10 years were recorded by diameter classes.

Office

The measurement data on approximately 5,000 trees in this study were analyzed by a method described by Gevorkiantz and Olsen (1). The method involved a 10-year growth prediction by individual trees based on the past 10-years' growth, adjusted by age and average 10-year growth during the life of the tree. Tables of diameter growth by d.b.h. and age were developed for various stocking and site classes. Volume growth was then determined by using heights from the different plot height curves and volumes from tables from Meyer (3). There was no significant difference in the growth rates of the few Douglas-fir and lodgepole pine trees, so they were not separated in the analysis. Mortality loss was approximated from the dead tree data for each plot. Because of large variation from plot to plot, mortality loss could not be evaluated with great accuracy.

Any method of growth prediction based on past growth is, of course, subject to errors in the event of appreciable changes in climate.

RESULTS

Separate growth tables were prepared for 12 different site-stocking conditions. It was apparent, however, that differences between several of the tables were only slight and that many of the groups could be combined. By using individual tree predictions based on the two variables, age and diameter, many of the effects of site and stocking were automatically accounted for in the analysis. For example, trees of the same size and age might reasonably be found on both good and poor sites, but in different crown classes. Suppression, disease, or injury might account for the below-average size of a particular tree on a good site, while on a poor site a tree of that size and age might be a normal dominant tree. The predicted growth for two trees, one from a poor and another from a good site, could be the same if they had the same past growth pattern. Thus a table showing future growth by both age and diameter can be applied to a range of site and stocking conditions. Most trees on good sites and under moderate stocking conditions are, of course, larger for their age than trees from poor sites or dense stands. Growth figures for trees from various sites and stocking conditions therefore appear at different points in the same table depending upon the age-size combination.

Large differences in site result in different heights for trees of the same age and diameter, so volume changes are evident over broad site changes. Such height differences due to site precluded pooling all growth data into one table, but it was possible to condense the original twelve tables into three. The application of the tables not only was simplified by this grouping, but their reliability was improved because of the greater number of plots upon which each was based.

The site II data for all stocking conditions were combined and are shown in table 1. Data for sites III, IV, and V and all stocking classes within them are condensed in table 2. Site VI data are combined in table 3. A close comparison of the tables will reveal that certain combinations of diameter and age show higher predicted growth on poor sites than on good. This apparent paradox exists for two reasons: First, small trees of an advanced age normally are not found on good sites. If present, they are suppressed or damaged and their current growth rate is slow. The same size trees of similar age on a poor site are likely to be average trees maintaining reasonably good growth. Second, large trees of a young age are not normally found on poor sites. If present, they are unusually thrifty trees, probably open-grown and putting on volume much faster than the average tree for that site. On the other hand, that same combination of age and size on a good site could reasonably be only an average tree putting on average growth. It is evident, then, that comparisons of individual tree growth between sites is meaningless until actual measurements of dominant and codominant trees from different sites are entered in the table and the growth predictions derived.

APPLICATION

Growth Prediction

Tables 1, 2, and 3 contain 10-year cubic volume growth predictions for second-growth ponderosa pine. Using the tables requires a simple stand table developed from a cruise of the area together with the age of the trees and the site evaluation. The stand table should show the number of trees by 1-inch diameter classes, and the age of the stand should be determined by boring a representative group of dominant and codominant trees. An uneven-aged stand requires a curve of age over diameter. Site can be classified by measuring the heights of a few dominant and codominant trees of average diameter and referring to the site curves in figure 1.

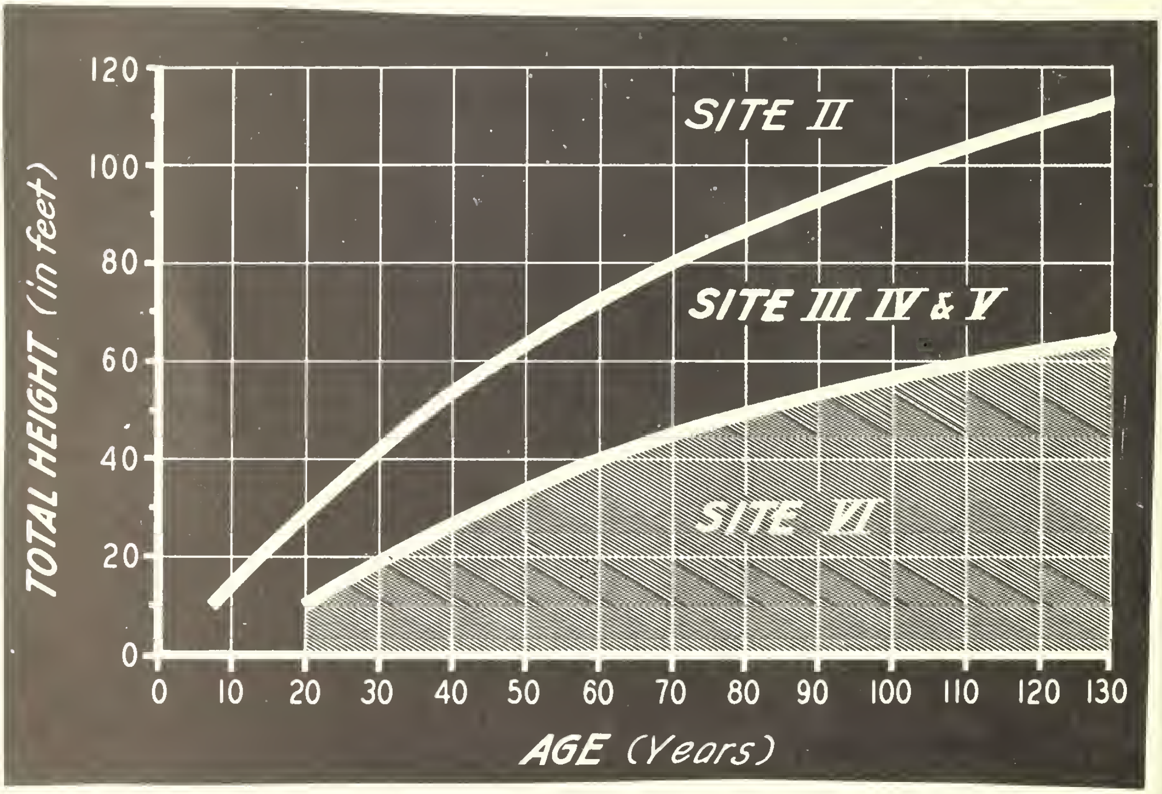

Figure 1.--Height of dominant and codominant trees of average breast-high diameter by site groups. After Meyer (3).

Table 1.--Site II. Future 10-year volume growth in cubic feet[1/]

D.b.h.	Age in years															
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Inches								Cubic feet								
2	0.13	0.08														
3	.74	.52	0.37	0.28												
4	1.48	.94	.67	.50	0.40	0.34										
5	3.50	1.90	1.42	1.14	.94	.78	0.67	0.59	0.55							
6		3.75	2.50	1.95	1.58	1.30	1.08	.93	.80	0.72	0.68	0.65				
7		6.50	3.90	3.05	2.50	2.10	1.78	1.53	1.32	1.17	1.05	.95	0.90	0.85		
8			7.50	5.10	3.95	3.22	2.70	2.30	2.00	1.74	1.52	1.35	1.23	1.13	1.05	1.00
9				8.40	6.60	5.40	4.60	4.00	3.53	3.15	2.85	2.60	2.35	2.18	2.04	1.90
10				12.50	9.35	7.60	6.50	5.65	5.05	4.55	4.16	3.85	3.60	3.40	3.27	3.20
11					13.60	10.75	8.90	7.70	6.80	6.10	5.55	5.10	4.70	4.40	4.20	4.05
12						14.90	12.10	10.50	9.35	8.50	7.82	7.30	6.90	6.52	6.25	6.05
13						19.20	15.80	13.70	12.10	10.80	9.90	9.15	8.52	8.02	7.60	7.28
14							19.40	17.00	15.10	13.50	12.20	11.20	10.34	9.60	9.02	8.55
15							23.00	20.70	17.95	15.90	14.25	13.05	12.10	11.38	10.75	10.24
16								24.90	21.70	19.50	17.65	16.20	15.03	14.15	13.42	12.82
17								31.50	26.70	23.20	20.95	19.55	18.50	17.70	16.96	16.34
18									32.00	29.10	26.35	24.10	22.55	21.35	20.35	19.46
19									37.30	34.00	31.00	28.00	25.50	23.85	22.55	21.40
20										40.00	36.00	32.10	29.20	27.00	25.10	23.70
21											42.00	38.50	33.50	30.00	27.60	25.50
22												44.00	40.90	36.10	33.00	30.60
23												51.50	46.30	39.50	36.50	34.10
24													52.50	47.50	41.40	38.10
25														53.00	48.15	44.90
26															54.50	49.50
27															64.00	60.00
28																70.00

Table 2.--Sites III, IV, and V. Future 10-year volume growth in cubic feet[1/]

D.b.h.	Age in years															
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Inches								Cubic feet								
2	0.30	0.14	0.08													
3	1.30	.62	.37	0.22	0.14											
4		1.30	.80	.56	.42	0.32	0.26	0.22								
5		2.68	1.42	1.00	.75	.58	.50	.45	0.43							
6			2.65	1.95	1.55	1.30	1.05	.90	.75	0.65	0.60	0.55	0.53			
7			4.55	2.80	2.15	1.75	1.45	1.25	1.10	1.00	0.95	.90	.88	0.82		
8				4.75	3.50	2.85	2.38	2.05	1.80	1.60	1.46	1.35	1.27	1.20	1.16	1.15
9				7.50	5.40	4.40	3.77	3.33	3.00	2.72	2.50	2.30	2.18	2.07	2.00	1.95
10					7.45	6.10	5.25	4.65	4.20	3.90	3.63	3.46	3.32	3.22	3.19	3.15
11					10.40	8.05	6.70	5.90	5.30	4.80	4.50	4.22	4.05	3.90	3.80	3.75
12						10.60	8.90	7.75	6.95	6.35	5.90	5.50	5.25	5.00	4.85	4.75
13						13.70	11.20	9.80	8.80	8.10	7.50	7.05	6.70	6.40	6.20	6.05
14							13.20	11.40	10.30	9.40	8.80	8.30	7.90	7.50	7.30	7.10
15							16.35	14.10	12.60	11.50	10.70	10.00	9.50	9.05	8.70	8.40
16								17.20	15.00	13.40	12.30	11.50	10.80	10.20	9.75	9.40
17								20.50	18.40	16.60	15.20	14.10	13.30	12.55	12.00	11.50
18									21.10	19.00	17.35	16.00	15.00	14.20	13.50	13.00
19									24.50	22.00	20.20	19.00	18.10	17.40	16.80	16.40
20										25.50	23.30	21.70	20.50	19.50	18.80	18.15
21											26.10	24.40	23.20	22.30	21.60	21.00
22												29.10	27.20	25.50	24.10	23.00
23												32.40	30.50	28.90	27.60	26.50
24													34.00	31.60	29.80	28.50
25														35.50	33.80	32.40
26															37.60	36.00

Table 3.--Site VI. Future 10-year volume growth in cubic feet[1/]

D.b.h.	Age in years															
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
Inches								Cubic feet								
2		0.30	0.14	0.08												
3			.80	.38	0.24	0.16										
4				1.18	.77	.57	0.43	0.33								
5					1.27	.95	.73	.58	0.48							
6					2.48	1.60	1.13	.85	.66	0.54	0.48	0.46	0.45			
7						2.96	2.06	1.56	1.05	.95	.90	.82	.78	0.76		
8							3.34	2.44	1.78	1.52	1.28	1.12	1.01	.94	0.90	0.88
9							5.10	3.75	2.94	2.30	1.88	1.57	1.35	1.20	1.08	1.00
10								5.50	4.35	3.45	2.82	2.35	2.05	1.82	1.65	1.54
11									6.05	4.73	4.00	3.43	3.05	2.75	2.52	2.35
12										6.05	4.90	4.16	3.70	3.37	3.18	3.10
13										8.20	6.60	5.07	4.90	4.45	4.13	3.95
14											9.30	8.00	7.00	6.30	5.80	5.45
15												10.20	8.93	7.95	7.20	6.65
16													11.00	9.78	8.80	8.10
17														12.35	11.15	10.25
18															12.80	11.55
19																13.45

1/ Includes stump and top without bark.

Table 4 presents a sample stand table for a 1-acre tract of second-growth ponderosa pine 70 years old on site IV. The predicted 10-year cubic volume growth of each tree, based on its diameter and age, was read from table 2 and entered in the fifth column of table 4. Note that for the smaller diameters, no growth figures appear in table 2 under age 70. In such cases, read the last entry present for that particular diameter class. Despite the fact that a stand is essentially even-aged, the smaller trees are usually considerably younger. Column 6 of table 4 shows the total growth of all trees in each diameter class and the total of this column is the predicted gross growth for the entire acre.

Table 4.--Sample stock table with future 10-year growth and present volume computations. One-acre basis. Age of stand 70 years, site IV, medium stocked

D.b.h.	Trees per acre	Present volume: Volume per tree[1/]	Present volume: Total volume	Growth prediction: Growth per tree[2/]	Growth prediction: Total growth
Inches	Number	Cubic feet		Cubic feet	
2	16	0.3	4.8	0.08	1.28
3	12	.6	7.2	.14	1.68
4	13	1.0	13.0	.22	2.86
5	23	1.7	39.1	.43	9.89
6	53	2.6	137.8	.60	31.80
7	33	3.9	128.7	.95	31.35
8	40	5.5	220.0	1.46	58.40
9	31	7.6	235.6	2.50	77.50
10	33	10.5	346.5	3.63	119.79
11	10	14.5	145.0	4.50	45.00
12	23	18.8	432.4	5.90	135.70
13	20	23.7	474.0	7.50	150.00
14	13	29.9	388.7	8.80	114.40
15	3	35.9	107.7	10.70	32.10
Totals	323		2,680.5		811.75

1/ From table 9, page 12.
2/ From table 2, page 5

Growth predictions by the individual tree method are superior to normal yield table predictions because they require no adjustment for stocking. Ponderosa pine commonly grows in clumps with intervening openings and average stocking is often far below normal over a sizable tract. In the clumps or groups, stocking is dense. Because of this growth characteristic, applying an average adjustment for stocking over a sizable area usually gives an unrealistic correction, whereas a stand table which shows the number of trees of a given diameter and age reflects the true condition of stocking.

The individual tree type of growth prediction has a further advantage over the normal yield table method in that a change in normality for the period under consideration does not affect the growth prediction. In young, understocked stands of ponderosa pine the normality change in basal area over a 10-year period is often considerable, yet at the present time no data are available to make adjustments for this change when using normal yield tables. Growth predictions based on individual trees do not require normality adjustments.

To show the effectiveness of the individual tree method, growth predictions were made on three sample stands. From increment core and bark measurements it was possible to reconstruct the stands to show the diameter and age 10 years before measurement, and growth predictions were made by (1) the individual tree growth tables, (2) the usual normal yield table method, and (3) the normal yield table method with adjustment for change in normality. Normality change was known, of course, for these reconstructed stands except for the possible error in mortality. The growth predictions were compared to actual growth and are shown in table 5. In the case of the individual tree method, the growth predictions were 96 percent, 102 percent, and 93 percent of actual growth for the three sample stands. The normal yield table method gave 25 percent, 40 percent, and 43 percent of actual growth for the same stands. When adjusted for normality changes the normal yield table method was much improved, giving 99 percent, 111 percent, and 121 percent of actual; but until data are available for making adjustments for normality changes, the latter method cannot be used. The advantage of the individual tree method is well demonstrated by these comparisons.

Table 5.--Comparison of actual 10-year growth with growth predicted by three methods

Method	1939 volume	1949 volume	10-year growth	Percentage of actual
	Cubic feet			Percent
SITE II - Age 65 years in 1949				
Actual condition1/	2,191	3,277	1,086	100
Normal yield table2/	2,071	2,347	276	25
Normal yield table with adjusted normality3/	2,071	3,149	1,078	99
Computed growth4/			1,043	96
SITE IV - Age 90 years in 1949				
Actual condition	2,286	2,848	562	100
Normal yield table	2,702	2,926	224	40
Normal yield table with adjusted normality	2,702	3,323	621	111
Computed growth			575	102
SITE VI - Age 70 years in 1949				
Actual condition	1,173	1,641	468	100
Normal yield table	1,421	1,624	203	43
Normal yield table with adjusted normality	1,421	1,988	567	121
Computed growth			437	93

1/ Based on a reconstructed stand for the 1939 volumes.

2/ The conventional normal yield table method using the 1939 normality percentage throughout.

3/ Using both the 1939 and 1949 normality percentages for adjusting the respective volumes.

4/ Using the growth tables on page 5 of this publication.

Mortality

Mortality is always difficult to evaluate. Because of the great variation in natural mortality, accurate corrections would require a great deal of data. The adjustments for loss presented here are approximations and are not intended to be as accurate as the gross growth predictions.

In this analysis, site had little effect on mortality loss. Age had only minor influence on volume mortality, although it did affect the number of dead trees by size classes. Stocking is the greatest single factor influencing mortality in second-growth ponderosa pine; the mortality observed in this study was caused principally by suppression. Densely stocked stands have appreciably more mortality than medium or lightly stocked stands regardless of other factors.

Two divisions appeared adequate to separate the effects of stocking on mortality: (1) well stocked and (2) medium to poorly stocked. In well-stocked stands under 60 years of age, mortality is high in small trees, but the actual volume loss is not great. Of the plots studied in this category, an average of 75 cubic feet per acre was lost during the 10-year period. This loss includes the actual volume of the dead trees plus their growth potential. Mortality accounted for a loss of 81 cubic feet per acre in well-stocked stands in the 60- to 80-year-old class, while in stands over 80 years old, only 48 cubic feet per acre were lost during the decade. In the medium to poorly stocked category, a negligible loss occurred in stands under 60 years old, while stands 60 to 80 years old lost an average of 31 cubic feet per acre. Stands over 80 years old lost 30 cubic feet per acre. These losses were converted to a percentage basis to make them more useful. The percentage losses, in even figures, appear in table 6 along with cubic-foot losses per acre.

Table 6.--Mortality on all sites in 10-year period by age and stocking classes

Stocking class[1/]	Loss					
	Under 60 years		60 to 80 years		Over 80 years	
	Cubic feet	Percent[2/]	Cubic feet	Percent	Cubic feet	Percent
Well stocked	75	10	81	10	48	5
Medium to poorly stocked	6	1	31	5	30	4

1/ Well stocked is considered 70 percent or more of normal; medium to poorly stocked is less than 70 percent of normal.

2/ Percentages are approximations based on average volume growth.

As a guide in assigning a stocking rating to a particular stand, table 7 shows basal areas and number of trees per acre at the dividing point between well stocked and medium to poorly stocked stands for three age classes and three site classes. The values include all trees 0.6 inch d.b.h. and larger. Because of past fires in many of our ponderosa pine stands, the numbers of trees per acre in the small diameter classes have often been materially reduced, yet the basal areas have built up through increased diameter growth on residual trees. For this reason, basal area is a more valid criterion for stocking then number of trees. Using average stocking figures for an entire tract of timber can often give inaccurate results as mentioned previously because of the patchy growth of most ponderosa pine stands. If a stand is composed of thick clumps with intervening openings, the stocking, as far as its effect on mortality is concerned, is high even though the average stocking for the entire tract might be rather low. Personal judgment must be exercised in the application of table 7.

Table 7.--Basal areas and number of trees per acre at the dividing point between well stocked[1/] and medium to poorly stocked stands for three age classes and three site classes

Age class	Site II		Sites III, IV, & V		Site VI	
	Basal area[2/]	Trees[2/]	Basal area[2/]	Trees[2/]	Basal area[2/]	Trees[2/]
	Square feet	Number	Square feet	Number	Square feet	Number
40- 59	165	370	134	690	110	1,860
60- 79	165	230	135	370	110	865
80-100	165	150	135	230	110	470

1/ Well stocked is 70 percent or more of normal.
2/ Includes all trees 0.6 inch d.b.h. and larger.

The sample stand shown in table 4 is medium stocked by either basal area or number of trees per acre. The mortality adjustment for a medium stocked 70-year-old stand, found in table 6, is 5 percent. The net growth is, then, 812 times 0.95 or 771 cubic feet per acre in even figures.

Because mortality is often irregular and occasionally severe, as in the case of insect attacks, fire, or snow breakage, it should be understood that the best growth prediction can be seriously upset by unusual and unpredicted loss.

Cordwood and Board-foot Volumes

Table 8 shows the number of stacked cords of 8-foot unpeeled wood to a 4-inch top diameter (inside bark) for each 100 cubic feet of total tree volume, including stump and top inside bark. Thus, the cubic volume figures from tables 1, 2, 3, and 9 can be converted directly to merchantable cordwood volumes. Further breakdown in table 8 adjusts for average diameter of trees and for crookedness or roughness of the sticks (2).

Table 8.--Number of cords of stacked wood1/ per 100 cubic feet2/ of total tree volume

Average tree d.b.h.	Condition of pulpwood sticks			
	Straight and smooth	Straight but slightly rough	Slightly crooked and rough	Considerably crooked and rough
Inches	Cords per 100 cubic feet			
6	0.76	0.79	0.88	0.93
7	.97	1.00	1.12	1.18
8	1.07	1.10	1.21	1.23
9	1.13	1.16	1.26	1.32
10	1.16	1.19	1.29	1.36
11	1.18	1.21	1.30	1.38
12	1.19	1.22	1.31	1.39
13	1.20	1.23	1.31	1.39
14	1.20	1.23	1.31	1.39

1/ Conventional pulpwood measure in 8-foot unpeeled sticks to a 4-inch inside bark top.

2/ Cubic-foot volume of entire tree including stump and top without bark (as read from tables 1, 2, 3, or 9).

Using the sample stand of table 4 as a further example, the net predicted 10-year growth was found to be 771 cubic feet. The average tree of this sample stand is 8 inches d.b.h., and although the growth prediction is for 10 years hence when the average d.b.h. will be slightly greater, the difference will not be sufficient to go to the next higher factor in the table, though the 8-inch factor will be slightly conservative. Multiplying 7.71 (net predicted growth in hundreds of cubic feet) by 1.07 (from table 8) gives 8.25 cords net growth per acre. This prediction includes all size classes, the smaller ones of which would not actually be of merchantable size for cordwood. If interested only in growth of cordwood of merchantable size, the prediction could be limited to all trees 6 inches d.b.h. and larger. Actually, the volume growth is so slight in these small diameter classes that little error is introduced by including them.

Table 9.--Total cubic-foot volume per tree by d.b.h. classes and site groups[1/]

D.b.h.	Site groups II	Site groups III, IV, V	Site groups VI	D.b.h.	Site groups II	Site groups III, IV, V	Site groups VI
Inches		Cubic feet		Inches		Cubic feet	
2	0.5	0.3	0.1	15	40.1	35 9	26.7
3	.8	.6	.4	16	47.7	42.4	31 5
4	1.2	1.0	.7	17	55.8	49.5	37.1
5	2.2	1.7	1.4	18	65.4	57.7	43 1
6	3.4	2.6	2.3	19	76.8	67.1	49 1
7	5.0	3.9	3.4	20	88.0	77.1	56.2
8	6.8	5.5	4.8	21	101.1	88.1	63.8
9	9.1	7.6	6.6	22	111.0	99.0	72.1
10	12.5	10.5	9.0	23	121.4	110.0	81.2
11	16.5	14.5	11.6	24	133.3	122.3	89.5
12	21.2	18.8	14.6	25	146.0	134.0	92.5
13	26.8	23.7	18.3	26	158.0	145.0	107.0
14	33.0	29.9	22.1	27	172.0	158.5	117.0

1/ Volumes include stump and top without bark. From Meyer (3). Based on average heights for each sites II and VI and composite average height for sites III, IV, and V.

If total volume per acre is desired, table 9 can be used in conjunction with a stand table such as shown in table 4, and present total volume computed. Rather than being broken down by height classes, the volumes in table 9 are divided according to the average height in the three broad site classes used throughout this study. The present sample stand has a volume of 2,680 cubic feet, and after adding the 771 cubic feet of growth, the predicted total cubic-foot volume in 10 years is 3,451. These figures can be converted to cords if desired.

Converting cubic feet to board feet involves principles similar to converting to cordwood, except that the merchantability limit is 10 inches d.b.h. A sufficiently accurate estimate of ingrowth, that is, trees reaching the 10-inch class during the prediction period, can be based upon the assumption that all 9-inch trees will reach 10 inches. Returning to the sample stand as an example, the predicted 10-year growth in cubic feet of 9-inch trees and larger, is 674 cubic feet. Correcting for mortality gives 640 cubic feet net growth.

Table 10 gives converting factors for both International 1/4-inch rule to a variable top diameter and Scribner rule to an 8-inch top diameter by d.b.h. and site classes. Factors for Scribner volumes are considerably lower than those for International volumes, principally because of the difference in top utilization in the basic data of the two tables used. An 8-inch top diameter is too large for present utilization standards in second-growth material, but no other Scribner volume table was available.

Table 10.--Ratios of International and Scribner board-foot volumes to cubic-foot volume by diameter classes

D.b.h.	Board feet per cubic foot[1/] of volume					
	International[2/] rule sites			Scribner[3/] rule sites		
	II	III, IV, V	VI	II	III, IV, V	VI
Inches	Board feet					
10	3.8	3.5	3.3	1.7	1.4	1.2
12	4.8	4.6	4.2	3.3	3.1	2.8
14	5.3	5.2	4.7	4.2	3.9	3.5
16	5.7	5.6	5.0	4.7	4.4	4.0
18	6.0	5.8	5.3	5.1	4.8	4.3
20	6.2	6.0	5.5	5.4	5.1	4.6
22	6.3	6.2	5.7	5.7	5.4	4.9
24	6.4	6.3	5.8	5.9	5.6	5.1
26	6.5	6.4	6.0	6.1	5.8	5.3

1/ Total cubic-foot volume including stump and top, excluding bark (as read from tables 1, 2, 3, or 9).

2/ International 1/4-inch rule to a variable top diameter.

3/ Scribner Decimal C rule to an 8-inch top.

The average diameter of trees 10 inches and larger in the sample stand is 12 inches, and because of ingrowth the average diameter will not increase appreciably in 10 years. Thus, a factor of 4.6 can be selected from table 10 under site IV, International rule, or a factor of 3.1 for the Scribner rule. The growth of 640 cubic feet is found to be equivalent to 2,944 board feet International or 1,984 board feet Scribner.

Total cubic-foot volumes per acre can likewise be converted to board feet. In the event that the average diameter of a stand increases appreciably during the prediction period, total cubic volume at the beginning of the period must be converted to board feet by one factor and total cubic-foot volume at the end of the period converted by an appropriately larger factor. The difference is the growth in board feet for the period. It would be underestimating board-foot growth to convert cubic-foot growth by only the larger factor.

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SPECIES ADAPTABILITY AND SEEDING SEASON FOR INCREASED FORAGE PRODUCTION IN NORTHEAST WASHINGTON

Anthony B. Evanko
Division of Range Management Research
Intermountain Forest and Range Experiment Station

INTRODUCTION

The livestock industry is an important component of the regional economy in the six northeast Washington counties (fig. 1). Totaling almost 8 million acres or 18 percent of the state acreage, this region produced one-fifth of the beef cattle and one-eighth of the sheep reported in Washington in 1950 (7).[1] Approximately 100,000 acres of cropland in this area are used only for pasture and managed rather intensively. An additional 3 million acres, most of which have been classed as conifer-grass and foothill-grass, are suitable for grazing to some degree. Much of this acreage, although potentially productive, has been unwisely managed in the past and contributes little to the livestock industry. Native vegetation on a large part of these lands has been largely replaced by less desirable forbs, shrubs, and weedy annual grasses.

Industrial development and population increase within the region create an ever-increasing demand for livestock products. Washington at present produces less than half of the beef and even less of the mutton that is consumed in the state. In the interests of the livestock industry, low-producing lands should be returned to and managed for maximum sustained forage production. Concurrently, an objective of vital concern--soil and watershed protection--will also be met. In many instances, production of native ranges can be increased by improved management practices. Abandoned croplands and other areas that have lost most of their good forage species, however, can best be restored by artificially seeding to desirable forage species followed by wise management.

Extensive efforts have been made over the years to rehabilitate low-producing range and marginal croplands, but the results of workers elsewhere in the West have only limited application to this area because of soil and climatic differences. Although reported recommendations do provide guides that have universal application in the artificial revegetation field, e.g. clean, well-prepared seedbeds, drilling, etc., it is essential to determine techniques and species adaptability on local bases.

1/ Underlined numbers in parentheses refer to Literature Cited, page 25.

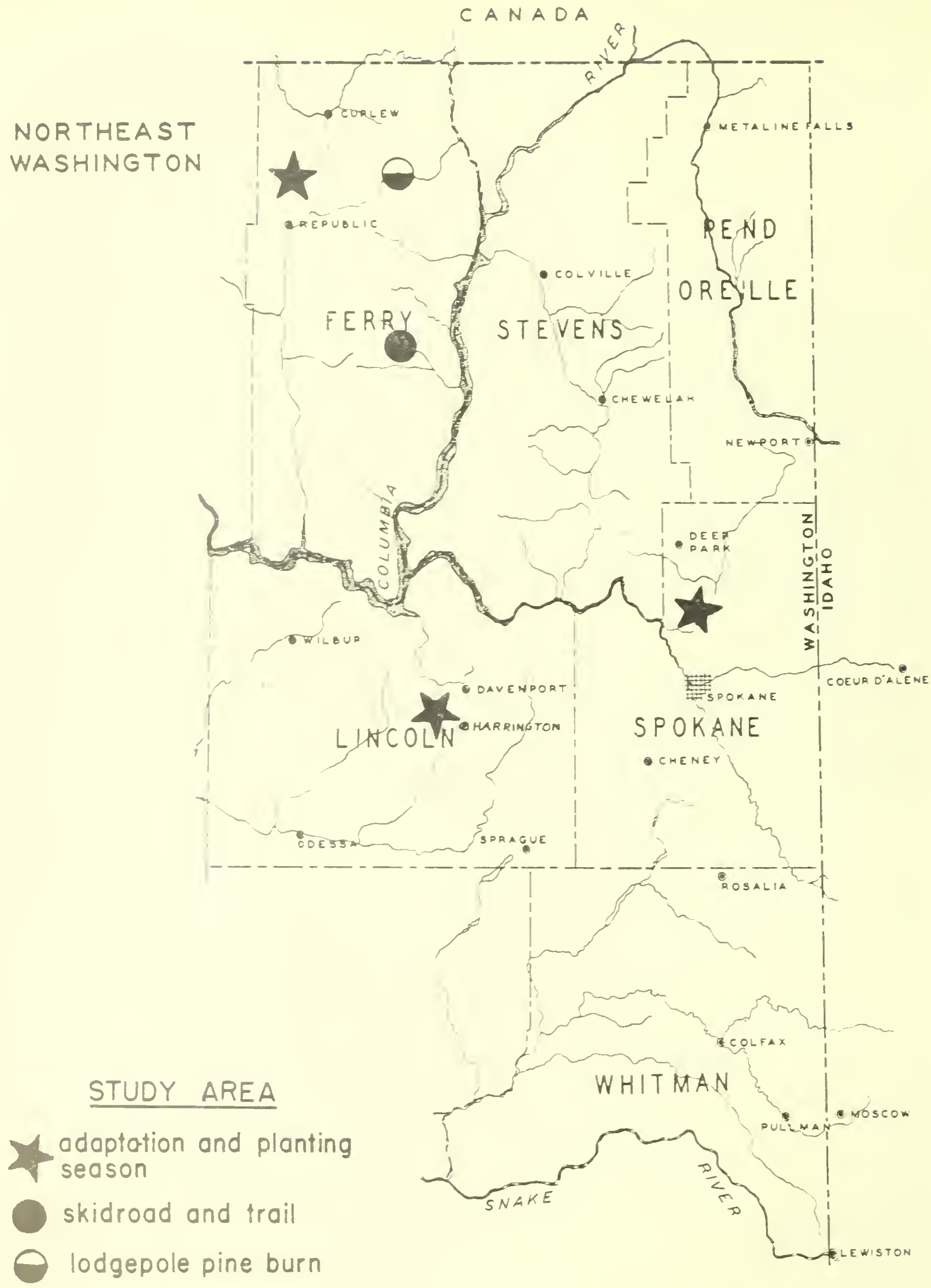

Figure 1.--Map of northeast Washington showing study area locations.

ADAPTATION TRIALS

Species adaptability and planting methods are commonly tested in small plots in artificial revegetation research. These results are then screened and the most promising species and methods are tested further in field-scale trials. The studies described herein were so designed originally but field trials were necessarily limited. Preliminary results of the small plot tests have been reported earlier (1), (2), (3), (4), and (9).

Test areas in Lincoln County characteristic of marginal croplands and in Ferry and Spokane Counties representing cleared woodlands that had been cropped and abandoned were selected for study (fig. 1). At these locations, seedings of a number of species, strains, and varieties of grasses and legumes were made in the spring and fall to determine adaptability and proper season of seeding. Each species was seeded with a Planet, Jr. seeder in plots consisting of three 18-foot rows spaced 1½ feet apart. Seedbeds were prepared by plowing, hand raking, and packing. Competing weed species were removed twice during each growing season for 2 years following seeding.

Relative success of all seedings was determined periodically throughout each growing season using a rating scheme which considered plant distribution within the rows and plant survival and vigor. Greatest emphasis was placed on plant vigor in these trials when assigning the ratings. Number of plants was considered of lesser importance since seeding rate could not always be controlled and seed viability was not always known. Six rating classes--excellent, good, fair, poor, very poor, and failure--were used. When the results were evaluated, species were placed into four categories based on performance in seedings made in 2 or more years. These categories and the rating classes to which they refer are as follows:

Performance category	Rating class
Outstanding	Excellent
Successful	Good
Satisfactory	Fair
Unsatisfactory	(Poor (Very poor (Failure

Little significance is attached to results from 1 year's plantings, even though excellent, because of the relatively limited period of testing. Results from 1 year's plantings have been included primarily to summarize the revegetation research effort in this area.

Spokane County

The study area is near Chattaroy, Washington at an elevation of 2,200 feet on a ponderosa pine[2] site that had been cleared, farmed for several years, and abandoned. The soil has been classified as a Springdale gravelly loam (8) with a weak profile development, low humus content, excessive drainage, and a low water-holding capacity. Precipitation for this general locality averages about 20 inches annually with one-third of the total occurring during the months of April through September (table 1). The growing season averages about 3½ months (6). An estimated 20 percent of the soil surface was occupied by annual and perennial weedy vegetation; namely, cheatgrass, sheep sorrel, Heath forget-me-not, Douglas knotweed, low dogbane, flannel mullein, amaranth, and Klamath weed (fig. 2A). Five percent of the soil surface was covered by litter and the remaining 75 percent was bare.

Table 1.--Precipitation[1] at three northeast Washington stations by period and years in which seedings were made at each study area

County, station, and year	Period: April through September	Period: Remaining 6 months	Total
	Inches	Inches	Inches
Spokane County (Deer Park)			
Norm	6.60	13.75	20.35
1950	2/ 4.95	2/ 18.04	-
1951	4.59	3/ 13.27	-
1952	4.50	9.94	14.44
1953	7.97	2/ 10.64	-
Ferry County (Republic)			
Norm	6.62	7.64	14.26
1948	2/ 15.10	3/ 3.36	-
1949	2.93	5.46	8.39
1950	3/ 3.83	4/ 5.61	-
1951	7.36	14.05	21.41
Lincoln County (Harrington)			
Norm	3.91	7.52	11.43
1950	4.69	13.21	17.90
1951	3.83	9.60	13.43
1952	3.67	5.13	8.80

1/ Weather Bureau climatological data, U. S. Dept. of Commerce
2/ Record of 1 month lacking
3/ Record of 2 months lacking
4/ Record of 3 months lacking

2/ Common and botanical names of plants mentioned in this paper appear on pages 23 and 24.

Figure 2.--(A) Abandoned submarginal cropland in Spokane County, Washington having almost no grazing value. (B) Three-year-old spring-seeded crested wheatgrass and Intermediate wheatgrass stands in tests on an adjacent comparable area. Standard crested wheatgrass, first 3 rows from right; Fairway crested wheatgrass, next 3 rows; and intermediate wheatgrass extending left off the photo.

Twenty-nine species were seeded in the spring and fall of at least 2 years and several other species were tested in only one fall and spring seeding.

With one exception, spring seedings were superior to those made in the fall at this location. Stands resulting from the 1950 fall seeding were as successful as those made in the spring, but species performance in subsequent fall seedings was generally unsatisfactory.

Outstanding stands in the spring seedings (table 2) were produced by:

Crested wheatgrass, 571
Fairway crested wheatgrass (fig. 2B)
Hard fescue
Intermediate wheatgrass (fig. 2B)
Orchardgrass, S-143
Pubescent wheatgrass
Standard crested wheatgrass (fig. 2B)
Whitmar beardless wheatgrass

The stands produced by the following species were almost as successful:

Manchar smooth brome
Primar slender wheatgrass
Sheep fescue
Siberian wheatgrass
Streambank wheatgrass
Tall fescue
Tall wheatgrass
Timothy
Western wheatgrass

Satisfactory stands were produced by green needlegrass, Russian wildrye, and initially by Ladak alfalfa. The alfalfa was reduced to unsatisfactory status by the second growing season. Performance of the remaining species in the spring seedings was unsatisfactory. Of this latter group, a strain of common slender wheatgrass was the only failure experienced.

In the fall seedings, no species were outstanding but the following were successful:

Crested wheatgrass, 571
Intermediate wheatgrass
Pubescent wheatgrass
Timothy

Table 2.--Average success ratings[1/] in 1953 of grass and legume species tested at three locations in northeast Washington by seeding season

Species	Spokane County		Ferry County			Lincoln County		
	Spring	Fall	Spring	Early fall	Late fall	Spring	Early fall	Late fall
Bluegrass, big, Sherman	VP(2)	VP(1)	[2/] F(2)	-	F(2)	F(2)	-	VP(1)
" , " , " , P-8903[3/]	F(1)	P(1)	-	-	-	F(1)	-	VP(1)
" , bulbous	P(2)	P(2)	F(2)	-	G(2)	X(1)	-	-
" , Canada, common	VP(2)	VP(2)	VP(2)	-	VP(2)	X(1)	-	-
" , " , P-410	P(2)	P(2)	-	-	-	F(1)	-	-
" , Canby	VP(2)	.VP(2)	-	-	-	X(1)	-	-
" , Kentucky	F(1)	P(1)	VP(2)	-	X(2)	VP(1)	-	-
" , " , P-3128	F(1)	F(1)	-	-	-	-	-	-
Brome, mountain, Bromar	P(2)	P(2)	F(3)	VP(1)	P(3)	P(3)	X(1)	X(3)
" , " , common	VP(2)	VP(2)	VP(3)	X(1)	VP(3)	VP(1)	-	-
" , smooth, Lancaster	G(1)	VP(1)	-	-	-	E(1)	-	VP(1)
" , " , Lyon	E(1)	P(1)	-	-	-	E(1)	-	VP(1)
" , " , Manchar	G(2)	F(2)	E(3)	G(1)	G(3)	E(3)	X(1)	X(3)
Canarygrass, Reed, Superior	-	-	X(3)	X(1)	X(3)	VP(3)	X(1)	X(2)
Fescue, hard	E(3)	F(3)	G(3)	G(1)	G(3)	G(3)	X(1)	VP(3)
" , Idaho	P(3)	F(3)	-	-	-	F(3)	-	P(3)
" , " , P-6435	G(1)	F(1)	-	-	-	F(1)	-	F(1)
" , sheep	G(2)	F(3)	-	-	-	E(3)	X(1)	VP(2)
" , tall	G(2)	F(3)	VP(3)	X(1)	VP(3)	F(3)	X(1)	VP(2)
Foxtail, creeping	F(1)	VP(1)	-	-	-	-	-	-
" , meadow	-	-	-	-	P(1)	-	-	-
Needlegrass, green	F(2)	VP(2)	P(2)	-	VP(2)	F(1)	-	-
Oatgrass, tall, Tualatin	-	-	-	-	X(1)	-	-	-
Orchardgrass, common	-	-	G(3)	VP(1)	P(3)	F(3)	X(1)	X(3)
" , " , P-3135	E(1)	F(1)	-	-	-	E(1)	-	X(1)
" , S-143	E(3)	P(3)	G(3)	VP(1)	VP(2)	F(3)	X(1)	X(1)
Redtop	-	-	-	-	P(1)	-	-	-
Ricegrass, Indian	E(1)	P(2)	-	-	X(1)	G(2)	X(1)	VP(2)
Rye, mountain	-	-	-	-	-	F(1)	X(1)	-
Ryegrass, perennial	-	-	-	-	X(1)	-	-	-
Timothy, Asiatic	G(1)	G(1)	-	-	-	VP(1)	-	VP(1)
" , common	G(3)	G(3)	P(3)	VP(1)	VP(2)	F(3)	X(1)	X(3)
Wheatgrass, beardless, Whitmar	E(2)	F(2)	E(3)	G(1)	G(3)	G(2)	-	VP(1)
" , crested, Fairway	E(3)	P(3)	G(3)	G(1)	G(3)	E(3)	G(1)	G(2)
" , " , Standard	E(2)	F(2)	G(3)	F(1)	G(3)	E(3)	F(1)	G(2)
" , " , 571	E(3)	G(3)	G(1)	-	F(1)	E(2)	-	E(2)
" , intermediate	E(3)	G(3)	G(3)	G(1)	G(3)	E(3)	P(1)	P(3)
" , " , P-14	E(1)	G(1)	-	-	-	E(1)	-	P(1)
" , pubescent	E(3)	G(3)	E(3)	G(1)	E(3)	E(3)	X(1)	F(2)
" , Siberian	G(2)	X(1)	E(1)	-	F(1)	E(3)	F(1)	G(1)
" , " , P-27	G(1)	P(1)	-	-	-	-	-	-
" , slender, common	X(2)	X(2)	F(2)	X(1)	P(2)	F(2)	-	X(1)
" , " , " , P-1711	E(1)	G(1)	-	-	-	G(1)	-	X(1)
" , " , " , P-8039	E(1)	G(1)	-	-	-	-	-	-
" , " , Primar	G(3)	P(3)	G(3)	F(1)	G(3)	E(3)	VP(1)	VP(2)
" , streambank	G(2)	VP(3)	-	-	G(1)	E(2)	VP(1)	P(2)
" , " , P-2415	E(1)	P(1)	-	-	-	-	-	-
" , tall	G(3)	VP(3)	F(3)	F(1)	P(2)	E(3)	X(1)	P(3)
" , western	G(2)	P(2)	G(3)	F(1)	G(3)	E(3)	X(1)	VP(2)
Wildrye, blue	-	-	-	-	X(1)	-	-	-
" , Russian	F(2)	X(2)	G(3)	X(1)	VP(3)	G(1)	-	-
Alfalfa, creeping	P(2)	VP(2)	X(1)	VP(1)	VP(1)	G(3)	X(1)	VP(2)
" , Ladak	P(2)	VP(2)	VP(2)	VP(1)	X(2)	G(3)	VP(1)	X(2)
" , Siberian	-	-	-	-	-	E(1)	X(1)	-
Burnet, small	-	-	X(2)	X(1)	X(2)	P(3)	X(1)	X(3)
Clover, Alsike	-	-	-	-	-	-	-	-
" , strawberry	-	-	X(1)	-	-	-	-	-
" , white, Ladino	-	-	X(1)	-	X(1)	-	-	-
" , yellow sweet	-	-	-	-	-	-	-	-
Trefoil, big, Granger	F(1)	-	VP(2)	-	X(1)	F(1)	-	-
Milkvetch, sicklepod	P(2)	X(2)	-	-	-	X(1)	-	-

1/ E = excellent, G = good, F = fair, P = poor, VP = very poor, X = failure, - = not seeded.
2/ Numbers in parentheses indicate the number of years seedings were made.
3/ Accession numbers of seed obtained from Soil Conservation nursery at Pullman, Washington.

Satisfactory stands were produced by:

Hard fescue
Idaho fescue
Manchar smooth brome
Sheep fescue
Standard crested wheatgrass
Tall fescue
Whitmar beardless wheatgrass.

The remaining species performed unsatisfactorily.

In spring and fall seedings of a single year of several species and strains, spring again proved to be the most suitable seeding season. Excellent stands were obtained with:

Indian ricegrass
Intermediate wheatgrass (P-14)
Lyon smooth brome
Orchardgrass (P-3135)
Slender wheatgrass (P-1711, P-8039)
Streambank wheatgrass (P-2415)

Somewhat less successful were the stands produced by:

Asiatic timothy
Idaho fescue (P-6435)
Lancaster smooth brome
Siberian wheatgrass (P-27).

Big trefoil, creeping foxtail, two strains of Kentucky bluegrass, and Sherman big bluegrass (P-8903) produced satisfactory stands but lacked the vigor and plant distribution of the preceding groups of species.

Plant establishment and vigor of the above species were generally less satisfactory (table 2) when fall-seeded. Although one season's results, such as these, are not considered adequate, they do confirm other results as to the superiority of spring seeding.

Based on the information obtained from the trials at this location, seven of the most successful species--Fairway crested wheatgrass, intermediate wheatgrass, orchardgrass (S-143), Primar slender wheatgrass, pubescent wheatgrass, tall wheatgrass, and Whitmar beardless wheatgrass--were selected for further testing on a larger basis. On a site similar to that used in the small plot trials and employing methods and equipment that would ordinarily be used by land owners, 1/5-acre seedings were made of each species in the spring (1953) using a single-disk grain drill.

The seedbed was plowed and floated before drilling. Each wheatgrass species was seeded at a rate of 8 pounds and orchardgrass at 6 pounds per acre to a depth of 1/2 to 3/4 inch.

Stand establishment and plant vigor for all species were outstanding in the first growing season (fig. 3). The seedings were doubtless favored by abundant moisture during the earlier portion of the growing season (1.85 inches above normal for the period of April, May, and June). Although 6-inch row spacing may have resulted in some reduction of plant vigor, the loss was more than offset by the ability of the seeded stands to control weedy species.

Ferry County

Adaptation nursery

This area was considered typical of cleared woodlands which had been cropped for several years and abandoned. Located at an elevation of 2,450 feet, the area receives about 14 inches of precipitation annually (table 1), approximately one-half of which occurs during the months April through September. An average 3-month frost-free period occurs from June to September (6). The soil is a sandy loam underlain by gravel. There was no evidence that the area had ever been plowed but it had been subject to heavy past grazing use by horses. Cover vegetation occupied about 0.4 of the soil surface and was composed of 60 percent grass and 40 percent forb species. Needleandthread grass, green needlegrass, cheatgrass, Idaho fescue, Sandberg bluegrass, beardless wheatgrass, and bluebunch wheatgrass, in that order of abundance, made up the grass cover, and forbs consisted of woolly Indianwheat, aster, silky lupine, western yarrow, rose pussytoes, Wyeth eriogonum, and flannel mullein.

Spring and late fall seedings of 26 grasses and legumes were made in 3 years and an early fall seeding in 1 year only at this location. In addition several other species were seeded in only one season of 1 year and will not be considered except for inclusion in table 2.

Spring seedings at this location usually resulted in more vigorous and evenly distributed plants than those made in the late fall. Stands resulting from the single early fall seeding were somewhat less successful than those made in late fall. The outstanding species at this location were Manchar smooth brome and Whitmar beardless wheatgrass when spring seeded, and pubescent wheatgrass in both spring and late fall seedings. Species performing successfully in spring and late fall seedings included:

Figure 3.--Spring-seeded intermediate wheatgrass (A) and Primar slender wheatgrass (B) stands on submarginal abandoned cropland in Spokane County, Washington $3\frac{1}{2}$ months after seeding.

Spring	Late fall
Fairway crested wheatgrass	Bulbous bluegrass
Hard fescue	Fairway crested wheatgrass
Intermediate wheatgrass	Hard fescue
Orchardgrass, common	Intermediate wheatgrass
Orchardgrass, S-143	Manchar smooth brome
Primar slender wheatgrass	Primar slender wheatgrass
Russian wildrye	Standard crested wheatgrass
Standard crested wheatgrass	Western wheatgrass
Western wheatgrass	Whitmar beardless wheatgrass

A group of species that were considered satisfactory when seeded in the spring included:

Bromar mountain brome
Common slender wheatgrass
Sherman big bluegrass
Tall wheatgrass

Of this group, only Sherman big bluegrass produced satisfactory stands when seeded in the late fall. The following species produced successful stands initially in the spring seedings:

Common mountain brome
Common timothy
Creeping alfalfa
Ladak alfalfa
Reed canarygrass
Small burnet
Tall fescue.

However, after three to five growing seasons, the stands had either failed or were considered unsatisfactory. Pocket-gopher activity was largely responsible for the reduction of the alfalfa stands.

The most successful species from these tests--standard crested wheatgrass, intermediate wheatgrass, pubescent wheatgrass, and Manchar smooth brome--were selected for further field testing under conditions that normally confront the land owner. In cooperation with a local rancher, 6-acre seedings were made of each species in the spring of 1952 on abandoned cropland that had produced 7 to 8 bushels of rye per acre. Before plowing, the area supported a sparse cover of weed species such as tumbling Russian-thistle, Jim Hill mustard, cheatgrass, meadow salsify, woolly Indianwheat, and dandelion (fig. 4A). In addition to plowing, the area was well harrowed and packed before seeding. The species were seeded with an ordinary double disk grain drill at a rate of 8 pounds per acre. Seeding depth was about 1/2 inch. The area was packed again after seeding.

Figure 4.-- Abandoned cropland in Ferry County, Washington returned to production of livestock herbage. (A) Unseeded area supporting a sparse cover of low-value annual weeds. Camera case 8 inches high. (B) Comparable adjacent area seeded in April 1952 to crested wheatgrass and intermediate wheatgrass -- left and right, respectively, of Mr. Bremner. Photos taken June 1953.

Excellent crested wheatgrass and intermediate wheatgrass stands resulted from these seedings (fig. 4B). An equally successful stand of smooth brome was considerably reduced by winter killing, especially on wind-swept portions of the area. The pubescent wheatgrass stand was unexplainably spotty. Portions of this seeding ranged from excellent to failure and cannot be attributed to site variation or seeding technique since the entire area was treated similarly. All stands improved in the second and third growing seasons.

Lodgepole burn

Also in Ferry County, adaptability of 18 forage species was studied on burned-over lodgepole pine areas at an elevation of about 5,000 feet. The soil was of granitic origin interspersed with small to boulder-size fragments. The study sites were a portion of a 140,000-acre 1929 burn on which a dense, stagnated lodgepole pine stand had become established. Two blocks, each about 100 feet square, one facing southwest and the other northeast, were used in the study. The lodgepole pine reproduction was slashed and burned in the fall, and 18 forage species were individually broadcast in the ashes (fig. 5A).

After five growing seasons, species producing successful stands both in plant vigor and distribution on the southwest exposure (fig. 5B) included:

Redtop
Sheep fescue
Timothy.

Producing satisfactory stands initially but incapable of maintenance on this exposure were:

Alsike clover
Big bluegrass
Common orchardgrass
Tall oatgrass.

Unsatisfactory performance at this location was obtained with:

Bluebunch wheatgrass
Green needlegrass
Intermediate wheatgrass
Ladak alfalfa
Manchar smooth brome
Pubescent wheatgrass
Russian wildrye
Small burnet
Standard crested wheatgrass
Tall fescue
Yellow sweetclover.

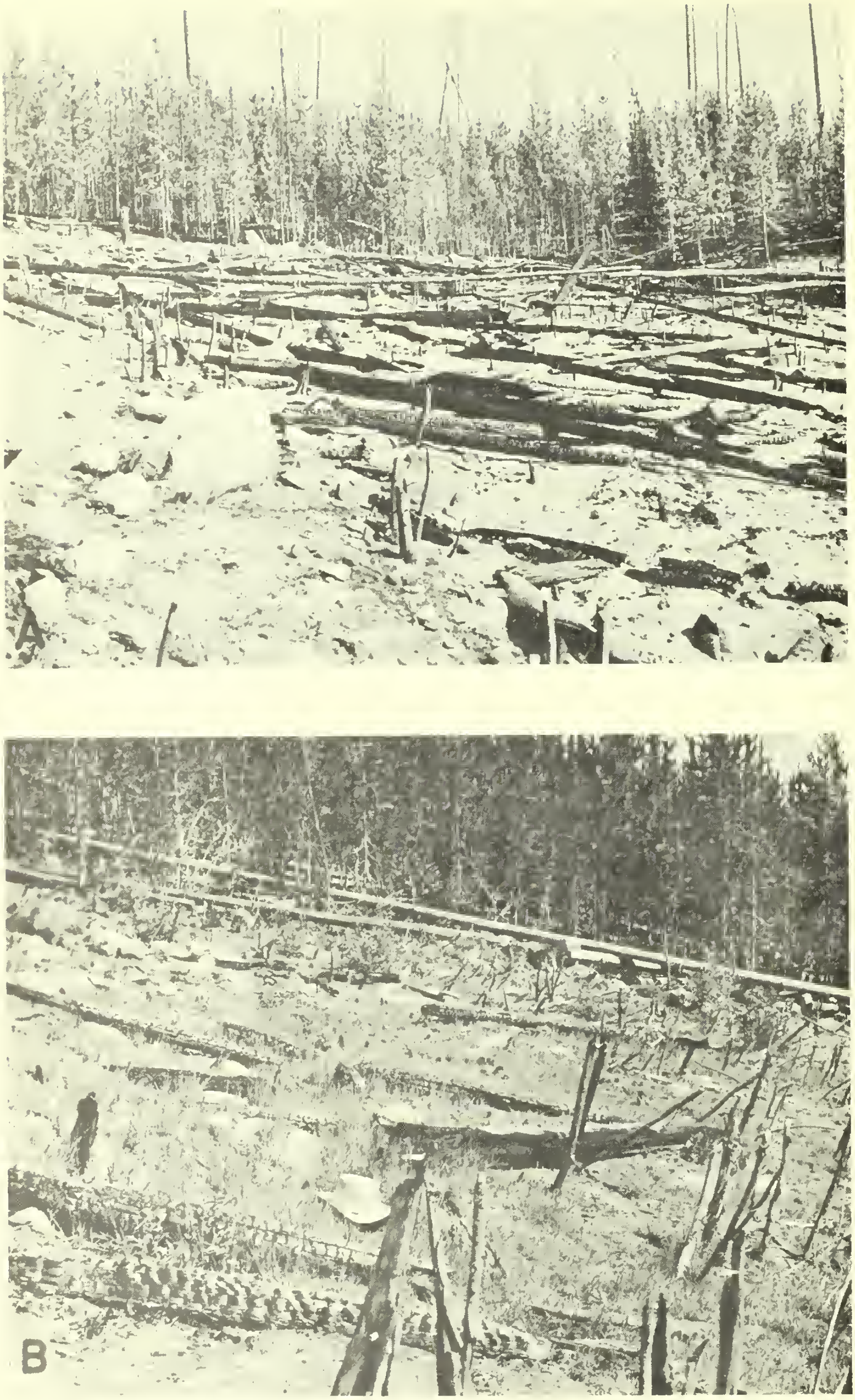

Figure 5.--(A) Condition of site after dense lodgepole pine reproduction (background) had been slashed and burned (foreground). (B) Fall-seeded in the ashes, timothy provides an adequate cover in the third growing season on the southwest exposure.

Under more favorable growing conditions on the northeast exposure, the following species continued to produce successful stands in the fifth growing season:

Pubescent wheatgrass
Redtop
Sheep fescue
Tall oatgrass

Satisfactory performance was also obtained with:

Big bluegrass
Common orchardgrass
Intermediate wheatgrass
Manchar smooth brome
Tall fescue
Timothy
Whitmar beardless wheatgrass.

Unsatisfactory stands resulted with the remaining species tested:

Alsike clover
Green needlegrass
Ladak alfalfa
Russian wildrye
Small burnet
Standard crested wheatgrass
Yellow sweetclover.

Shrub encroachment at this location has increased, however, and may eventually result in a reduction of the more successful stands.

The apparent preference of game animals for south-facing slopes and the increased availability of forage on the area undoubtedly influenced species performance in this study. Alsike clover, yellow sweetclover, Manchar brome, and orchardgrass were heavily used, and redtop and tall fescue were used somewhat less, by deer and rabbits on the southwest-facing area soon after snow-melt. On the northeasterly exposure, however, only Alsike clover was used heavily and small burnet lightly, indicating that grazing by deer and rabbits was a lesser factor to species performance at this location than on the southwest-facing site.

<u>Logged areas</u>

Species suitability for revegetating skid roads, trails, and other areas disturbed by logging was also tested in the mixed ponderosa pine type in Ferry County. Replicated seedings at two southerly exposures, at 2,100 and at 4,100 feet elevation, were made in the fall upon completion of logging activities. The soil was a shallow sandy loam of granitic origin, most of which had been removed during road construction and skidding. Consequently the resulting seedbed was compacted, rocky subsoil. Sixteen species were individually broadcast on plots 1/2-chain long and the width of the skid trail. After seeding, the plots were brush-dragged in an attempt to cover the seed. No effort was made to protect the seedings from cattle grazing.

Species performance was quite similar at the two locations. Stand ratings were based primarily on plant distribution since all species were closely grazed. Despite heavy cattle use, successful stands were produced, in descending order, by:

Redtop
Chewings fescue
Creeping red fescue
Hard fescue
Sheep fescue
Timothy
Orchardgrass

Manchar brome and Sherman big bluegrass produced satisfactory stands, but plant vigor was poor. Unsatisfactory performance was obtained with the following:

Intermediate wheatgrass
Pubescent wheatgrass
Siberian wheatgrass
Standard crested wheatgrass
Tall oatgrass

The following three species failed:

Beardless wheatgrass
Blue wildrye
Bromar mountain brome

It is of significance that several species became successfully established under heavy cattle use. With some degree of protection from grazing, in at least the initial growing season, performance probably would have been more satisfactory for a greater number of species.

Lincoln County

Adaptation trials at this location were concerned with 30 grass and legume species seeded in the spring and late fall of 3 years and early fall of 1 year on marginal cropland. The study area is near Harrington, Washington, at an elevation of 2,200 feet and receives approximately 11.5 inches of precipitation annually, about one-third of which occurs during the months of April through September (table 1). An average frost-free period of nearly 4 months occurs during the months of June to late September (6). The soil has been classified as a Hesseltine loam (8)--a 6-inch brown loam surface layer underlain by 3 to 5 feet of rocky loam subsoil under which occurs basaltic bedrock. Excessive drainage and deficient organic matter discourage farming of this soil. The area had been abandoned after several years' cropping. Vegetation cover was composed of big sagebrush, cheatgrass, needleandthread grass, Sandberg bluegrass, and woolly Indianwheat (fig. 6A).

Spring seedings were superior to early and late fall seedings (table 2, fig. 6B). Crested wheatgrass was the only species that produced successful stands, and pubescent wheatgrass satisfactory stands, in the fall seedings. Outstanding species in the spring seedings included:

Crested wheatgrass (3 strains)
Intermediate wheatgrass
Manchar smooth brome
Primar slender wheatgrass
Pubescent wheatgrass
Sheep fescue
Siberian wheatgrass
Streambank wheatgrass
Tall wheatgrass
Western wheatgrass

Performance of the following species was considered somewhat less successful than the preceding group:

Creeping alfalfa
Hard fescue
Indian ricegrass
Ladak alfalfa
Whitmar beardless wheatgrass

Satisfactory stands in spring seedings have been maintained by the following species, although a reduction in plant vigor and numbers has occurred since the first growing season:

Common orchardgrass
Common slender wheatgrass
Idaho fescue
Orchardgrass, S-143
Sherman big bluegrass
Tall fescue
Timothy

Figure 6.--(A) General view of marginal cropland in Lincoln County, Washington with vegetation cover composed of cheatgrass, big sagebrush, Sandberg bluegrass, and needle-andthread grass, mainly. (B) Adjacent area on which small plot adaptation and seeding season trials were conducted. Two-year-old stands of spring-seeded fescue species in immediate foreground and taller wheatgrass species in center.

Successful initial stands of Bromar mountain brome, Reed canarygrass, and small burnet have gradually declined so that they were unsatisfactory by the third and fourth season. The remaining species that were tested either failed or were unsatisfactory in all respects.

DISCUSSION

Inasmuch as the adaptability trials were conducted solely on lands that were considered marginal or submarginal for cropping, the results may differ from those obtained by other workers on more productive lands in this general area. Maximum opportunity for establishment was also afforded by removal of competing vegetation during the first two growing seasons. Adaptability of several species and their ability to become established under competition was, however, confirmed on a limited scale in subsequent field plantings. The tests were made on areas characterized by droughty soils low in fertility with a low water-holding capacity. Reported results were obtained without fertilization. Precipitation during the trials ranged from above to below the norm so that species adaptability and seeding season were studied under varied moisture conditions.

The relative similarity in species adaptability and performance at the three sites, despite substantial differences in annual precipitation, can best be explained by soil textural differences. The pattern of precipitation is essentially the same at the three study areas, but the scantiness of precipitation in Lincoln County is accentuated by the longest growing season (table 3). At the Spokane County site, receiving the highest precipitation (20.35 inches), the upper 6- to 8-inch soil layer is very gravelly and is underlain by a porous substratum consisting mainly of gravel and boulders. Drainage throughout this soil type is excessive. The soil of the Ferry County site (annual precipitation 14.26 inches) is appreciably finer but also well-drained, approximately a 3-foot sandy loam underlain by gravel. At the Lincoln County site (precipitation 11.43 inches), 3 or more feet of well-drained, fine-textured loam is underlain by basaltic bedrock. Thus it happens that the study area receiving most precipitation has the soil with most rapid internal drainage and lowest water-holding capacity; the study area receiving least precipitation has the finest soil with highest water-holding capacity; and the study area with intermediate precipitation has a soil with intermediate soil-moisture characteristics. It therefore appears that differences in moisture-retaining qualities of these soils offset material differences in precipitation, and this accounts for the similarity in species adaptation and performance at the three study areas.

Table 3.--Average growing season and quarterly precipitation at three locations in northeast Washington

	Spokane County	Ferry County	Lincoln County
Growing season	102 days	96 days	119 days
Precipitation			
January through March	31 percent	25 percent	30 percent
April through June	20 "	29 "	23 "
July through September	12 "	17 "	11 "
October through November	37 "	29 "	36 "

Based on the findings of these tests, spring seedings are superior to late fall seedings. Although tested less adequately, early fall seeding was more unsatisfactory than late fall seeding. The success of late fall seedings in these tests probably would have been enhanced had they been delayed until late November or early December. However, because of inclement weather at that time, seedings usually must be made earlier. The results of the late fall seedings compare favorably with those of early fall seedings in central Utah reported by Frischknecht (5) and probably for similar reasons. The frost banding and heaving of seedlings noted in Utah were also evident in the early and late fall seedings of the tests reported here. This was particularly true at the Lincoln and Spokane County locations. Emerged seedlings from the fall seedings were subject to frost action before snow cover occurred in at least 2 years of the tests and again in the early spring following snowmelt. Many of the seedlings were completely heaved out of the soil, while the roots of others were so exposed that they died. Still others broke at the soil surface where the frost bands occurred. Species that were least susceptible to frost injury and heaving included crested (571), intermediate, and pubescent wheatgrasses in Spokane County and Siberian wheatgrass and three strains of crested wheatgrass in Lincoln County.

Seedling stands of adapted species from fall seedings in Ferry County were generally satisfactory and in most instances compared favorably with spring-seeded stands. Because of unfavorable growing conditions in the fall germination at this location, in all probability, did not occur until the following spring so that the seedlings were not subjected to alternate freezing and thawing.

SEEDING RECOMMENDATIONS

Under the conditions experienced during the period in which species adaptability and season of seeding were studied on marginal or submarginal cropland at three locations in northeast Washington, certain recommendations for seeding can be made. For the general area encompassed in these studies, with precipitation ranging from $11\frac{1}{2}$ to about 20 inches annually, spring seeding results in the most successful stands. Predominantly coarse-textured and well-drained soils in this area can be worked soon after snowmelt (approximately late March). Unless seedings can be made late enough in the fall so that germination does not occur until spring, fall seedings should not be attempted.

Suitable species for seeding in this area are: hard fescue, Manchar brome and crested (Fairway, standard, and 571), intermediate, Primar slender, pubescent, Siberian, western, and Whitmar beardless wheatgrasses. Tall wheatgrass, given only a satisfactory rating in the Ferry County trials, has been successful in subsequent field tests in that area and can be included in the preceding group. Indian ricegrass, sheep fescue, and streambank wheatgrass were not tested at the Ferry County location which receives about 14 inches of annual precipitation. However, successful performance of these species when spring-seeded at the Lincoln and Spokane County areas receiving $11\frac{1}{2}$ and 20 inches of annual precipitation, respectively, suggest that they would also be suitable for the entire area. Spring seedings of timothy and tall fescue can be expected to be successful in areas with 20 or more inches of annual precipitation. Orchardgrass (S-143) can be successfully spring-seeded in those portions of northeast Washington where precipitation averages 14 or more inches annually. Successful stands of creeping and Ladak alfalfa may be obtained in areas <u>with fine-textured soils</u> receiving as little as $11\frac{1}{2}$ inches of precipitation.

To restore cover vegetation on skid roads and trails in the mixed ponderosa pine type, seedings should be made soon after logging operations have been completed to take advantage of the loose, disturbed soil which provides a satisfactory bed for broadcast seed. Although some seed is covered by soil sloughing, a brush drag or a section of a spike-tooth harrow is more reliable and efficient. Redtop, Chewings, creeping red, hard, and sheep fescues, timothy, and orchardgrass are suitable species for seeding logged-over areas.

Satisfactory cover vegetation for burned-over densely stocked lodgepole pine areas can be obtained by broadcast seeding in the ashes soon after the burn. Adapted species for northerly and southerly exposures at an elevation of 5,000 feet include redtop, sheep fescue, and timothy. In addition, big bluegrass, common orchardgrass, intermediate wheatgrass, Manchar brome, pubescent wheatgrass, tall oatgrass, tall fescue, and Whitmar beardless wheatgrass are also suitable on northerly exposures.

Though seeding methods were not studied in these trials, experience here and elsewhere has shown that drilling in a clean, firm seedbed is the most satisfactory method of seeding. In some situations, however, because of slope and stoniness, less desirable methods of seedbed preparation and seeding are more practicable. For most species, seeding depth should not exceed 3/4 inch, 1/2 inch being preferable. In this area, packing after drilling has been found to enhance seeding results.

Six-inch row spacing, in range and field seedings to be used for grazing, provides a good ground cover. Although the seeded plants may be less vigorous than plants in wider spacings, weeds are usually more effectively controlled. (For seed production, however, wide spacing from 30 to 36 inches, produces the greatest yields.) Clipping of weedy seedings in the initial growing season is commonly done to prevent seed formation and to reduce competition. Generally clipping in the first season is adequate but where wide spacings are used, control of weeds may be necessary for a longer period until the seeded species are sufficiently established to dominate the area.

Such items as seed size, purity, and germinability, planting method, and condition of seedbed must be considered in determining seeding rate. Generally drilling in a well-prepared seedbed and using good seed, a 7 to 8 pounds per acre rate is adequate for large-seeded species such as tall wheatgrass and smooth brome; and with big bluegrass, sheep fescue, and other species with small seed 4 to 5 pounds per acre is recommended. The seeding rate should be increased by one-third to one-half on poor seedbeds or when seed is broadcast. Further adjustments in seeding rates may be necessary depending upon seed viability and foreign material in the seed.

As a general rule, seedings should be completely protected during the establishment period to permit the new plants maximum opportunity of developing a good root system. Usually, conservative use can be made of the stands late in the second growing season. On droughty soils where plant establishment is slow and with species such as big bluegrass that develop root systems slowly, grazing should be deferred until the third season. Frequently the cost of deferment can be more than offset by harvesting a seed crop in the second season. Maintenance of seeded stands is dependent upon management practices. Heavy prolonged grazing reduces plant vigor and permits the invasion of less desirable species. Spring grazing should be of the type that will permit the plants to make ample regrowth after the animals are removed. Grazing in the summer and/or fall should allow about half the plant's volume to remain for soil protection and maintenance of plant vigor.

COMMON AND BOTANICAL NAMES OF SPECIES DISCUSSED

Grasses

Asiatic timothy	Phleum phleoides
Beardless wheatgrass	Agropyron inerme
Big bluegrass	Poa ampla
Bluebunch wheatgrass	Agropyron spicatum
Blue wildrye	Elymus glaucus
Bulbous bluegrass	Poa bulbosa
Canada bluegrass	Poa compressa
Canby bluegrass	Poa canbyi
Cheatgrass	Bromus tectorum
Chewings fescue	Festuca rubra var. commutata
Creeping foxtail	Alopecurus arundinacea
Creeping red fescue	Festuca rubra
Crested wheatgrass	Agropyron cristatum
Green needlegrass	Stipa viridula
Hard fescue	Festuca ovina var. duriuscula
Idaho fescue	Festuca idahoensis
Indian ricegrass	Oryzopsis hymenoides
Intermediate wheatgrass	Agropyron intermedium
Kentucky bluegrass	Poa pratensis
Meadow foxtail	Alopecurus pratensis
Mountain brome	Bromus marginatus
Mountain rye	Secale montanum
Needleandthread grass	Stipa comata
Orchardgrass	Dactylis glomerata
Perennial ryegrass	Lolium perenne
Pubescent wheatgrass	Agropyron trichophorum
Redtop	Agrostis alba
Reed canarygrass	Phalaris arundinacea
Russian wildrye	Elymus junceus
Sandberg bluegrass	Poa secunda
Sheep fescue	Festuca ovina
Siberian wheatgrass	Agropyron sibiricum
Slender wheatgrass	Agropyron trachycaulum
Smooth brome	Bromus inermis
Streambank wheatgrass	Agropyron riparium
Tall fescue	Festuca elatior var. arundinacea
Tall oatgrass	Arrhenatherum elatius var. Tualatin
Tall wheatgrass	Agropyron elongatum
Timothy	Phleum pratense
Western wheatgrass	Agropyron smithii

Forbs

Alfalfa	Medicago sativa var. media
Alsike clover	Trifolium hybridum
Amaranth	Amaranthus sp.
Aster	Aster sp.
Big trefoil	Lotus uliginosus
Dandelion	Taraxacum officinale
Douglas knotweed	Polygonum douglasii
Flannel mullein	Verbascum thapsus
Heath forget-me-not	Myosotis stricta
Jim Hill mustard	Sisymbrium altissimum
Klamath weed	Hypericum perforatum
Low dogbane	Apocynum pumilum
Meadow salsify	Tragopogon pratensis
Rose pussytoes	Antennaria rosea
Sheep sorrel	Rumex acetosella
Siberian alfalfa	Medicago falcata
Sicklepod milkvetch	Astragalus falcatus
Silky lupine	Lupinus sericeus
Small burnet	Sanguisorba minor
Strawberry clover	Trifolium fragiferum
Tumbling Russian-thistle	Salsola kali var. tenuifolia
Western yarrow	Achillea lanulosa
White clover, Ladino	Trifolium repens
Woolly Indianwheat	Plantago purshii
Wyeth eriogonum	Eriogonum heracleoides
Yellow sweetclover	Melilotus officinalis

Shrubs & Trees

Big sagebrush	Artemisia tridentata
Lodgepole pine	Pinus contorta var. latifolia
Ponderosa pine	Pinus ponderosa

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E C O N O M I C S   R E S E A R C H   N E E D S   R E L A T E D   T O   W I L D   L A N D   M A N A G E M E N T   A N D   D E V E L O P M E N T   I N   T H E   M O U N T A I N   S T A T E S

By Division of Forest Economics

Harry W. Camp, Chief

Intermountain Forest and Range Experiment Station
Forest Service
U. S. Department of Agriculture
Ogden, Utah

A VIEW OF THE REGION

In a region as big and varied as the eight Mountain States[1] it is difficult to generalize about wild land problems. The contrasts rather than the similarities catch the eye. The dense white pine forests of North Idaho, for example, have little in common with the deserts of New Mexico and Arizona. This contrast is hardly any greater than that between the valley bottoms and mountaintops, or between one side of the mountain and the other in some areas. Nevertheless, the deserts and the forests, the valleys and the mountaintops in this region share certain characteristics and problems which are significant from the standpoint of how much and what we should do in the way of management and development of these wild land resources.

> Wild lands are geographically and economically dominant. Wild land resources are important in every region and no region can survive without them. Nevertheless, it is fair to say that the forests and rangelands of the Mountain States are closer to the life and welfare of the people in these states than is probably the case in any other region.

This fact is overwhelmingly apparent in the land-use data. Only 7 percent of the total land area in the Mountain States is classed by the Census Bureau as cultivated or in improved pasture--1 acre out of 14. In the other 40 states, one-third of the area is in these categories.

If we exclude transcontinental transportation facilities and military establishments, most of the rest of the basic income of these states is derived from extractive industries, the first stage processing of local raw materials, and from other industries directly related to use of the natural resources. A substantial part of this income, of course, is from agricultural production. However, even the farmer depends on wild lands to an unusual degree. His livestock spends several months of the year on the open range. His fields are irrigated with water from the grassed and timbered hills.

1/ Idaho, Montana,. Wyoming, Utah, Nevada, Colorado, New Mexico, and Arizona. For the lack of a better term these eight states are called the Mountain States. Actually this area encompasses all or part of five physiographic provinces. Included are the Rocky Mountain, Basin and Range, and the Colorado Plateau provinces plus part of the Columbia River Plateau and the Great Plains.

In this semiarid to arid climate more and more lands are being irrigated to increase and stabilize agricultural income. As a matter of fact, more than half of all irrigated land in the United States is in the Mountain States. The West has been the locale of most of the big projects to harness streams for irrigation, power, industrial use, and domestic use. The problems and conflicts associated with developing this water are a reminder of how much the future of this area depends on the amount of it available and the way it is used. The struggle between California and several of the inland states for the waters of the Colorado River drives home the singular importance of water supplies to the hopes and aspirations of the Mountain States. One observer has gone so far as to say that should California get the share of the Colorado River water it claims "development of the resources of Colorado, Wyoming, and Arizona would be permanently prevented, and the Mountain West would be forever removed from the main currents of American economic life."[2/] (Figure 1)

From almost any point of view the wild land resources look impressively important to life, income, and happiness in the Mountain States.

> Other states have a direct and vital interest in the wild land management of the Mountain region because this region supplies much of their water.

The Rocky Mountains are the main watershed of this Nation. The rivers that rise here, for the most part go beyond regional boundaries to become the lifeblood of other areas they pass through. The Missouri, Columbia, and Colorado Rivers in particular are among the great waterways of the Nation.

The interregional importance of water and the relationship of land management to water yields give the Mountain States wild lands and their management an importance far beyond any local values.

> Much of the land is publicly owned; thus the public has an especially great responsibility for developing sound policies and programs for the use and management of wild land resources in the region.

2/ America's New Frontier--The Mountain West, by Morris E. Garnsey. Alfred A. Knopf, publisher, New York. 1950

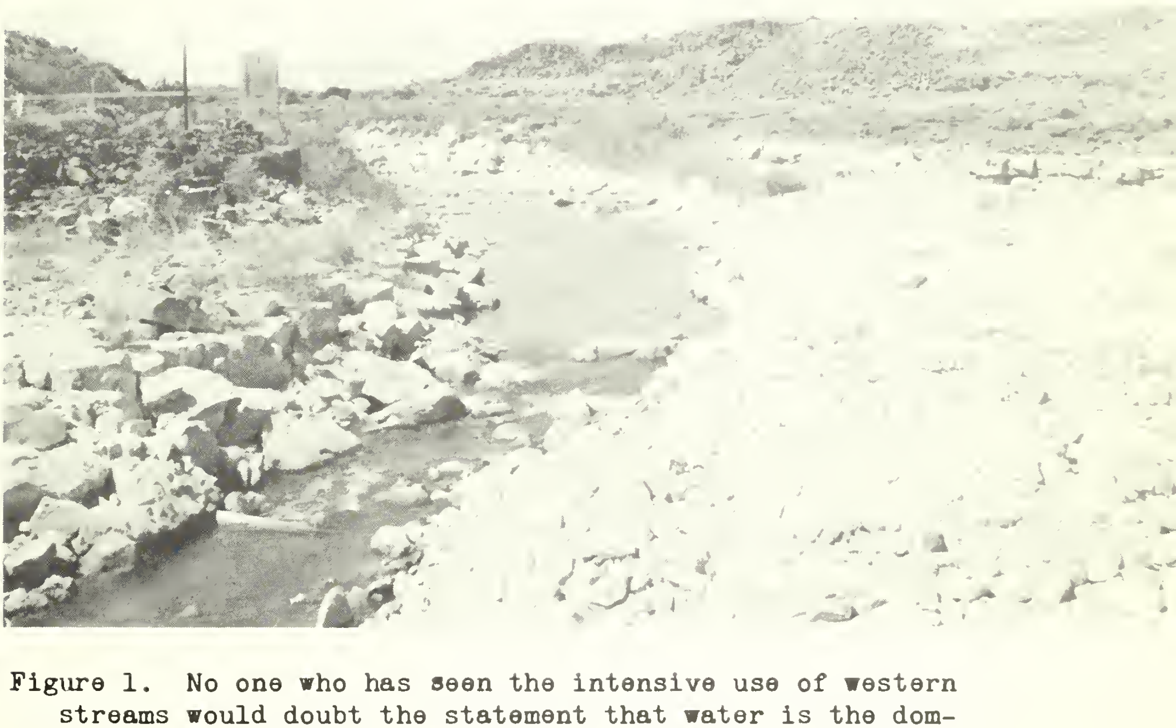

Figure 1. No one who has seen the intensive use of western streams would doubt the statement that water is the dominating influence in development of the West. The upper photo shows a brimful irrigation canal at Milner, Idaho on the Snake River. On September 1, 1955 five canals at Milner were drawing water from the river at the rate of 8,750 cubic feet per second. The lower photo shows that the Snake River below the take-off for these canals was reduced to a mere trickle--12 cubic feet per second.

Management of our natural resources involves two responsibilities: the responsibility of the landowners to handle these resources wisely, and the responsibility of the public to create the economic environment--that is the facilities, services, and conditions--which makes such management possible. One of the major features of the wild land picture in the Mountain States is that the public not only has the latter responsibility for the environment but the lion's share of the land ownership responsibility as well. Because productive capacity for commercial products has in general been low and public values high, proportionately more of the land area has remained in public hands in the Mountain States than in any other part of the Continental United States. National forests, national parks, grazing districts, other federally owned or managed lands, and the holdings of the 8 states add up to about 350 million acres. Two out of every 3 acres in the region today are the property of the Federal government and the states. If any underlining is needed we might add that these 2 out of 3 acres include most of the critical watershed area in the region. (Figure 2)

It is also significant that a major portion of the Federal government's land ownership responsibility lies in these 8 states. Federally owned or managed properties in the Continental United States include a total of 456 million acres. Two-thirds of that area is in the Mountain States.

The responsibility associated with land ownership has two aspects: the responsibility to conserve and protect and the responsibility to develop. Resources which are abused cannot make a full contribution to the economy of the country. Neither can resources held in idleness. Because the drive for conservation was for decades spearheaded by government agencies, the responsibility to conserve has on the average been fairly well met on public lands. On the other hand, the public is several decades behind private owners in developing its resources. There are good and logical reasons why this is so. Nevertheless the amount of Federal and state land in the region and the dependence of the Mountain States on this land constitute a tremendous challenge to the agencies that manage it to develop dynamic policies for using the land as well as protecting it.

> The physical margins are narrow; thus the resilience of the Mountain States as an environment is low, and the land resource is particularly susceptible to damage from overuse or misuse.

Figure 2. The public equity in the wild land resources and the public responsibility for their development are nowhere any greater than in the Mountain States where 2 out of every 3 acres are managed by the Federal government and the states.

The ease with which unwise use can destroy land values is dramatically emphasized in certain Utah watersheds where several generations of overgrazing have upset the natural balance to the point where floods and mudflows follow summer cloudbursts. Vulnerability to damage is not confined to Utah nor to grasslands, however. It is a general problem in the region. Civilization has come closest to completely destroying its environment in those parts of the world where the annual precipitation is low. The climate of the Mountain States falls under the general heading of "dry." Even in those areas that have more abundant precipitation, summer dryness, abetted by a short growing season, prevents the vegetation from reaching the luxuriance achieved in many other parts of the country. Where vegetation is light, slopes steep, and soils erodible man must walk carefully if he is to avoid destroying his own environment. (Figure 3)

The economic margins also are narrow insofar as return to the land is concerned.

The resources of the Mountain States have been used ever since white men moved into the country. At first, only furs, buffalo hides, and gold could pay the freight. Over the years, utilization has expanded progressively to include more of the resources. Today we are shipping out timber, copper, beef, and a multitude of other products. But even so, distance to mill and to market, operating difficulties associated with mountainous country, and low productivity per acre combine to prevent full use of the wild land resources and to keep the operating margins lower than if the same resources were located in other regions.

In the long run, the growth of the West and the Nation and technological progress should diminish these handicaps. Nevertheless, the present prospect is that this economic weakness will persist for a long time, and so long as it does persist it will tend to aggravate land abuse and to shortchange land management. As an example, we can point to forest areas that have been left in poor shape following logging because there was no market for some of the usable wood and because the timber operations were unable to finance the cultural measures needed.

Multiple use and integrated use are particularly urgent in the Mountain States.

The close relation between life in the valley bottoms and the amount, timeliness, and quality of the water from the mountains; the ease with which land values and water values can be impaired; and the inability of commercial crops in some areas to carry all the land management costs by themselves make multiple use a pressing consideration.

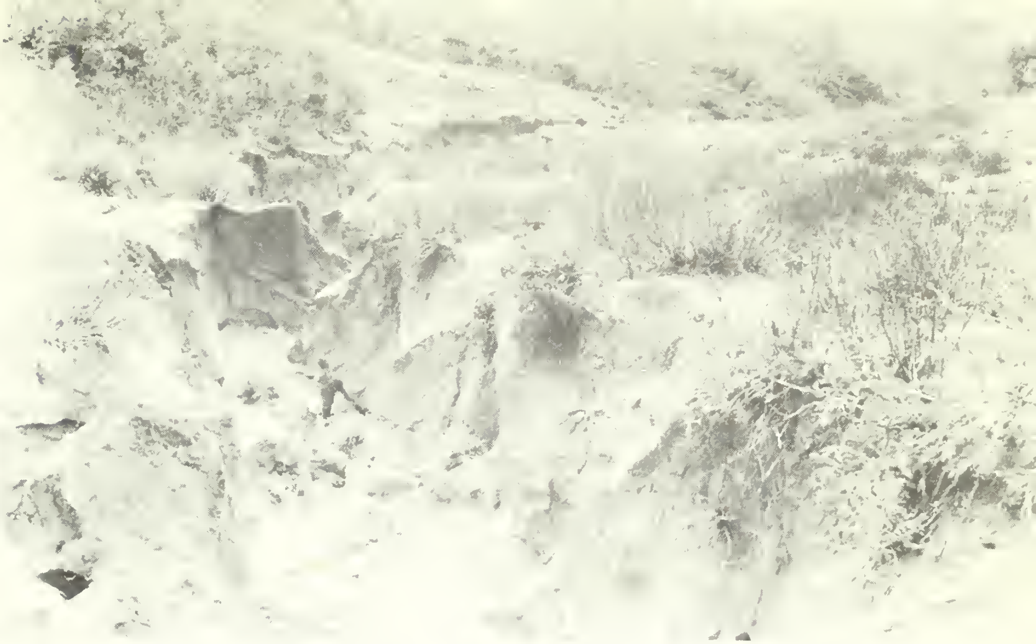

Figure 3. Excessive use or careless use of the land where the slopes are steep and the soils erodible can have quick and unfortunate repercussions. The upper picture shows a deep gully in Utah which resulted from overgrazing the watershed above it. The lower picture shows a striking example of the damage that can result from poor logging practices.

The fact that direct values must be weighed against indirect values and private values against public values makes multiple use an extremely complex thing. Development of sound multiple-use programs is no doubt the most important part of resource management as well as the most difficult.

We are still in the formative stages of resource development; so both the responsibility and opportunity for sound planning are doubly great.

The grass of the Mountain States has been heavily used, but much timber, water, and minerals is yet to be developed. New industrial plants and some new communities will be built to utilize these raw materials. We will be establishing patterns of use which will persist for decades to come and decisions made during the next few years by land managers, governmental agencies, and industries will be molding an economy. The decisions on matters such as: what kind of industrial plants should we have? how big should they be? and where should they be located? will affect the lives and welfare of many people. Sound economic information will never be any more important and influential than now and in the next few years. (Figure 4)

A PROGRAM FOR ECONOMIC STUDIES

The task of handling the wild lands of the Mountain States is as complex as it is big. If most is to be made of these resources the complexities will have to be unraveled. We will need to develop a better understanding of resource capabilities, potentialities, and limitations. There are many technical and economic questions to be answered.

In the past few decades considerable progress has been made in answering the technical questions related to wild land management and development. Knowledge of the economic aspects of the problem has expanded more slowly. A review of the activities of economic researchers over the years reveals this type of research has lagged behind other wild land studies. Consequently, there is today a deficiency of experience, background, and "know how" in this field.

For the next few years at least, it would appear the efforts of economics research in the Mountain States should be directed toward helping to answer some of the following broad and basic questions:

- What are the extent and utility of the wild land resources?
- What contribution can they make now and potentially to the economy of the states and the Nation?

Figure 4. Lodgepole pine--a coming wood. Buffalo no longer range over the prairie, the copper mines of Butte, Montana sink a mile into the earth, white pine has been a sought after species for half a century. Nevertheless, other of the Mountain States' resources have yet to come into their own. Timber industries, for example, are just awakening to the opportunity that lies in the hundreds of thousands of acres of lodgepole pine such as pictured here.

- What are the opportunities for multiple use?

- When conflicts occur between uses how shall priorities between them be established?

- How much effort and expense for protecting, developing, and enhancing the productivity of the wild land resources can be justified by social and economic values?

- What criteria should be employed to judge the alternatives for developing the wild land resources?

Each of these questions has many facets. Rather than attempt to itemize all of the studies that might be undertaken, we have listed a few specific studies that illustrate the range of possibilities. These are only examples and some of them overlap. No attempt has been made to indicate priority. In the main, the projects undertaken for some time to come should be those having the most immediate policy implications. Following is a list of the sample projects briefly discussed in the following pages:

1. Place of national forests in the economy.

2. Pulp mill opportunities in the Inland Empire.

3. Timber industry opportunity in southeastern Idaho and western Wyoming.

4. Proper emphasis for multiple-use management of Utah's mountain watersheds.

5. Timber requirements and forest management objectives.

6. A desirable stand improvement program.

7. Use of planting in stand regeneration.

8. Pruning.

9. The place of wildlife in land management at Jackson Hole, Wyoming.

10. Chipped wood residues.

11. Wood transportation by truck.

12. Marketing Rocky Mountain timber.

13. Forest pest control.

14. Evaluating the range resource.

1 PLACE OF NATIONAL FORESTS IN THE ECONOMY

As the United States has grown in the past half century and has developed a progressively larger appetite for natural resources the national forests have gradually come into their own. The greater use and importance of the forests have added to the administrators' responsibility to develop sound programs of multiple use. Unlike the private owner, whose success is readily measured in terms of the money he makes, the national forest supervisor must measure his accomplishments in terms of their contribution to the welfare of the communities in and near his forest and also in terms of national welfare. His judgment in this respect is made difficult by the fact that the values he must weigh are of many kinds, some of which are hard to measure, and all of which are no more easily compared with each other than horses and apples.

The problem of orienting national forest administration is as big as the forests themselves and it has many, many aspects. How should the many uses of the national forests be coordinated? Is the range management on the forests integrated as well as it might be with the local ranch economy? How large a timber industry will the national forests support? What kind and scale of watershed management program is desirable? These questions and a thousand more are relevant, and of course much of our future economics program will be devoted to answering them.

One project that would help clarify the over-all picture and contribute to more purposeful management would be a study of the place of the national forests in the local and national economies. Such a study would have two broad phases: (1) the value and importance of the resources in the national forests, (2) the relation of national forest management and policies to the economy of dependent communities.

Orientation of project

Such a study might cover the following subject matter:

- Present use of national forest resources.

- Potential productivity of the timber, range, and other resources of the national forests.

- Present contribution of the national forests to local communities.

- Potential contribution of the national forests to these communities.

- Programs and policies required to bring out the full contribution of the national forests.

Discussion

Some of the information could be gathered on a regional basis. However, the relation of national forests to the people who live near them could be learned best by selecting one or two forests for case studies.

2 PULP MILL OPPORTUNITIES IN THE INLAND EMPIRE

There continues to be interest in the opportunities for pulp mill development in western Montana, north Idaho, and northeastern Washington. At present western Montana has no such plant. Potlatch Forests, Incorporated, operates one pulp and paper mill in Lewiston, Idaho, and the Inland Empire Paper Company operates a pulp and paper mill at Spokane, Washington. Obviously sufficient raw material is available in the Inland Empire for several more plants, but we still lack clear-cut answers to some important questions: How much wood might be available for pulping? What kinds? Where are the wood supplies located? Where are the desirable pulp mill sites? To what extent is this region financially attractive to pulp mills? Some aspects of this last question can be answered only by the companies that are considering locating in the Inland Empire. We are in a position, however, to answer the other questions.

Orientation of project

A study of pulp mill opportunities in the Inland Empire should include the following factors:

- The types and species of round wood available for pulping in the Inland Empire, and the suitability of each for this purpose.
- Sawmill residues that would be available for new pulp mills.
- Sustainable output of wood of each type in various parts of the Inland Empire.
- Wood consumption patterns of the existing plants.
- Desirable pulp mill sites from the standpoints of water supply, labor, and transportation.
- The pulpwood capacity that could be located at each site without risk of undue water pollution.
- The allowable annual production of each type of wood tributary to each pulp site.

Discussion

A study of this problem was started in 1952 but was set aside for the purpose of helping the regional forester's office at Missoula in an analyses of the Libby Dam problem. The usefulness of a similar study for eastern Montana and continued requests for this type of information relating to the Inland Empire have led to the suggestion that the project be undertaken again.

3 TIMBER INDUSTRY OPPORTUNITY IN SOUTHEASTERN IDAHO AND WESTERN WYOMING

The forests of southeastern Idaho and western Wyoming have been utilized only slightly for timber products. However, the recent growing interest of industry in Rocky Mountain timber has revived hope of considerable industrial development. There has been much discussion of the possibility of a pulp mill or two, medium-size sawmills, and hardboard plants.

In view of the current optimism and interest in timber industry expansion it becomes important to know how much of an industry the forests can support and what type of development would produce the greatest benefits in the long run. In view of the economic problems handicapping this region, it certainly seems wise to explore as many angles as possible before embarking on any major program. A careful analysis of the area and its problems and opportunities should be especially helpful to new industries seeking to locate here. Furthermore, there is an unusual chance to develop the timber resources of this locality in a planwise manner because practically all of the timber is in the national forests and most of the developing is yet to be done.

Orientation of project

This study can be subdivided into the six phases indicated below:

- Appraisal of the long-range market outlook for Rocky Mountain timber.
- The relative feasibility of various types of industrial development, primarily pulp mills, hardboard plants, and medium-size sawmills.
- Local considerations that make each type of industrial development more or less desirable.
- Sustainable production of different kinds of timber.
- The long timber haul problem in areas not served by railroads.

- The possibilities for coordinating the wood procurement of the several timber industries to get better and more complete use of the timber than would otherwise be possible.

Discussion

This region is just now coming into its own as a timber producer. There is therefore an opportunity to avoid hit-or-miss industrial expansion. Thorough analysis of the situation should provide some guidelines helpful in orienting future policies and programs.

4 PROPER EMPHASIS FOR MULTIPLE-USE MANAGEMENT OF UTAH'S MOUNTAIN WATERSHEDS

Mountain watersheds in Utah have been used for almost a century. This use has caused deterioration which has in some localities been severe to the point of causing serious erosion and floods. Because of physiographic, ecologic, and climatic conditions, the mountain slopes in Utah are relatively sensitive; that is, their equilibrium can be upset by less human use than in places having greater climatic and physiographic stability. For this reason the primary question in management of the national forests here is: What kind of use and how much use can be made of these lands without creating adverse effects that are greater than the benefits?

A corollary question is how much management expense can be justified by the value and importance of the resource? Watershed and range management experts and ecologists have spent many years gathering the physical facts relating to these questions. However, much remains to be done in the way of arranging these many facts and factors in their proper relation to each other and making value comparisons before the physical problem can be properly translated into program and policy decisions. To say it somewhat differently, the greatest contribution that can be made now would be to bring our technological knowledge into clear focus in socioeconomic terms.

Orientation of project

A study of this sort would attempt to answer the following questions:

- To what extent does the State of Utah depend upon the products of the mountain watersheds for existence and livelihood? What is the relative contribution--past, present, and future--of water, wildlife, grass, timber, and the other resources of the national forests to the State?

- To what extent has use of the resources resulted in deterioration?

- What degree of continued use is tolerable?

- To what extent do water values or flood and erosion problems justify deemphasis of nonwater uses?

- What broad programs and policies relating to management of this land will best serve the interests of the State?

Discussion

The considerations involved in this problem are complex and confusing. Yet, they are the most fundamental issues in wild land management in this locality today. It is to be hoped that a study of this sort would as a minimum develop some broad answers and provide a pattern of study for further refinement of our thinking on the subject in years to come.

We are in a particularly good position to make such a study in Utah because a great deal of basic range, ecological, and flood control research has been done in this area, and the history of Utah's watersheds is well documented.

5 TIMBER REQUIREMENTS AND FOREST MANAGEMENT OBJECTIVES

Managing the forest lands of America to meet national timber needs is a large and difficult job. It is a big job because of the size of the total forest resource and timber requirements. It is a difficult job, first of all, because of the time required to produce timber. We must always be planning for sometime in the future, and the future is full of uncertainty. Second, much of the timber produced is consumed in markets so far away from the forest that it is hard for the forest manager to interpret market needs and trends. Third, because of the size of the total forest resource, the significance of the particular forest unit in the over-all production of timber products cannot be ascertained easily.

The job of making forest management plans would be made significantly easier, and many deficiencies in planning would be corrected if an advance study were made of the economic factors affecting the future development and use of the forests in the region. Periodically, attempts have been made to assess the over-all forest situation in the United States. During the past 35 years there have been the Capper Report of 1920, the Copeland Report of 1932, the Joint Congressional Committee Report of 1938, and the Reappraisal Report of 1945. The Forest Service's latest and most comprehensive effort of this type is now near completion. National appraisals of future timber needs have also been made by the President's Materials Policy Commission and the Stanford

Research Institute. Because of the better forest inventory data now available and the improved techniques and methods for assessing future demands for timber products, these current appraisals should be helpful in regional and local forest planning.

Orientation of project

In the course of the recent national studies, trends in the use of forest products were studied along with population trends and other factors that will affect future consumption of timber products. The forest inventory, the rate the timber is growing, and the rate it is being cut and destroyed were also analyzed. The study proposed here is that of interpreting the national appraisals as they apply to the forests of this region. The net result of this study should be to establish the broad descriptive economic framework into which the management of each forest unit in the region could be fitted. The following points should be considered:

- The inventory and growth potential of each national forest of the region.
- Current rates of cutting on each forest.
- Natural and economic factors affecting the development and use of the timber in the Rocky Mountains.
- The development that will be required in each national forest if the country is to satisfy its future timber demands as now foreseen.

Discussion

The several recent analyses of long-range timber requirements and long-range productive capacity of the timberland have been mainly on a national basis. Further study is necessary to interpret the regional and local significance of these long-range comparisons.

Forest management in the Rocky Mountains is still a far cry from tree farming in the literal sense of the expression. Only part of the cultural measures which might be carried out to increase quantity and quality of timber yields are actually in practice to any extent. However, the time is rapidly approaching when we will have to consider the desirability and feasibility of more intensive cultural practices such as weeding and thinning. In large part this is a problem for forest management research, but superimposed over the technical problems is the economic question: How much stand improvement work can we afford to do, and how much should we be doing? Any answer certainly must be related to the long-range timber supply outlook and future timber product needs.

Orientation of project

This activity should be shared with forest management researchers. There is opportunity for both short-range and long-range studies. These studies should shed light on the following specific topics for the individual types of timber:

- The cost of stand improvement measures.
- The values created by these measures.
- The relative desirability of stand improvement work, and the amount of this work which is appropriate.

Discussion

Decisions on whether to do stand improvement and how much to do are becoming increasingly important. The present low intensity of silvicultural practice may in fact represent a default in part of our responsibility for future timber supplies. Any information on feasibility and desirability of stand improvement measures would be very helpful to policy makers.

7 USE OF PLANTING IN STAND REGENERATION

In some localities it takes a long time for new stands to become established after logging. This means the land lies idle or partially idle for a period of years. As the wood requirements of the country increase and as the timber supply becomes tighter, idleness of forest land will become less acceptable. However, the alternative to idleness is planting, which is expensive, especially where much land preparation must be done in advance. The issue therefore is: At what point is it more desirable to establish the next stand by planting rather than to wait for the slower natural regeneration.

Orientation of project

Any study of the economics of planting should be done in collaboration with forest management research. The studies should be directed toward solving the following problems for the individual timber types:

- Time expectancy of natural regeneration under local circumstances.
- Costs of planting.
- Cost involved in waiting for natural regeneration.
- Ultimate stand values resulting from each practice.
- Criteria for determining when to plant.

Discussion

Knowledge of planting techniques has advanced to the point where planting can be done with reasonable assurance of success in many Rocky Mountain forests. However, there is considerable uncertainty of opinion about when planting is desirable in stands following logging. Any study that sets up some economic guidelines would aid forest administrators in developing a policy for replanting.

In 1950 the Northern Rocky Mountain Forest and Range Experiment Station prepared a research note, "The Profit In Pruning Western White and Ponderosa Pine." This study indicated that pruning of these species probably would be a profitable enterprise. There is other evidence that pruning may be worth while. Plywood industry estimates from the West Coast indicate it costs about 2-1/2 cents for every patch which must be placed on a sheet of veneer because of knots or knot holes. One radial inch of knot in a log affects the quality of 10 sheets of veneer; thus the patching cost resulting from that 1 inch of one knot is 25 cents, or about the same as the cost of pruning an entire 16-foot butt log of a young Douglas-fir. The question is: Has the time arrived when we should practice pruning as a regular part of our management job.

Orientation of project

Any study of the economics of pruning should be done in cooperation with forest management research. The studies should be directed to the following problems for each species:

- Cost of pruning.
- Effect of pruning on grade recovery, including the relation of the pruning operation to cull factors.
- Probable value of pruned timber in comparison to the probable value if no pruning were done.
- Guides for determining when to prune and how much pruning to do.

Discussion

Past studies of pruning in the Mountain States are certainly no more than indicative of the general opportunity. More facts and figures are needed to help the administrators decide rationally how much pruning to do.

9 THE PLACE OF WILDLIFE IN LAND MANAGEMENT AT JACKSON HOLE, WYOMING

The elk herd is a major resource on the Teton National Forest in Wyoming. The herd, estimated at between 16,000 and 17,000 head, is a national attraction and an asset to the local economy. However, some wildlife and range managers have pointed out that overpopulation of elk combined with heavy use by domestic livestock has depleted the range and created a serious land management problem. They have questioned whether such a large elk herd and the consequently large feeding program required to sustain the elk over winter could be justified if all the disadvantages were weighed against the advantages.

Opinions about the Jackson Hole herd have been sharply divided for some time. However, existence of the controversy merely underlines the desirability of determining the proper place of the elk herd in the land management of this area.

Orientation of project

This study should answer the following questions:

- What is the relative importance of the various wild land uses in the Jackson Hole area?
- To what extent is there conflict between uses?
- To what extent do the uses cause undesirable pressures on the land resource?
- What alternative management programs could be used to reconcile conflicts in land use?
- What are the economic advantages of each of the alternative programs to various groups such as ranchers, businessmen, sportsmen, the whole community, and the Nation?
- What are the other apparent advantages, in addition to the economic, of the alternative programs?

Discussion

Local communities, the Forest Service, the Wyoming game department, the U. S. Fish and Wildlife Service, the National Park Service, the Conservation Foundation, University of Wyoming, the Wildlife Management Institute, and possibly other groups have a deep interest in this problem. For that reason, any economic studies undertaken would probably be most fruitful if done cooperatively by several of the interested groups.

Perhaps the outstanding timber industry development in recent years has been the use of sawmill and veneer mill residues for pulping in the West. The one big pulp mill in the Mountain States operates mainly on such material. This mill, owned by Potlatch Forests, Incorporated, at Lewiston, Idaho, is operating on chips obtained not only from "company" sawmills but from other sawmills some of which are hundreds of miles away.

The trend toward greater use of wood chips from residues is one of the most significant recent developments in wood utilization. The chips provide an additional revenue for the sawmills and veneer mills producing them and an economical raw material for the pulp mills. The net effect is to improve the competitive position of the plants able to take advantage of this arrangement and to get more complete use of the timber.

The basic question raised by these developments is to what extent the use of wood residues can be expanded to promote industrial development and improve the position of the timber industries. Much of the answer lies in the economics of producing and transporting chips.

Orientation of project

A study of use of chipped wood should include the following points:

- Cost of producing and shipping chips.
- Price paid for chips.
- Volume of chippable material available at sawmills.
- Increase in revenue to sawmills provided by a chip market.
- The break-even point between chips and round material so far as pulp mills are concerned.
- Extent to which pulp mill locations should be influenced by chip supplies.

Discussion

Pulp mill utilization of wood chips is a new development in the Mountain States. It appears to offer an opportunity for improving the economic position of the timber industries and for that reason is worth careful study.

Transportation is the largest and most variable element of cost in wood procurement in the Rocky Mountains. Operability of timber stands in this region is dependent more upon the cost to move the timber from stump to mill than upon any other single factor. The importance of transportation costs necessitates understanding them completely and offers a particularly big opportunity to reduce costs of wood procurement by increasing the efficiency of log hauling.

In 1947 Byrne, Nelson, and Googins of the Pacific Northwest Forest and Range Experiment Station published the report, "Cost of Hauling Logs by Motor Truck and Trailer." This has been a best seller and an invaluable reference for persons interested in transportation costs. However, there is need for additional information on certain aspects of trucking costs.

Orientation of project

In the Rocky Mountains, because of the long trucking distances, two aspects of trucking need special attention:

- What is the relationship of distance of haul to transportation costs?

- To what extent does the approach to highway planning and truck transportation in large western areas not served by railroads take proper account of the absence of rail facilities?

Discussion

These transportation problems illustrate the opportunity for useful economics research in wood procurement. Expansion of timber industries in the Rocky Mountains makes it increasingly important to understand the relative efficiency of different logging methods and situations and to have accurate cost information for timber appraisal purposes. Much of the responsibility for gathering such information belongs to administrators, engineers, and operators themselves. However, because of his training in analysis and an opportunity to apply continuous attention to specific problems, the economics researcher can also contribute a great deal in this field.

The industrial limitations of the Rocky Mountain forests arise mainly from marketing problems. Intrinsically the timber in this region is good--better than some of the timber being utilized elsewhere. Yet much of it is difficult to market. Wood products must be shipped long distances in some cases, making for high transportation costs. This has created a competitive handicap which has held back timber development. Although much has been said over the years about the timber marketing and transportation problems of the Rocky Mountains they have received relatively little attention from researchers. It appears there is much to be gained from a better understanding of the marketing factors in the utilization of Rocky Mountain timber. Certainly the hopes for full development of the timber resource depend upon our ability to overcome economic problems which arise from the marketing situation.

Orientation of project

The following are some of the aspects which should be analyzed in studies dealing with marketing:

- The value of some of the less utilized species for lumber as indicated by grade recovery possibilities.
- The relation of freight rates to the distribution of Rocky Mountain timber products and a comparison of timber product transportation costs of this region and others.
- Opportunities for developing further outlets within the Rocky Mountain region for Rocky Mountain timber.
- The long truck haul problem in marketing Rocky Mountain timber.
- Opportunities for improving the competitive position of Rocky Mountain timber industries through integrated utilization.

Discussion

This region has the usual problems of how to improve the competitive position of the markets of individual landowners and industrial plants. It also has the larger and even more fundamental problem of how to improve the competitive position of the region itself. A number of factors contribute to the present inability of the Mountain States to achieve full economic partnership among the regions. Some of the most important of them are marketing problems of the first magnitude.

The forests of the Rocky Mountains have been plagued by insects and diseases down through the ages. In the past half century these pests have on occasion mushroomed to disastrous proportions and killed billions of board feet of good timber. The most spectacular losses have occurred in overmature stands. Thus many foresters have felt the control problem will greatly diminish when the virgin stands have been cut over and the forests are on a managed basis. No doubt the total problem will diminish but it is also apparent that the task of insect and disease control will always be large. Billions of board feet of timber will be lost to insects and diseases in years to come. We will be exchanging problems of protecting virgin forests for those of protecting second-growth forests.

The prospect that we face a continuing major timber protection task makes it particularly important to develop properly oriented and properly scaled programs for combating insects and diseases. Development of such programs will probably depend mainly upon three factors: Techniques of control which are reasonably cheap as well as effective; an understanding of how far we can afford to go in protecting timber; stability and continuity of public efforts in forest protection.

There is still a great deal to be learned about how to control some of the insects and diseases but we know even less about how far we can afford to go with control. This question has many ramifications. It depends on what control efforts will cost--not just this year but also in years to come. It depends on what would happen if the insect infestation or disease epidemic were not battled--not only to the trees currently attacked but also to other trees in the future.

Long-run continuity of purpose and action has an importance sometimes overlooked. Year-to-year uncertainties and changes because of fluctuations in financing will disrupt any public programs. They can have a particularly bad effect on forestry programs where continuity is essential. This problem can be illustrated by a clear-cut example in the control of the white pine blister rust disease in the Inland Empire. This disease is controlled by pulling or otherwise eradicating wild currant and gooseberry bushes--a job which ordinarily must be done not once but several times before the problem is solved. However, many areas covered once in the past were not covered again in subsequent years because of lack of funds. On many of those areas the money spent on the original eradication effort was therefore wasted.

Orientation of project

Some of the major economic aspects of the forest protection problem are:

- Proportion of national timber needs which should be supplied by the forests of this region.
- Level of forest protection and management required to meet these timber growing objectives.
- Benefits and costs of different levels of protection and management.
- Alternative approaches to the protection problem.
- Extent to which timber values can carry the protection and management costs.
- Degree of protection justified by nontimber values.
- Extent to which public participation in the protection of private forests is desirable.
- Changes necessary to secure continuity of protection programs.

Discussion

Concepts of timber values have changed a great deal in the past two decades. For example, lodgepole pine which was once regarded as a weed species is now recognized to have an industrial future. Undoubtedly there will be further changes in our idea of timber values in years to come and as they change the protection programs we can justify will change also. However, that in no way minimizes the necessity for developing a means for appraising long-range protection needs and a program for establishing a level of protection commensurate with the forest land management objectives.

From the days of the first settlers the grasslands of the Mountain States have supported domestic livestock. These lands were, in fact, one of the first resources of the West to be fully utilized--in many cases overutilized. As a consequence of long and heavy use the problem in many places is how to repair the ravages of abuse and to adjust livestock and livestock use to the productive capacity of the land. Increasing attention must be given to the matter of balancing the livestock industry with the resource if the industry itself is to continue to flourish and if unnecessary impairment of watershed and other values is to be avoided.

In 1936 the U. S. Department of Agriculture made a complete and comprehensive analysis of the range situation in a document entitled "The Western Range." The history of range use, capabilities of the resource, problems, and programs were exhaustively analyzed. Though the findings of "The Western Range" were not completely accepted in all quarters, the report was an important step forward in an overall appraisal of the range resource. Relatively little has been done since then to supplement and amplify the studies of the economic aspects of range resource use. It may not be desirable to undertake a project quite so ambitious as the 600-page "The Western Range," but certainly many of the aspects studied at that time need further attention from range technicians and economists alike. Pressure on the range resource has increased and it will continue to increase as the population of the United States grows, carrying upward the demand for meat and other livestock products.

Orientation of project

The range problem has many ramifications but a few of the aspects which should receive attention are listed below:

- Longtime trends in livestock use of the range in the Mountain States.
- Present use of the range land by domestic livestock.
- Past and present contributions of the range resource to the wealth and welfare of the Mountain States.
- Estimated present capacity of the range to support domestic livestock.

- Effects of grazing on yield of usable water.
- Relation of range use to recreation use.
- Estimated carrying capacity of the range if damaged areas are rehabilitated.
- Problems involved in making coordinated use of private and public lands.
- Adjustments in the livestock industry which may be necessary for best use of the range resource.
- Appraisal of the impact upon the livestock industry of adjustments necessary for best use of the range resource.
- Economic appraisal of big game and domestic livestock use of the range resource.

Discussion

Controversy over "facts" as well as conclusions in "The Western Range" has no doubt tended to discourage subsequent study of over-all range resource management. The measurement of the physical factors of range land are considerably more difficult and involve considerably more personal judgment than measurements in forest stands. However, much progress has been made in the techniques of both measurement and sampling. This, and the increasing pressures on the resource make it highly desirable to expand activities in this field.

ENGELMANN SPRUCE--ITS PROPERTIES, USES, AND PRODUCTION[1]/

By I. V. Anderson
Forest Utilization Service

There is a danger that all overripe virgin forests, sooner or later, will fall victim to insects or disease if the timber is not logged. Such was the fate that overtook the overmature Engelmann spruce forests of the Northern Rocky Mountain country in 1951. A vast Engelmann spruce beetle population was bred in wind-thrown spruce uprooted in November 1949 and in 1950. During its first year the infestation took a toll of over 600 million board feet of spruce timber scattered throughout western Montana and northern Idaho. It was soon evident that this epidemic could be controlled by no ordinary method such as spraying of individual trees. A task force comprised of representatives of the lumber industry and the public agencies decided that control through utilization was their only salvation. Prior to that time production of Engelmann spruce lumber in the northern Rocky Mountain area had never exceeded 35 million feet. The first year after the big flight of bugs over 300 million feet of logs were moved. During the summer of 1954 and winter of 1955 this was increased to approximately 440 million. And during the summer of 1955 and winter of 1956 it is anticipated that approximately 500 million feet of Engelmann spruce will be logged (10). It is hoped that this large-scale removal of timber from infested areas will control the epidemic by the end of 1956.

Focusing the spotlight on Engelmann spruce bug timber salvage has developed a vast backlog of information on the utilization of the species. A special committee on the utilization of Engelmann spruce was formed and worked under the guidance of the emergency salvage task force. Information was developed on the lumber grade recovery of Engelmann spruce as indicated by shipping records. A number of mill scale studies were made to determine the yield of lumber from Engelmann spruce of different ages, site classes, and degrees of stocking (2). Studies of utilization practices in the woods were made and included recommendations for log trimming allowance needed under different methods of logging Engelmann spruce. The help of the Forest Products Laboratory at Madison, Wisconsin was also enlisted. This institution produced and put into circulation, reports on the use of Engelmann spruce for house construction, mechanical and machining properties of the species, kiln and air drying of Engelmann spruce lumber, value for pulp and paper products, ties, mine timbers, and veneer and plywood. These data were so voluminous that only a brief digest of them can be presented in this paper.

1/ This paper was presented at the August 1955 meeting of the Inland Empire Section of the Forest Products Research Society.

PROPERTIES AND USES

Engelmann spruce is a most versatile wood and finds a ready market now for a host of uses. Its uses range from rough construction to fine interior finish and specialty products. While it is a very light wood it has a high strength-weight ratio which fits it for specialty uses. It is interesting to compare some of its mechanical properties with other softwood species marketed from the same producing area (11)

MECHANICAL PROPERTIES

Engelmann spruce is one of the lightest of the important commercial woods of the United States. With the exception of western redcedar it is the lightest wood marketed from the Inland Empire area. Table I shows that it weighs 23.7 pounds per cubic foot compared to western redcedar which weighs 23.1 pounds.

In spite of its light weight Engelmann spruce is significantly stronger than western redcedar. Table 1 indicates a modulus of rupture of 8,700 pounds per square inch for spruce as compared to 7,700 pounds for cedar.

However, the fact that one wood is lighter ~~and~~ somewhat ~~weaker~~ than many of the commonly used construction woods does not mean that it cannot be used where strength is required. For instance, in house construction 2- by 4-inch studs of Engelmann spruce at the usual 16-inch spacing will meet all requirements. Likewise, the strength of the species is entirely adequate to permit its use in ordinary 1-inch lumber for wall, roof sheathing, and subflooring and similar uses. Most of the strength properties of Engelmann spruce are comparable to ponderosa pine. Its stiffness rating is practically the same as ponderosa pine and its volumetric shrinkage is less than pine. Due to this similarity of properties Engelmann spruce is now being used interchangeably in many cases for ponderosa pine.

MACHINING PROPERTIES

Ponderosa pine and Douglas-fir are two of the principal species now being used for mill work items. Hence, it is appropriate to compare the machining of Engelmann spruce with these two species since most everyone is familiar with them. In tests recently made, spruce was somewhat below ponderosa pine in machining properties (3). It was, however, somewhat better than Douglas-fir. It was concluded that if proper precautions are taken, the machining properties of Engelmann spruce are adequate for ordinary uses. Planing tests were made of Engelmann spruce with a

Table 1.--Some mechanical properties of Engelmann spruce compared to other woods[1]

Species	Modulus of rupture P.S.I.	Fiber stress at proportional limit P.S.I.	Hardness[2] End	Hardness[2] Side	Weight per cubic foot
					pounds
Engelmann spruce	8,700	5,500	560	350	23.7
Western redcedar	7,700	5,300	660	350	23.1
White fir[3]	9,800	6,300	770	470	26.6
Lodgepole pine	9,400	6,700	530	480	28.7
Western white pine	9,500	6,200	440	370	26.6
Ponderosa pine	9,200	6,300	550	450	27.9

1/ All data computed at 12 percent moisture content.

2/ Load required to imbed a 0.444-inch ball to one-half its diameter.

3/ Average for grand fir (*Abies grandis*), California red fir (*A. magnifica*), and white fir (*A. concolor*) modern molder having a 4-knife cutterhead with a 6½-inch cutting circle. It was found under the test conditions used that Engelmann spruce was intermediate between ponderosa pine and Douglas-fir. Most common defects developed in spruce were fuzzy and raised grain. Raising of the grain was easily corrected if the boards were seasoned down to the proper moisture content. Most of the spruce lumber shipped from the Inland Empire has a moisture content of about 12 percent and consequently contains a minimum amount of fuzziness. Engelmann spruce works very well on the shaper. Little difficulty was encountered in tests with side grain cuts and only a moderate amount of tearouts on end grain cuts. Tests also showed that Engelmann spruce was intermediate between ponderosa pine and Douglas-fir in turning on a lathe, consequently, it was considered very satisfactory for this purpose.

SEASONING PROPERTIES

About three-fourths of the Engelmann spruce lumber produced in this area is kiln dried and the balance air-seasoned. Most operators now follow the practice of sorting for thickness, sap and heart stock, and common and select grades. The purpose, of course, for separating sap and heartwood is to take advantage of the shorter time required to kiln dry the heart stock. Sapwood in Engelmann spruce frequently has a moisture content of 150 percent contrasting to less than 50 percent in the heartwood. Hence, the reason for separating these two classes of stock is obvious. The sapwood of logs from bug-killed trees loses its moisture rapidly and has been found in many instances to be about the same moisture content as heartwood. Hence, many operators do not separate sap from heart, particularly in 2-year-old bug-killed timber. There are no particularly troublesome problems in the kiln drying of Engelmann spruce lumber whether thick or thin (7). Drying schedules are available giving the detail of drying 4/4 select, and common lumber.

One operator has worked out a schedule that is particularly suitable for protection of knots; 8/4 sap and heart boards can also be kiln dried with a minimum of seasoning defect. About 25 percent of the Engelmann spruce lumber now being produced is air-seasoned (6). Considerable face-checking and end splits are apt to develop if air drying time is accelerated. During the hot weather of July, August, and September it is possible to dry 4/4 spruce lumber down to a moisture content of 12 percent to 14 percent in 10 to 20 days. However, this is not considered advisable. Since a great deal of seasoning defect develops, it is better to increase the drying time to at least 30 days by decreasing pile height, providing pile roofs, and manipulation of other factors such as pile spacing, flues, chimneys, etc. For instance, it is generally recognized that placing stickers flush with the ends of the boards reduces the amount of end checking.

PRESERVATIVE TREATMENT

While Engelmann spruce is sometimes considered a little difficult to reat, it has been treated commercially on a successful basis for many ars. For instance, Engelmann spruce railway ties that have been carelly pressure-treated with creosote or creosote oil solutions have given average service life of from 25 to 29 years (9). Meager information ailable indicates that air-seasoned Engelmann spruce takes oil treatment tter than retort-seasoned material. Optimum treating temperatures are 0° to 200° F. when impregnating with creosote or creosote oil solutions.

SPECIALTY USES

Because of its high strength-weight ratio, Engelmann spruce was rated suitable for aircraft construction during both World Wars. For years has been a choice wood for making high-grade violins. A violin maker Spokane, Washington recalls this incident regarding origin of violin od: One of his clients, a violinist in one of America's greatest symphony chestras, was highly pleased with one of his violins. He wanted to trace e origin of the wood and have a duplicate made. The wood (spruce) was cured from a musical supply firm in Leipzig, Germany. They gave the igin of the wood as a locality in northwestern United States, so the wood s probably Sitka ~~or~~ Engelmann spruce. The violin maker ended his recolctions by saying "Good violin wood is where you find it. I have used gelmann spruce of the Inland Empire for years and have never sold a violin r less than $500.00." Due to its resonant character Engelmann spruce is ghly prized for the manufacture of musical instruments, including pianos. is also used for paneling, interior finish, kitchen furniture, ironing ards, stepladders, and similar uses.

USED FOR TIES AND MINE TIMBERS

This species has been used in the Central Rocky Mountain area for mine mbers and crossties for many years. Woods used for ties should be hard d have good bending and compressive strength. These properties are mbined in Engelmann spruce to the extent that this species is considered ly slightly less suitable for ties than ponderosa pine, lodgepole pine, d woods with similar properties.

If the ties are placed on good ballast protected by tie plates, treated gelmann spruce gives good service. While Engelmann spruce does not have e bending and compressive strength of some of the other species commonly ed for mine timbers such as western larch and Douglas-fir, it gives satisctory service for this use (9). The Forest Products Laboratory states at "Tests of Rocky Mountain mine timbers showed that the grade factor ershadowed the effect of species, so that little difference in strengh was served between Engelmann spruce and other species." Engelmann spruce mbers have given satisfactory service for many mines in Colorado and Wyoming.

SUITABILITY FOR PULP AND PAPER

To date Engelmann spruce has not been widely used for pulp and paper making, although the paper industry regards it highly. It has a long fiber, a relatively light color, and an absence of resinous substance which makes it readily pulped by the sulfite, sulfate, and groundwood processes. While Engelmann spruce is somewhat lower in density than the white and black spruc commonly used in the eastern paper industry, its lower density is offset to a great extent by a relatively high solid volume of wood per cord resulting from its thin bark and straightness. Hence, its yield of pulp on a cord basis is comparable to the other spruces. It has been determined that dead Engelmann spruce trees killed by Dendroctonus beetles are satisfactory for paper making if salvaged before extensive decay takes place. Surveys to date have indicated that on many sites of the Engelmann spruce forests of the northern Rocky Mountain areas, bug-killed spruce trees will remain suitable for pulp and paper making for as long as 15 years. Hence, it is hoped that much of the timber killed in recent years that has not been salvaged for lumber will be used for pulp and paper. High-grade newsprint can be made from Engelmann spruce and is now being produced by the Inland Empire Paper Company of Spokane. Excellent quality book papers are also being made. The strength and brightness of papers made from Engelmann spruce are above average. Table 2 gives some typical yields obtained from Engelmann spruce when pulped by the different methods. For instance, the yield of groundwood pulp is 1,970 pounds per cord of wood used (8). This is a rather high yield.

Table 2.--Typical yields per cord obtained in pulping Engelmann spruce1/

Sulfate pulps2/	
Yield unbleached kraft	940 - 1,020 pounds
Yield bleached kraft	855 pounds
Sulfite pulps2/	
Yield unbleached pulp	980 pounds
Yield bleached pulp	920 pounds
Groundwood pulp2/	
Yield of pulp	1,970 pounds

1/ Wood weighed 20 pounds per cubic feet--basis oven-dry and green volume.

2/ Basis air-dry pulp--not adjusted for loss from barking, sawing, and mill effluent of commercial operation.

USE FOR HOME CONSTRUCTION

Homebuilders are using a large share of the Engelmann spruce lumber being produced today. For this purpose it can be used interchangeably with such western woods as ponderosa pine, sugar pine, Idaho white pine, western redcedar, and white fir. It has many properties that make it desirable to the homebuilder (5). In nailholding properties it is classed with ponderosa pine and white fir. It is classified as a low-shrinkage wood and at identical moisture content it behaves about the same as ponderosa pine. It is also relatively free from warping, light in weight, and easy to work. It is a uniformly white wood that has a pleasing knots pattern and a rather even distribution of small sound knots, hence, it is adaptable to use as interior wall paneling. Other uses in the house are for exterior trim, roof boards, sidings, wall sheathing, shelving, subflooring, and framing. Since it is somewhat low in strength compared to wood like Douglas-fir, this fact must be taken into consideration when it is used for floor joists and roof rafters. Shorter spans can be used and if that is not practical, size of joists can be increased to compensate for the strength deficiency. Engelmann spruce can, however, be used in the same stud size as any of the heavier and stronger species. It is also practical to use Engelmann spruce for floor and roof decking in house construction. It is thought that the material of 2 and better common grade 4-inch thick, 5-inch wide, end-jointed, and tongue-and-grooved, will make satisfactory roof and floor decking that will meet any normal strength requirement in home construction. This would be true, of course, provided the span is compatible with good framing requirements.

VENEER AND PLYWOOD

At the present time no rotary cut veneer is being produced from Engelmann spruce. Normally the trees do not have very much clear length of bole and the clear wood is not very deep radially. Hence, it does not appear practical to consider Engelmann spruce as a source of peeler stock throughout its production range. It is, however, considered as an excellent wood for production of slicing cants. Informed individuals have estimated that at least 50 million feet of slicing cants could be produced in the northern Rocky Mountain area. It is estimated that 1 million feet of cants makes from 6 to 8 million square feet of knotty plywood panel, hence a sizeable industry could be built on Engelmann spruce for this class of plywood.

QUALITY OF ENGELMANN SPRUCE LUMBER

The emergency spruce utilization as a Dendroctonus beetle control measure has stimulated studies in the quality of Engelmann spruce lumber produced from spruce stands of varying characteristics (2). Studies were of course, primarily directed toward learning the extent of depreciation due to bug infestation. Particular emphasis was placed on the rate of deterioration of the timber. Considerable information was developed on lumber grade recoveries for Engelmann spruce trees, 1, 2, and 3 years after being struck by beetles.

Considerable other tree and log quality information was secured in connection with these spruce depreciation studies. For instance, it was found that age, site, and degree cf stocking have a very significant effect on lumber grade recoveries, hence, influence the value of the lumber produced from a stand very materially. Naturally, as an Engelmann spruce tree grows in size and age it also grows in terms of the value of the lumber produced. On good, well-stocked sites, Engelmann spruce trees were noted that had developed as much as 2 and 3 logs clear length in the butt portion of the tree. Naturally, these trees produced a high percentage of D and better select lumber. However, as the trees grow older more defect comes into the picture and defect can often eliminate or at least neutralize the effect of age on quality of lumber produced.

Practically all of the grade recovery studies were confined to overmature old-growth timber. This timber ranges in age from 225 to 300 years of age. Like Idaho white pine, Engelmann spruce is also considered old or overmature at this age. The influence of age on Engelmann spruce is also very similar to Idaho white pine. Sites of this old overmature timber were classified in accordance with Forest Survey standards of the United States Forest Service into good, medium, and poor sites. Table 3 gives a comparison of the lumber recovery for these different three sites. It was found that the lumber recovery from poor sites in this old overmature type of timber was only 84 percent as valuable as the lumber produced from trees on good sites. For a number of reasons, classification of Engelmann spruce timber by sites and age is probably a more practical way of quality appraisal than individual tree or log appraisal. First, on the better sites, Engelmann spruce trees are often 8 or 9 logs in height. It would be quite difficult to ascertain the character of the logs 4 or 5 logs high in the tree. One can, however, determine the general quality of the tree by the first 2 or 3 logs, but the process is much more timeconsuming than classification by site and age.

Table 3.--Comparison of lumber recovery and estimated lumber value of overmature Engelmann spruce stands on good, medium, and poor sites[1/]

Site class	Select and better	Common 1 & 2	Common 3	Total 3 com. & better	Common 4	Common 5	Selling value[2/]
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Good	20	18	35	73	20	7	100
Medium	7	28	38	73	22	5	93
Poor	2	20	40	62	30	8	84

1/ Site classification based upon Forest Survey standards of United States Forest Service.

2/ Selling values converted to percentage basis using value of lumber from the good site as 100 percent.

In table 3 it will be noted that the good site produced 20 percent of D and better select lumber. The stand was considered well stocked and contained a volume of 20 to 25 thousand feet per acre. Slightly over 30 percent of the volume of the study was from trees having 1 clear log, while 6 percent of the volume of the trees had 2 clear logs.

The medium site class only produced lumber having 7 percent D and better select. Here only 3 percent of the volume of the study trees had 1 or more clear logs contrasted to 37 percent for the trees in the study classed as good site. Hence, it is evident that clear length plays a very important part in grade recovery. If quality appraisal were being attempted on a small area containing only a few acres, classification or grading on a tree basis would, no doubt, be necessary. However, where 40 acres or more of each classification are involved, it is believed that sufficiently accurate information can be obtained on lumber quality by using the site classification method of appraisal combined, of course, with age and adjusted for any unusual defect factor.

If data were available on Engelmann spruce stands at rotation age, which is 120 years, and somewhat below rotation, say at 90 years of age, similar to that contained in table 3, it would be complete enough for accurate quality appraisals of Engelmann spruce stands throughout the Rocky Mountain area. There is little information on grade recoveries of Engelmann spruce timber at 120 years of age or less. Indications are that yields as high as 60 percent of 1 and 2 common lumber can be expected from this age of timber. Quality should also be more uniform in these younger age classes since they are less affected by defect and other mortality and depreciation factors. A high recovery of 1 and 2 common will also tend to bring these stands up in value to that of the older and overmature timber. Smallness of size, however, will be a penalizing factor because small timber costs more to log as well as to manufacture into lumber in the sawmill.

A composite of the grade recoveries of Engelmann spruce as indicated by average shipments of one of the older operators in the northern Rocky Mountain area is interesting. Table 4 which presents this information shows that about 7 percent of D and better select lumber was shipped. This is somewhat below production of Idaho white pine selects but the production of 1 and 2 common and 3 common are practically the same. As in the Idaho white pine, the higher common grades carry the bulk of the value in Engelmann spruce lumber. This, of course, is an exception in the old overmature stands grown on the better sites.

Table 4.--Percentage of grades of Engelmann spruce lumber shipped by an average spruce producer during a 3-year period

Grade	Percent
D and better select	7.0
1 and 2 common	24.5
3 common	36.2
4 common	16.3
5 common	6.8
Shorts	7.8
Other	1.4

PRODUCTION AND AVAILABLE VOLUME

There is still a substantial volume of Engelmann spruce lumber remaining in the forests of the Rocky Mountain area, and Engelmann spruce lumber will be on the market for many, many years in the future. Spruce is the dominant species on about 730,000 acres of commercial forest land of all ownership in this area. It is widely distributed in other timber types and is one of the faster growing trees, hence, there is not much need for apprehension over the future supply provided there is good management. About 78 percent of the spruce volume is contained on national forest land where allowable annual cuts are developed by working circles. Conservative estimates indicate that at least 250 million board feet of spruce lumber can be produced each year indefinitely from the northern Rocky Mountain area. Much of the spruce stands of today are old growth and overmature. They are being rapidly opened up with new utilization roads, and as logging progresses more slash is created and potentially greater bug risks develop than existed before, hence, the remaining virgin stands are still quite vulnerable to bug attack and natural decadence. However, roads make timber accessible for current logging. Trees infested in the future can be logged before deterioration takes place. Market conditions of the future will also influence the annual cut of Engelmann spruce to a certain extent. The foregoing statements apply to only the northern Rocky Mountain area including Montana, northern Idaho, and eastern Washington.

Engelmann spruce is also found in substantial commercial quantities in Colorado, Utah, and Wyoming. New mills are fast becoming established in these areas which will accelerate spruce lumber production.

Considering these facts and the trends occurring in the production of other western softwood species it is estimated that the total production of Engelmann spruce lumber throughout the entire range of the species will vary between 300 and 500 million feet per year between now and 1975, depending upon the market and the incidence of bugs, disease, and fire. Due to the bug epidemic, the future cut will be somewhat erratic geographically. Some localities have suffered much greater damage than others. This erratic pattern of damage will be reflected for the next 50 years in that some communities that heretofore produced small amounts of Engelmann spruce will be producing much more than others because the remaining spruce supply is closer at hand.

SUMMARY

The bug epidemic in Engelmann spruce has accelerated the marketing of this species. It is expected that from now on out, Engelmann spruce lumber will assume its place alongside such other western softwood species as Idaho white pine, white fir, western larch, and ponderosa pine in the western lumber economy. It is a most versatile species, being used for specialty items and house construction. Because of its long fiber, it is particularly desirable as a groundwood pulp. It will also continue to supply the small knotted type of common board in competition with ponderosa pine and Idaho white pine. It is expected that as the more remote areas of Engelmann spruce are opened up for utilization the quality of lumber production will also include greater volumes of select grades. There are also no appreciable areas of young or rotation age Engelmann spruce in the region and it will probably be 50 years before production of this class of material is a significant factor on the lumber market.

Engelmann spruce lumber production will probably exceed 300 million feet annually between now and 1975, and substantial volumes of bug-killed spruce will be salvaged for pulpwood.

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Figure 1.--Overmature Engelmann spruce trees sometimes produce 2 or 3 surface clear logs.

Figure 2.--Selected cutting of bug-infested trees is sometimes done by small mill operations.

igure 3.--Engelmann spruce logs are light and straight so big loads of 10 thousand feet per truck load are common.

REGRESSION COEFFICIENTS FOR COMPUTING CUBIC-FOOT VOLUME OF ROCKY MOUNTAIN TREES

Paul D. Kemp, Forester
Division of Forest Economics

This paper presents regression coefficients by species and diameters used in formulas by the Forest Survey to compute partial cubic-foot volume of trees in the Rocky Mountain area. The basic formula used is of the form:

$$V = bx$$

where V = partial cubic-foot volume, i.e., the cubic-foot volume inside bark from a 1-foot stump to a 4.0-inch top d.i.b.

b = regression coefficient

$$x = \frac{(\text{DBH in inches})^2(\text{total height in feet from ground to tip})}{100}$$

The advantages of formulas in contrast to conventional volume tables in the determination of tree volume are: (1) they facilitate machine operations when punch cards are used, (2) eliminate tedious interpolations, (3) reduce unknown biases associated with grouping by diameter and height classes, (4) permit calculation of growth to any degree of refinement that changes in diameter and height can be measured, and (5) they facilitate the comparison between species and of changes by species and/or inventories.

DEVELOPMENT OF BASIC FORMULA

The general approach in the development of the formulas was suggested by Spurr.[1] However, contrary to Spurr's findings, the relationship between total cubic volume on D^2H for all standard cubic volume tables tested was curvilinear--slightly within, and obviously between, diameter classes. In dealing with partial cubic volume, i.e., volume between a 1-foot stump and 4-inch top inside bark, the curvilinearity is greatly accentuated and cannot be ignored if unbiased estimates of volume and growth by diameter classes are required.

1/ Spurr, Stephen H. 1951. Forest Inventory. The Ronald Press. pp. 111-121.

Under the circumstances, only 2 alternatives were possible: (1) a complex curvilinear formula, or (2) a modification of the simple D^2H relationship that would introduce curvilinearity. The first, and probably superior, alternative required more thorough study than was warranted. Furthermore, the gain in a complex formula may be more than offset by disadvantages in its use. The second alternative was adopted. At the risk of introducing some subjectiveness which is inherent in free-hand curves, curvilinearity was allowed for by varying the regression coefficients by diameter class. In other words, instead of a single equation for a species, volumes are determined by a series of harmonized equations. The number in this series is determined by diameter intervals of 0.1 inch and coefficient intervals of .001. Further refinements are possible by carrying additional places in the coefficients.

The procedure of using a series of harmonized equations by diameter class, however, accounts only for curvilinearity between diameter classes. To account for the smaller curvilinearity within diameter classes, i.e., by height classes, the same procedure could be followed by setting up additional equations. In this proposal, the curvilinearity within diameter classes is ignored and volume is derived by the simple equation of the form $V = bx$, where $b =$ the regression coefficient, and $x = D^2H/100$. This equation tends to underscale short trees and overscale tall trees to a maximum of about $\pm$ 3 percent. A slightly better fit (but still straightline) could be obtained with an equation of the form $V = bx + a$ but the gain would be offset by disadvantages of adding the constant.

DERIVATION OF REGRESSION COEFFICIENTS

The regression coefficients were derived from an analysis of standard conventional volume tables in the following manner:

1. Total volumes and heights were summed by diameter class, generally using the full range of height classes shown in the tables.

2. Preliminary regression coefficients for each diameter class were derived by the formula

$$b = \frac{\sum v}{D^2 \frac{\sum H}{100}}$$

where v = volume of individual trees
H = height of individual trees
D = 1-inch diameter class

The coefficients were plotted on ordinary cross section paper over diameter class on a vertical scale that permitted reading directly to 3 places. Freehand curves drawn through these points formed a well-defined pattern, with values descending sharply from the 10- to 40-inch class and more gradual above the 40-inch class. Ponderosa pine was a notable exception in that after dipping downward in the customary manner, the coefficients increased slightly with increase in diameter. This may be explained in part at least by the fact that because of the characteristic flat-topped crowns of this species, total heights even though measured to the tip are low as compared to trees of normal top taper.

The coefficients read from the smoothed curve, i.e., the final coefficients of total cubic volume on $D^2H/100$ were next reduced to partial cubic volume coefficients by multiplying by the appropriate proportions (average by diameter class) of total cubic volume between a 1-foot stump and 4-inch top. These partial coefficients were then replotted over diameter and final values read from the smoothed curve by 0.1-inch diameter classes. In some cases such as for lodgepole pine and alpine fir, partial cubic volume tables were available and regression coefficients were computed directly from these tables.

Standard tables used to derive the regression coefficients follow:

Ponderosa pine	
Young growth	Table 32, USDA Tech. Bull. 630
Old growth	Table 28, USDA Tech. Bull. 407
White pine	
Young growth	Table 35, USDA Tech. Bull. 323
Old growth	Table 35 modified, and tree measurements
Douglas-fir	
Young growth	Table 39, USDA Tech. Bull. 323
Old growth	Table 39 modified, and tree measurements
Western larch	
Young growth	Table 36, USDA Tech. Bull. 323
Old growth	Table 36 modified, and tree measurements
Grand fir	
Young growth	Table 38, USDA Tech. Bull. 323
Old growth	Table 38 modified, and tree measurements
Lodgepole pine	Rocky Mountain Forest and Range Experiment Station. Preliminary cubic volume table for lodgepole pine, 1948, table 2 standard volume tables for lodgepole pine in Alberta. Forest Research Division Tech. note 9, 1955.

Western redcedar	
Young growth	Table 40, USDA Tech. Bull. 323
Old growth	Table 40 modified, and tree measurements
Alpine fir	Alpine fir table by Joye E. Smith, 4/5/50 from Rocky Mountain Forest and Range Experiment Station files.
Western hemlock	
Young growth	Table 37, USDA Tech. Bull. 323
Old growth	Table 37 modified, and tree measurements
Spruce	Table 89, USDA Volume tables for important timber trees of the Western States. Part 1, Western species.
Cottonwood	R-1 Forest Survey table
Aspen	R-1 Forest Survey table
Juniper	R-1 Forest Survey table

As indicated above, the regression coefficients are essentially a means of translating acceptable conventional tables into formulas. In a sense they might be considered as merely putting finer and more easily determined graduations on previously used standards. In this process some of the distinctions within diameter class of the original tables were sacrificed for offsetting advantages. Actually, such fine distinctions may be more apparent than real. Rather than to strive for the unattainable absolute, a primary Forest Survey objective is to measure change and it is believed that the coefficients accomplish this by the same token that a scale may be in absolute error by 2 percent but still detect differences of a hair.

It should be noted, however, that since short trees tend to be underscaled and tall trees overscaled, growth determinations tend to be biased on the high side. This bias is small but can be measured and appropriate corrections made as required.

Regression coefficients of partial cubic-foot volume[1] on $D^2H/100$
Young growth

DBH (inches)	Western white pine	Ponderosa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodgepole pine	Alpine fir	Juniper	Cottonwood	Aspen
5.0	.079	.048	.046	.051	.076	.094	.065	.090	.105	.092	.060	.090	.110
5.1	.092	.055	.055	.068	.083	.100	.070	.097	.116	.107	.079	.097	.121
5.2	.104	.063	.064	.082	.090	.107	.075	.105	.127	.118	.092	.103	.130
5.3	.114	.070	.072	.093	.097	.113	.080	.111	.137	.127	.103	.107	.138
5.4	.123	.077	.080	.103	.104	.119	.085	.118	.147	.134	.112	.112	.145
5.5	.130	.083	.087	.111	.112	.126	.090	.124	.157	.140	.120	.115	.151
5.6	.137	.089	.093	.118	.118	.132	.095	.130	.167	.146	.127	.119	.157
5.7	.143	.094	.099	.124	.125	.138	.100	.135	.175	.152	.132	.122	.162
5.8	.149	.100	.104	.130	.131	.143	.106	.140	.183	.157	.138	.126	.166
5.9	.154	.105	.109	.135	.137	.149	.111	.145	.191	.163	.143	.129	.170
6.0	.158	.110	.114	.140	.143	.154	.116	.150	.199	.168	.147	.132	.174
6.1	.162	.115	.118	.144	.149	.159	.122	.154	.205	.172	.151	.135	.178
6.2	.166	.119	.122	.147	.153	.164	.127	.158	.209	.175	.155	.137	.181
6.3	.170	.124	.126	.151	.159	.169	.132	.162	.213	.178	.159	.140	.184
6.4	.173	.128	.129	.155	.164	.173	.137	.165	.217	.180	.162	.143	.187
6.5	.177	.132	.133	.158	.168	.178	.143	.169	.220	.183	.165	.146	.190
6.6	.179	.135	.136	.161	.172	.183	.147	.172	.223	.185	.168	.148	.192
6.7	.182	.137	.139	.163	.176	.187	.151	.174	.225	.188	.171	.150	.195
6.8	.185	.140	.141	.166	.180	.191	.155	.177	.227	.190	.174	.153	.197
6.9	.187	.142	.143	.169	.183	.195	.158	.180	.229	.192	.177	.155	.199
7.0	.190	.144	.145	.171	.186	.199	.161	.182	.231	.194	.180	.158	.201
7.1	.192	.146	.147	.173	.190	.203	.164	.184	.233	.196	.182	.160	.203
7.2	.194	.148	.149	.175	.193	.206	.168	.186	.235	.197	.185	.162	.205
7.3	.196	.149	.151	.177	.196	.210	.170	.188	.236	.199	.187	.164	.207
7.4	.198	.151	.152	.179	.198	.213	.173	.190	.237	.200	.189	.167	.208
7.5	.200	.152	.154	.181	.201	.216	.176	.192	.238	.202	.191	.169	.210
7.6	.201	.153	.155	.183	.203	.217	.178	.193	.239	.203	.192	.171	.211
7.7	.203	.155	.156	.184	.204	.219	.179	.194	.240	.204	.193	.173	.212
7.8	.204	.156	.157	.185	.206	.220	.181	.195	.241	.205	.194	.174	.213
7.9	.205	.157	.159	.186	.208	.221	.183	.196	.242	.206	.195	.176	.215
8.0	.207	.159	.160	.187	.209	.222	.184	.197	.243	.207	.196	.178	.216
8.1	.208	.160	.161	.188	.210	.223	.185	.198	.244	.208	-	.180	.217
8.2	.209	.161	.162	-	.211	.224	.186	.199	.245	.208	.197	.181	.218
8.3	.210	.162	.163	.189	.212	.225	.188	.200	-	.209	.198	.183	-
8.4	.211	.163	.164	-	.213	.226	.189	-	-	.210	-	.184	.219
8.5	.212	.164	.165	.190	.214	.226	.190	.201	.246	.210	.199	.186	.220
8.6	.212	.165	.166	-	-	.227	.191	-	.246	.211	-	.187	-
8.7	.213	.166	-	.191	.215	-	.192	.202	.247	-	.200	.188	.221
8.8	.214	.167	.167	-	-	.228	.193	-	-	.212	-	.189	.222
8.9	-	-	.168	-	.216	-	-	.203	.248	-	.201	.190	-
9.0	.215	.168	-	-	-	.229	.194	-	-	.213	-	.191	.223
9.1	-	.169	.169	.192	.217	-	.195	-	-	-	.202	-	-
9.2	.216	.170	.170	-	-	.230	.196	.204	.249	.214	-	.192	-
9.3	-	.171	-	-	-	-	-	-	-	-	-	.193	-
9.4	.217	-	.171	-	.218	-	.197	-	-	-	.203	-	.224
9.5	-	.172	-	-	-	-	-	-	-	.215	-	.194	-
9.6	.218	.173	.172	-	-	-	.198	-	-	-	-	-	-
9.7	-	.174	-	-	-	.231	-	-	-	-	.204	.195	-
9.8	-	-	-	-	-	-	.199	-	-	-	-	-	-
9.9	.219	.175	.173	-	.219	-	.200	-	.250	-	.205	.196	-
10.0	-	.176	-	-	-	-	-	-	-	-	-	-	-
10.1	-	-	-	-	-	-	-	-	-	-	-	-	-
10.2	-	.177	.174	-	-	.232	.201	.203	.249	-	-	.197	-
10.3	-	.178	-	-	-	-	-	-	-	-	-	-	-
10.4	.220	-	.175	-	-	-	-	-	-	-	.206	-	-
10.5	-	.179	-	-	-	-	.202	-	-	-	-	-	-
10.6	-	-	-	-	-	-	-	-	-	-	-	-	-
10.7	-	.180	-	-	-	-	-	-	.248	-	-	.198	-
10.8	-	-	-	-	.220	-	-	.202	-	-	-	-	-
10.9	-	.181	-	-	-	-	.203	-	-	-	-	-	-
11.0	-	.182	.176	-	-	-	-	-	.247	-	.207	-	-
11.1	-	-	-	-	-	-	-	-	-	-	-	-	-
11.2	-	.183	-	-	-	-	-	.201	-	.214	-	-	-
11.3	.219	-	-	.191	-	-	-	-	.246	-	-	.199	-
11.4	-	-	-	-	-	-	-	-	-	-	-	-	-
11.5	-	.184	-	-	-	-	-	.200	-	.213	-	-	-

Continued

DBH (inches)	Western white pine	Ponder-osa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodge-pole pine	Alpine fir	Juniper	Cotton-wood	Aspen
11.6	-	-	-	-	-	-	-	-	.245	-	-	-	-
11.7	-	.185	-	-	-	-	-	-	-	-	-	-	-
11.8	-	-	-	-	-	-	-	.199	-	.212	-	-	-
11.9	-	-	.177	-	-	-	-	-	.244	-	-	.200	-
12.0	-	.186	-	-	-	-	-	-	-	-	-	-	-
12.1	.218	-	-	-	-	.231	-	.198	-	-	-	-	-
12.2	-	-	-	-	-	-	-	-	-	.211	-	-	-
12.3	-	.187	-	.190	-	-	.204	-	.243	-	-	-	-
12.4	-	-	-	-	-	-	-	.197	-	-	-	-	-
12.5	-	-	-	-	-	-	-	-	-	.210	-	-	-
12.6	.217	-	-	-	-	.230	-	-	.242	-	-	-	-
12.7	-	.188	-	-	-	-	-	.196	-	-	-	-	-
12.8	-	-	-	-	-	-	-	-	-	-	-	-	-
12.9	-	-	-	-	.219	-	-	-	.241	.209	-	-	-
13.0	-	-	-	-	-	-	-	.195	-	-	-	-	-
13.1	.216	.189	-	.189	-	.229	-	-	-	-	-	-	-
13.2	-	-	-	-	-	-	-	-	.240	.208	-	-	-
13.3	-	-	-	-	-	-	-	.194	-	-	-	.201	-
13.4	-	.190	-	-	-	.228	-	-	-	.207	-	-	-
13.5	-	-	-	-	-	-	-	-	.239	-	-	-	-
13.6	.215	-	-	.188	-	-	-	.193	-	-	-	-	-
13.7	-	-	-	-	-	-	-	-	-	.206	-	-	-
13.8	-	-	-	-	-	.227	-	-	.238	-	-	-	-
13.9	-	.191	-	-	-	-	-	.192	-	.205	-	-	-
14.0	-	-	.176	-	-	-	-	-	-	-	-	-	-
14.1	.214	-	-	-	-	.226	-	-	-	-	-	-	-
14.2	-	-	-	.187	-	-	-	.191	.237	.204	-	-	-
14.3	-	.192	-	-	-	-	-	-	-	-	-	-	-
14.4	-	-	-	-	-	-	-	-	-	.202	-	-	-
14.5	.213	-	-	-	-	.225	-	.190	.236	-	-	-	-
14.6	-	-	-	-	-	-	-	-	-	-	-	-	-
14.7	-	-	-	.186	-	-	.205	-	-	.201	-	-	-
14.8	-	.193	-	-	-	-	-	.189	.235	-	-	-	-
14.9	-	-	-	-	-	.224	-	-	-	.200	-	-	.223
15.0	.212	-	-	-	-	-	-	-	-	-	-	-	-
15.1	-	-	-	.185	-	-	-	.188	.234	-	-	-	-
15.2	-	-	.175	-	-	-	-	-	-	-	-	-	-
15.3	-	-	-	-	-	.223	-	-	-	.199	-	-	-
15.4	-	.194	-	-	.218	-	-	.187	.233	-	-	-	-
15.5	.211	-	-	-	-	-	-	-	-	-	.208	-	-
15.6	-	-	-	-	-	-	-	-	-	.198	-	-	-
15.7	-	-	-	.184	-	.222	-	.186	.232	-	-	-	-
15.8	-	-	-	-	-	-	-	-	-	.197	-	-	-
15.9	.210	-	-	-	-	-	-	-	-	-	-	-	-
16.0	-	.195	.174	-	-	.221	-	.185	-	-	-	-	-
16.1	-	-	-	-	-	-	-	-	.231	.196	-	-	-
16.2	-	-	-	.183	-	-	-	-	-	-	-	-	-
16.3	-	-	-	-	-	-	-	.184	.230	.195	-	-	-
16.4	-	-	-	-	-	.220	-	-	-	-	-	-	-
16.5	.209	-	-	-	-	-	-	-	-	-	-	-	-
16.6	-	-	-	-	-	-	-	.183	-	.194	-	-	-
16.7	-	-	.173	.182	-	-	-	-	.229	-	-	-	-
16.8	-	-	-	-	-	.219	-	-	-	.193	-	-	-
16.9	.208	.196	-	-	-	-	-	.182	-	-	-	-	-
17.0	-	-	-	-	-	-	-	-	-	-	-	-	-
17.1	-	-	-	-	-	-	-	-	.228	.192	-	-	-
17.2	-	-	.172	.181	-	.218	-	-	-	-	-	-	.222
17.3	.207	-	-	-	-	-	-	.181	.227	.191	-	-	-
17.4	-	-	-	-	-	-	-	-	-	-	-	-	-
17.5	-	-	-	-	-	-	.206	-	-	-	-	-	-
17.6	-	-	-	.180	-	.217	-	.180	.226	.190	-	-	-
17.7	-	.197	.171	-	-	-	-	-	-	-	-	-	-
17.8	.206	-	-	-	-	-	-	-	-	.189	-	-	-
17.9	-	-	-	-	-	-	-	.179	.225	-	-	-	-
18.0	-	-	-	-	.217	.216	-	-	-	.188	-	-	-
18.1	-	-	-	.179	-	-	-	-	-	-	-	-	-
18.2	-	-	.170	-	-	-	-	.178	.224	-	-	-	-

Continued

DBH (inches)	Western white pine	Ponder-osa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodge-pole pine	Alpine fir	Juniper	Cotton-wood	Aspen
18.3	.205	-	-	-	-	-	-	-	-	.187	-	-	-
18.4	-	-	-	-	-	.215	-	-	-	-	-	-	-
18.5	-	.198	-	-	-	-	-	.177	.223	.186	-	-	-
18.6	-	-	-	.178	-	-	-	-	-	-	-	-	-
18.7	.204	-	.169	-	-	-	-	-	-	-	-	-	-
18.8	-	-	-	-	-	-	-	-	.222	.185	-	-	-
18.9	-	-	-	-	-	.214	-	.176	-	-	-	-	-
19.0	-	-	-	-	-	-	-	-	-	.184	-	-	.221
19.1	-	-	.168	.177	-	-	-	-	-	-	-	-	-
19.2	.203	-	-	-	-	-	-	.175	.221	.183	-	-	-
19.3	-	-	-	-	-	.213	-	-	-	-	-	-	-
19.4	-	-	-	-	-	-	-	-	-	-	-	-	-
19.5	-	.199	-	-	-	-	-	.174	.220	.182	-	-	-
19.6	.202	-	.167	.176	-	-	-	-	-	-	-	-	-
19.7	-	-	-	-	-	.212	-	-	-	.181	-	-	-
19.8	-	-	-	-	-	-	-	-	.219	-	-	-	-
19.9	-	-	-	-	-	-	-	.173	-	.180	-	-	-
20.0	-	-	.166	.175	-	-	-	-	-	-	-	-	-
20.1	.201	-	-	-	-	-	-	-	.218	.179	-	-	-
20.2	-	-	-	-	-	.211	-	.172	-	-	-	-	-
20.3	-	-	.165	-	-	-	-	-	-	.178	-	-	-
20.4	-	-	-	-	-	-	-	-	.217	-	-	-	.220
20.5	.200	-	-	.174	-	-	-	-	-	.177	-	-	-
20.6	-	-	-	-	-	.210	-	.171	-	-	-	-	-
20.7	-	-	-	-	.216	-	-	-	.216	.176	-	-	-
20.8	-	.200	.164	-	-	-	-	.170	-	-	-	-	-
20.9	.199	-	-	-	-	-	-	-	-	.175	-	-	-

1/ Volume between 1-foot stump and 4-inch inside bark top diameter.

Regression coefficients of partial cubic-foot volume[1/] on $D^2H/100$
Old growth

DBH (inches)	Western white pine	Ponder-osa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodge-pole pine	Alpine fir	Juniper	Cotton-wood	Aspen
18.0	.208	.197	.181	.189	.227	.221	.218	.177	.225	.188	-	.201	.222
18.1	.208	-	-	-	-	.220	-	-	-	-	-	-	-
18.2	.207	-	-	-	-	-	-	-	.224	-	-	-	-
18.3	.207	-	.180	.188	.226	-	-	.176	-	.187	-	-	-
18.4	-	-	-	-	-	-	-	-	-	-	-	-	-
18.5	-	-	-	-	-	-	-	-	.223	.186	-	-	-
18.6	-	-	-	-	-	.219	-	-	-	-	-	-	-
18.7	-	.198	-	.187	-	-	-	.175	-	-	-	-	-
18.8	-	-	-	-	.225	-	-	-	.222	.185	-	-	-
18.9	-	-	.179	-	-	-	.217	-	-	-	-	-	-
19.0	-	-	-	-	-	-	-	-	-	.184	-	-	-
19.1	-	-	-	-	-	.218	-	.174	-	-	-	-	-
19.2	-	-	-	-	-	-	-	-	.221	.183	-	-	.221
19.3	-	-	.178	-	-	-	-	-	-	-	-	-	-
19.4	.206	-	-	-	.224	-	-	-	-	-	-	-	-
19.5	-	-	-	.186	-	-	-	.173	.220	.182	-	-	-
19.6	-	-	-	-	-	.217	-	-	-	-	-	-	-
19.7	-	-	-	-	-	-	-	-	-	.181	-	-	-
19.8	-	-	.177	-	-	-	-	-	.219	-	-	-	-
19.9	-	.199	-	-	-	-	-	.172	-	.180	-	-	-
20.0	-	-	-	-	.223	-	-	-	-	-	-	-	-
20.1	-	-	-	.185	-	-	-	-	.218	.179	-	-	-
20.2	-	-	.176	-	-	.216	-	-	-	-	-	-	-
20.3	-	-	-	-	-	-	-	.171	-	.178	-	-	-
20.4	-	-	-	-	-	-	-	-	.217	-	-	-	-
20.5	-	-	-	-	-	-	-	-	-	.177	-	-	-
20.6	.205	-	.175	-	.222	-	-	-	-	-	-	-	-
20.7	-	-	-	.184	-	.215	-	.170	.216	.176	-	-	-
20.8	-	-	-	-	-	-	-	-	-	-	-	-	-
20.9	-	-	-	-	-	-	-	-	-	.175	-	-	-
21.0	-	-	-	-	-	-	-	-	-	-	-	-	-
21.1	-	.200	.174	-	-	-	-	.169	-	-	-	-	-
21.2	-	-	-	-	.221	.214	.216	-	.215	.174	-	-	.220
21.3	-	-	-	-	-	-	-	-	-	-	-	-	-
21.4	-	-	-	.183	-	-	-	-	-	-	-	-	-
21.5	-	-	.173	-	-	-	-	.168	-	.173	-	-	-
21.6	-	-	-	-	.220	.213	-	-	.214	-	-	-	-
21.7	-	-	-	-	-	-	-	-	-	.172	-	-	-
21.8	-	-	-	-	-	-	-	-	-	-	-	-	-
21.9	-	-	-	-	-	-	-	-	.213	-	-	-	-
22.0	-	-	.172	-	-	-	-	.167	-	.171	-	-	-
22.1	.204	-	-	.182	-	.212	-	-	-	-	-	-	-
22.2	-	-	-	-	-	-	-	-	-	.170	-	-	-
22.3	-	.201	-	-	.219	-	-	-	.212	-	-	-	-
22.4	-	-	-	-	-	-	-	-	-	-	-	-	-
22.5	-	-	.171	-	-	-	-	.166	-	.169	-	-	-
22.6	-	-	-	-	-	.211	-	-	.211	-	-	-	-
22.7	-	-	-	-	-	-	-	-	-	.168	-	-	-
22.8	-	-	-	.181	-	-	-	-	-	-	-	-	-
22.9	-	-	.170	-	.218	-	-	.165	-	-	-	-	-
23.0	-	-	-	-	-	-	-	-	.210	.167	-	-	-
23.1	-	-	-	-	-	.210	-	-	-	-	-	-	-
23.2	-	-	-	-	-	-	.215	-	-	-	-	-	-
23.3	-	-	-	-	-	-	-	-	-	.166	-	-	-
23.4	-	-	.169	-	-	-	-	-	-	-	-	-	-
23.5	.203	-	-	.180	.217	-	-	.164	.209	-	-	-	-
23.6	-	.202	-	-	-	-	-	-	-	.165	-	-	-
23.7	-	-	-	-	-	.209	-	-	-	-	-	-	-
23.8	-	-	-	-	-	-	-	-	-	-	-	-	-
23.9	-	-	.168	-	-	-	-	-	.208	.164	-	-	.219
24.0	-	-	-	-	-	-	-	.163	-	-	-	-	-
24.1	-	-	-	-	.216	-	-	-	-	-	-	-	-
24.2	-	-	-	-	-	.208	-	-	-	.163	-	-	-
24.3	-	-	.167	-	-	-	-	-	-	-	-	-	-
24.4	-	-	-	.179	-	-	-	-	.207	-	-	-	-
24.5	-	-	-	-	-	-	-	-	-	.162	-	-	-

Continued

DBH (inches)	Western white pine	Ponder-osa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodge-pole pine	Alpine fir	Juniper	Cotton-wood	Aspen
24.6	-	-	-	-	-	-	-	.162	-	-	-	.200	-
24.7	-	-	.166	-	.215	.207	-	-	-	-	-	-	-
24.8	.202	-	-	-	-	-	-	-	-	-	-	-	-
24.9	-	.203	-	-	-	-	-	-	-	.161	-	-	-
25.0	-	-	-	-	-	-	-	-	.206	-	-	-	-
25.1	-	-	-	-	-	.206	-	-	-	-	-	-	-
25.2	-	-	.165	.178	-	-	-	.161	-	-	-	-	-
25.3	-	-	-	-	-	-	-	-	-	.160	-	-	-
25.4	-	-	-	-	.214	-	-	-	-	-	-	-	-
25.5	-	-	-	-	-	-	-	-	-	-	-	-	-
25.6	-	-	-	-	-	.205	.214	-	.205	-	-	-	-
25.7	-	-	.164	-	-	-	-	.160	-	.159	-	-	-
25.8	-	-	-	-	-	-	-	-	-	-	-	-	-
25.9	-	-	-	-	-	-	-	-	-	-	-	-	-
26.0	-	-	-	.177	.213	-	-	-	-	.158	-	-	-
26.1	-	.204	.163	-	-	.204	-	-	-	-	-	-	-
26.2	-	-	-	-	-	-	-	-	-	-	-	-	-
26.3	.201	-	-	-	-	-	-	-	-	-	-	-	-
26.4	-	-	-	-	-	-	-	-	-	.157	-	-	-
26.5	-	-	.162	-	-	-	-	.159	.204	-	-	-	-
26.6	-	-	-	-	-	.203	-	-	-	-	-	-	-
26.7	-	-	-	-	.212	-	-	-	-	.156	-	-	-
26.8	-	-	-	-	-	-	-	-	-	-	-	-	-
26.9	-	-	-	-	-	-	-	-	-	-	-	-	-
27.0	-	-	.161	.176	-	-	-	-	-	.155	-	-	.218
27.1	-	-	-	-	-	.202	-	-	-	-	-	-	-
27.2	-	-	-	-	-	-	-	-	-	-	-	-	-
27.3	-	.205	-	-	-	-	-	.158	-	-	-	-	-
27.4	-	-	-	-	-	-	-	-	-	.154	-	-	-
27.5	-	-	.160	-	.211	-	-	-	.203	-	-	-	-
27.6	-	-	-	-	-	.201	-	-	-	-	-	-	-
27.7	-	-	-	-	-	-	-	-	-	.153	-	-	-
27.8	.200	-	-	-	-	-	.213	-	-	-	-	-	-
27.9	-	-	-	.175	-	-	-	-	-	-	-	-	-
28.0	-	-	.159	-	-	-	-	-	-	-	-	-	-
28.1	-	-	-	-	-	.200	-	.157	-	-	-	-	-
28.2	-	-	-	-	.210	-	-	-	-	.152	-	-	-
28.3	-	-	-	-	-	-	-	-	-	-	-	-	-
28.4	-	-	-	-	-	-	-	-	-	-	-	-	-
28.5	-	.206	.158	-	-	-	-	-	-	-	-	-	-
28.6	-	-	-	-	-	.199	-	-	.202	.151	-	.199	-
28.7	-	-	-	-	-	-	-	-	-	-	-	-	-
28.8	-	-	-	-	-	-	-	-	-	-	-	-	-
28.9	-	-	.157	.174	-	-	-	.156	-	.150	-	-	-
29.0	-	-	-	-	-	-	-	-	-	-	-	-	-
29.1	-	-	-	-	.209	.198	-	-	-	-	-	-	-
29.2	-	-	-	-	-	-	-	-	-	-	-	-	-
29.3	-	-	-	-	-	-	-	-	-	-	-	-	-
29.4	-	-	.156	-	-	-	-	-	-	.149	-	-	-
29.5	-	-	-	-	-	-	-	-	-	-	-	-	-
29.6	-	.207	-	-	-	.197	-	-	-	-	-	-	-
29.7	-	-	-	-	-	-	-	-	-	-	-	-	-
29.8	-	-	-	-	-	-	-	.155	-	.148	-	-	-
29.9	-	-	.155	.173	-	-	.212	-	-	-	-	-	-
30.0	.199	-	-	-	.208	-	-	-	-	-	-	-	-
30.1	-	-	-	-	-	.196	-	-	-	-	-	-	-
30.2	-	-	-	-	-	-	-	-	-	.147	-	-	-
30.3	-	-	-	-	-	-	-	-	-	-	-	-	-
30.4	-	-	.154	-	-	-	-	-	.201	-	-	-	-
30.5	-	-	-	-	-	-	-	-	-	-	-	-	-
30.6	-	-	-	-	-	.195	-	-	-	.146	-	-	-
30.7	-	-	-	-	-	-	-	-	-	-	-	-	-
30.8	-	-	-	-	-	-	-	-	-	-	-	.198	.217
30.9	-	.208	.153	-	.207	-	-	.154	-	-	-	-	-
31.0	-	-	-	.172	-	-	-	-	-	.145	-	-	-
31.1	-	-	-	-	-	.194	-	-	-	-	-	-	-

Continued

DBH (inches)	Western white pine	Ponder-osa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodge-pole pine	Alpine fir	Juniper	Cotton-wood	Aspen
31.2	-	-	-	-	-	-	-	-	-	-	-	-	-
31.3	-	-	-	-	-	-	-	-	-	-	-	-	-
31.4	-	-	-	-	-	-	-	-	-	.144	-	-	-
31.5	-	-	.152	-	-	-	-	-	-	-	-	-	-
31.6	-	-	-	-	-	.193	-	-	-	-	-	-	-
31.7	-	-	-	-	-	-	-	-	-	-	-	-	-
31.8	-	-	-	-	-	-	-	-	-	.143	-	-	-
31.9	-	-	-	-	.206	-	-	-	-	-	-	-	-
32.0	-	-	.151	-	-	-	-	-	-	-	-	-	-
32.1	-	.209	-	-	-	.192	.211	.153	-	-	-	-	-
32.2	-	-	-	-	-	-	-	-	-	.142	-	-	-
32.3	.198	-	-	-	-	-	-	-	-	-	-	-	-
32.4	-	-	-	.171	-	-	-	-	-	-	-	-	-
32.5	-	-	.150	-	-	-	-	-	-	-	-	-	-
32.6	-	-	-	-	-	.191	-	-	-	.141	-	-	-
32.7	-	-	-	-	-	-	-	-	-	-	-	-	-
32.8	-	-	-	-	-	-	-	-	-	-	-	-	-
32.9	-	-	-	-	.205	-	-	-	-	-	-	-	-
33.0	-	-	.149	-	-	-	-	-	-	-	-	-	-
33.1	-	-	-	-	-	.190	-	-	-	.140	-	-	-
33.2	-	.210	-	-	-	-	-	-	-	-	-	-	-
33.3	-	-	-	-	-	-	-	-	-	-	-	.197	-
33.4	-	-	-	-	-	-	-	-	-	-	-	-	-
33.5	-	-	-	-	-	-	-	-	-	-	-	-	-
33.6	-	-	.148	.170	-	.189	-	.152	-	.139	-	-	-
33.7	-	-	-	-	-	-	-	-	-	-	-	-	-
33.8	-	-	-	-	-	-	-	-	-	-	-	-	-
33.9	-	-	-	-	-	-	-	-	-	-	-	-	-
34.0	-	-	-	-	-	-	-	-	-	.138	-	-	-
34.1	-	-	.147	-	-	-	-	-	-	-	-	-	-
34.2	-	-	-	-	-	.188	-	-	-	-	-	-	-
34.3	-	-	-	-	-	-	-	-	-	-	-	-	-
34.4	-	-	-	-	.204	-	-	-	-	.137	-	-	-
34.5	-	-	-	-	-	-	-	-	-	-	-	-	-
34.6	-	.211	-	-	-	-	-	-	-	-	-	-	-
34.7	-	-	-	-	-	.187	-	-	-	-	-	-	-
34.8	-	-	.146	-	-	-	-	-	-	.136	-	-	-
34.9	-	-	-	-	-	-	-	-	-	-	-	-	-
35.0	-	-	-	-	-	-	-	-	-	-	-	-	-
35.1	-	-	-	-	-	-	-	.151	-	-	-	-	-
35.2	.197	-	-	-	-	.186	-	-	-	.135	-	-	-
35.3	-	-	.145	-	-	-	-	-	-	-	-	-	-
35.4	-	-	-	-	-	-	-	-	-	-	-	-	-
35.5	-	-	-	-	-	-	-	-	-	-	-	-	-
35.6	-	.212	-	.169	-	-	-	-	-	.134	-	-	-
35.7	-	-	-	-	-	-	-	-	-	-	-	.196	-
35.8	-	-	-	-	-	.185	-	-	-	-	-	-	-
35.9	-	-	.144	-	.203	-	-	-	-	-	-	-	-
36.0	-	-	-	-	-	-	-	-	-	.133	-	-	-
36.1	-	-	-	-	-	-	-	-	-	-	-	-	-
36.2	-	-	-	-	-	-	-	-	-	-	-	-	-
36.3	-	-	-	-	-	-	-	-	-	-	-	-	-
36.4	-	-	-	-	-	-	-	-	-	.132	-	-	-
36.5	-	-	.143	-	-	.184	-	-	-	-	-	-	-
36.6	-	-	-	-	-	-	-	-	-	-	-	-	-
36.7	-	.213	-	-	-	-	-	.150	-	-	-	-	-
36.8	-	-	-	-	-	-	-	-	-	-	-	-	-
36.9	-	-	-	-	-	-	-	-	-	.131	-	-	-
37.0	-	-	-	-	-	-	-	-	-	-	-	-	-
37.1	-	-	-	-	-	-	-	-	-	-	-	-	-
37.2	-	-	.142	-	-	-	-	-	-	-	-	-	-
37.3	-	-	-	-	-	-	-	-	-	-	-	-	-
37.4	-	-	-	-	-	.183	-	-	-	.130	-	-	-
37.5	-	-	-	-	-	-	-	-	-	-	-	-	-
37.6	-	-	-	-	-	-	-	-	-	-	-	-	-
37.7	-	-	-	-	-	-	-	-	-	-	-	-	-
37.8	-	.214	-	-	.202	-	-	-	-	.129	-	-	-

Continued

DBH (inches)	Western white pine	Ponder-osa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodge-pole pine	Alpine fir	Juniper	Cotton-wood	Aspen
37.9	-	-	.141	-	-	-	-	-	-	-	-	-	-
38.0	-	-	-	-	-	-	-	-	-	-	-	.195	-
38.1	-	-	-	-	-	-	-	-	-	-	-	-	-
38.2	-	-	-	.168	-	-	-	-	-	-	-	-	-
38.3	-	-	-	-	-	.182	-	-	-	.128	-	-	-
38.4	-	-	-	-	-	-	-	-	-	-	-	-	-
38.5	-	-	.140	-	-	-	-	-	-	-	-	-	-
38.6	-	-	-	-	-	-	-	-	-	-	-	-	-
38.7	-	-	-	-	-	-	-	-	-	-	-	-	-
38.8	-	.215	-	-	-	-	-	-	-	.127	-	-	-
38.9	-	-	-	-	-	-	-	.149	-	-	-	-	-
39.0	-	-	-	-	-	-	-	-	-	-	-	-	-
39.1	-	-	-	-	-	-	-	-	-	-	-	-	-
39.2	-	-	-	-	-	-	-	-	-	-	-	-	-
39.3	-	-	.139	-	-	.181	-	-	-	.126	-	-	-
39.4	-	-	-	-	-	-	-	-	-	-	-	-	-
39.5	-	-	-	-	-	-	-	-	-	-	-	-	-
39.6	.196	-	-	-	.201	-	-	-	-	-	-	-	-
39.7	-	-	-	-	-	-	-	-	-	-	-	-	-
39.8	-	-	-	-	-	-	-	-	-	.125	-	-	-
39.9	-	.216	-	-	-	-	-	-	-	-	-	-	-
40.0	-	-	-	-	-	-	-	-	-	-	-	-	-
40.1	-	-	.138	-	-	-	-	-	-	-	-	-	-
40.2	-	-	-	-	-	-	-	-	-	-	-	-	-
40.3	-	-	-	-	-	-	-	-	-	-	-	-	-
40.4	-	-	-	-	-	-	-	-	-	-	-	.194	-
40.5	-	-	-	-	-	-	-	-	-	-	-	-	-
40.6	-	-	-	-	-	-	-	-	-	-	-	-	-
40.7	-	-	-	-	-	-	-	-	-	-	-	-	-
40.8	-	-	-	-	-	.180	-	-	-	-	-	-	-
40.9	-	.217	.137	-	-	-	-	-	-	-	-	-	-
41.0	-	-	-	-	-	-	-	.148	-	-	-	-	-
41.1	-	-	-	.167	-	-	-	-	-	-	-	-	-
41.2	-	-	-	-	-	-	-	-	-	-	-	-	-
41.3	-	-	-	-	-	-	-	-	-	-	-	-	-
41.4	-	-	-	-	-	-	-	-	-	-	-	-	-
41.5	-	-	-	-	-	-	-	-	-	-	-	-	-
41.6	-	-	-	-	-	-	-	-	-	-	-	-	-
41.7	-	-	-	-	-	-	-	-	-	-	-	-	-
41.8	-	-	-	-	.200	-	-	-	-	-	-	-	-
41.9	-	-	.136	-	-	-	-	-	-	-	-	-	-
42.0	-	.218	-	-	-	-	-	-	-	-	-	-	-
42.1	-	-	-	-	-	-	-	-	-	-	-	-	-
42.2	-	-	-	-	-	-	-	-	-	-	-	-	-
42.3	-	-	-	-	-	-	-	-	-	-	-	-	-
42.4	-	-	-	-	-	-	-	-	-	-	-	-	-
42.5	-	-	-	-	-	-	-	-	-	-	-	-	-
42.6	-	-	-	-	-	.179	-	-	-	-	-	-	-
42.7	-	-	-	-	-	-	-	-	-	-	-	-	-
42.8	-	-	-	-	-	-	-	-	-	-	-	.193	-
42.9	-	-	.135	-	-	-	-	-	-	-	-	-	-
43.0	-	-	-	-	-	-	-	-	-	-	-	-	-
43.1	-	-	-	-	-	-	-	-	-	-	-	-	-
43.2	-	.219	-	-	-	-	-	-	-	-	-	-	-
43.3	-	-	-	-	-	-	-	-	-	-	-	-	-
43.4	-	-	-	-	-	-	-	-	-	-	-	-	-
43.5	-	-	-	-	-	-	-	-	-	-	-	-	-
43.6	-	-	-	-	-	-	-	-	-	-	-	-	-
43.7	-	-	-	-	-	-	-	-	-	-	-	-	-
43.8	-	-	-	-	-	-	-	.147	-	-	-	-	-
43.9	-	-	-	-	-	-	-	-	-	-	-	-	-
44.0	-	.220	-	-	-	-	-	-	-	-	-	-	-
44.1	-	-	.134	-	-	-	-	-	-	-	-	-	-
44.2	-	-	-	-	-	.178	-	-	-	-	-	-	-
44.3	-	-	-	-	-	-	-	-	-	-	-	-	-
44.4	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued

DBH (inches)	Western white pine	Ponder-osa pine	Western white larch	Douglas-fir	Grand fir	Spruce	Hemlock	Cedar	Lodge-pole pine	Alpine fir	Juniper	Cotton-wood	Aspen
44.5	-	-	-	-	-	-	-	-	-	-	-	-	-
44.6	-	-	-	-	-	-	-	-	-	-	-	-	-
44.7	-	-	-	-	-	-	-	-	-	-	-	-	-
44.8	-	-	-	-	-	-	-	-	-	-	-	-	-
44.9	-	-	-	-	.199	-	-	-	-	-	-	-	-
45.0	-	-	-	.166	-	-	-	-	-	-	-	-	-
45.1	-	-	-	-	-	-	-	-	-	-	-	-	-
45.2	-	.221	-	-	-	-	-	-	-	-	-	.192	-
45.3	-	-	-	-	-	-	-	-	-	-	-	-	-
45.4	-	-	-	-	-	-	-	-	-	-	-	-	-
45.5	-	-	-	-	-	-	-	-	-	-	-	-	-
45.6	-	-	-	-	-	-	-	-	-	-	-	-	-
45.7	-	-	-	-	-	-	-	-	-	-	-	-	-
45.8	-	-	.133	-	-	-	-	-	-	-	-	-	-
45.9	-	-	-	-	-	-	-	-	-	-	-	-	-
46.0	-	-	-	-	-	.177	-	-	-	-	-	-	-
46.1	.195	.222	-	-	-	-	-	-	-	-	-	-	-
46.2	-	-	-	-	-	-	-	-	-	-	-	-	-
46.3	-	-	-	-	-	-	-	-	-	-	-	-	-
46.4	-	-	-	-	-	-	-	-	-	-	-	-	-
46.5	-	-	-	-	-	-	-	-	-	-	-	-	-
46.6	-	-	-	-	-	-	-	-	-	-	-	-	-
46.7	-	-	-	-	-	-	-	-	-	-	-	-	-
46.8	-	-	-	-	-	-	-	-	-	-	-	-	-
46.9	-	-	-	-	-	-	-	-	-	-	-	-	-
47.0	-	-	-	-	-	-	-	-	-	-	-	-	-
47.1	-	-	-	-	-	-	-	-	-	-	-	-	-
47.2	-	.223	-	-	-	-	-	-	-	-	-	-	-
47.3	-	-	-	-	-	-	-	-	-	-	-	.191	-
47.4	-	-	.132	-	-	-	-	-	-	-	-	-	-
47.5	-	-	-	-	-	-	-	-	-	-	-	-	-
47.6	-	-	-	-	-	-	-	-	-	-	-	-	-
47.7	-	-	-	-	-	-	-	-	-	-	-	-	-
47.8	-	-	-	-	-	.176	-	-	-	-	-	-	-
47.9	-	-	-	-	-	-	-	-	-	-	-	-	-
48.0	-	-	-	-	-	-	-	-	-	-	-	-	-
48.1	-	.224	-	-	-	-	-	-	-	-	-	-	-
48.2	-	-	-	-	-	-	-	-	-	-	-	-	-
48.3	-	-	-	-	-	-	-	-	-	-	-	-	-
48.4	-	-	-	-	-	-	-	-	-	-	-	-	-
48.5	-	-	-	-	-	-	-	-	-	-	-	-	-
48.6	-	-	-	-	-	-	-	-	-	-	-	-	-
48.7	-	-	-	-	-	-	-	-	-	-	-	-	-
48.8	-	-	-	-	.198	-	-	-	-	-	-	-	-
48.9	-	-	-	-	-	-	-	-	-	-	-	-	-
49.0	-	-	-	-	-	-	-	-	-	-	-	-	-
49.1	-	-	-	-	-	-	-	-	-	-	-	-	-
49.2	-	-	-	-	-	-	-	-	-	-	-	-	-
49.3	-	.225	-	-	-	-	-	-	-	-	-	.190	-
49.4	-	-	-	-	-	-	-	-	-	-	-	-	-
49.5	-	-	-	-	-	-	-	-	-	-	-	-	-
49.6	-	-	-	-	-	-	-	-	-	-	-	-	-
49.7	-	-	-	-	-	.175	-	-	-	-	-	-	-
49.8	-	-	-	-	-	-	-	-	-	-	-	-	-
49.9	-	-	-	-	-	-	-	-	-	-	-	-	-
50.0	.195	.225	.132	.166	.198	.175	.211	.147	-	-	-	.190	-

1/ Volume between 1-foot stump and 4-inch inside bark top diameter.

Intermountain Forest and Range

Experiment Station.

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HOW IMPORTANT IS RELIEF IN AREA ESTIMATES FROM DOT SAMPLING ON AERIAL PHOTOS?

Karl E. Moessner
Division of Forest Economics

STATEMENT OF PROBLEM

Favored by the Forest Survey in Eastern United States since 1946, dot sampling on aerial photographs has provided acceptable data even where contour maps are nonexistent and base maps are unreliable.

In the level terrain of the Midwest and South, scale variations on photos are minor and proportions obtained by dot sampling are used without adjustment. In the more mountainous areas of the Northeast where contour maps are reasonably common, foresters have developed satisfactory though complicated methods of adjusting dot sampling data for bias introduced by relief. But in the Rocky Mountains where good contour and base maps are rare, this method of using aerial photos has had few advocates. Yet it is in these rugged, unmapped, and often inaccessible areas where dot sampling, if usable, can do most to reduce the cost of surveys.

Photogrammetrists, concerned largely with engineering data, are quick to state that aerial photos are not maps and that point locations are subject to displacement in areas of high relief. High points, being nearer the aerial camera, photograph larger. The centers of the photos fall closer together in high country. Scale varies both within and between photographs.

Foresters often have found forest types stratified by elevation. Because of this, they have assumed that dot sampling on aerial photos of mountainous country without correcting for variation in scale would result in biased data. In some cases, to avoid bias, dots have been located precisely by radial line plotter. In other cases, data have been adjusted for scale changes due to elevation differences. These methods, and others patterned after them, are effective only when reliable base maps and good elevation data are available. Either method adds appreciably to the cost of survey.

The question naturally arises, "Is the bias introduced significant enough to make the adjust worthwhile?"

This study was designed to answer this question for a typical Rocky Mountain area.

Literature and Basic Theories

Rogers[1/], Wilson[2/], and many others[3/, 4/], have discussed the possible bias due to dot sampling on photos of areas with high relief. Rogers first recommended the precise location of sample dots on the aerial photos by means of a radial line plotter, as one means of eliminating the displacement and possible bias due to relief. He later recommended the seemingly more efficient solution of adjusting the areas obtained by factors based upon the mean relative elevation of the sample dots. This method, though usable for broad classes such as forest area, becomes complicated and almost unworkable for detailed forest types, common to many surveys.

Wilson suggested the use of a templet concentrating the dots near photo center, as a means of reducing displacement (and bias) within a single photo. He found that proportions from broad strata such as forest and nonforest tended to be compensating or at least were unbiased. However, his findings indicated some bias in highly stratified types with small area. He recommended planimetric templets as a means of eliminating this bias. Wilson stated that innumerable variations in scale distortion from relief displacement are possible on a single photo. But he emphasizes that the effects of relief displacement may be ignored whenever a single dot centered over the principal point of the photo is used. The only possible bias from relief would then be in the average scale of the photos, or in the distance between photos.

Our preliminary studies in typical Rocky Mountain areas show no significant difference between data obtained at photo center and those obtained from other points within the effective area of the photo. This seems to indicate that a significant bias must be introduced into the data primarily by the spacing of photo centers.

1/ Rogers, Earl J. 1948. A short-cut for scaling aerial photos. Northeastern Forest Expt. Sta. Paper 20.

2/ Wilson, R. C. 1949. The relief displacement factor in forest area estimates by dot templets on aerial photographs. Photogrammetric Eng. 15: 225-236.

3/ Aldrich, R. C. 1955. A method of plotting a dot grid on aerial photographs of mountainous terrain. Jour. Forestry 53: 910-913.

4/ Hartman, Fred J. 1947. A simplified method of locating sample plots on aerial photos. Northeastern Forest Expt. Sta. Note 3.

When photos are flown at a constant elevation above sea level, the use of uniform forward lap will place them closer together in high country. This occurs because objects closer to the camera photograph at a larger scale, and a given percentage of forward lap, therefore, represents less distance on the ground. Dots located in relation to photo centers will be somewhat closer together in the higher elevations. If forest types and conditions are consistently stratified by elevation, then this accumulation of samples in the higher areas could result in a significant bias. Conversely, the lack of consistent stratification, or a variation in the percentage of overlap could easily reduce this expected bias to nonsignificance. A practical test of the presence and significance of bias is therefore prerequisite to any suggestion for its cure.

OBJECTIVES

In general, we wanted to know if the data obtained by dot sampling directly on aerial photos were biased by the combination of elevation differences and forest patterns common to the Rocky Mountains. We also wanted to know if the location of sample dots at equal map intervals would result in significantly different data. And finally, would the assumed improvement in the data justify the additional cost incurred by precise map location of dot samples.

The study was designed to answer these specific questions:

1. Do the proportions obtained from dot samples located by simple templet on aerial photos differ significantly from those obtained when the dots are located at equal map intervals and transferred to the photos by radial plot?

2. Do the proportions obtained from samples at photo center vary significantly from those obtained from samples located throughout the photo?

3. Will the effect be different for specific cover types, such as ponderosa pine, Douglas-fir, alpine fir, alpine meadow; and for broad combinations such as all forest area, or all sawtimber area?

5. How do the costs of sampling directly on the photos compare with the costs of locating sampling points at equal map intervals and then transferring these to the photos for interpretation?

RESULTS

For the area and type of photos studied, analysis of variance shows:

1. For the most part, locating dot samples by templets oriented over photo centers does not result in proportions significantly different from those obtained when dots are located equidistant by map.

2. Proportions obtained from dots located 1 to 4 inches from photo center are not significantly different from those obtained from dots located at photo center.

3. Of the timber types tested, only lodgepole pine showed a significant difference between methods of sampling. Of the composite types, only pines and Douglas-fir (which included lodgepole) showed significant differences.

4. Neither stand height nor cubic volume indicated significant differences between sampling methods.

Comparisons of the two sampling methods were also made by "t"-test. The number of dot samples obtained for each photo templet position on each flight line were paired with the number obtained for the map positions on each flight line. The proportions determined from them and the ones which differed significantly are shown in the following tables:

Table 1.--Proportion of total dot sample by basic cover type and position on the aerial photo

Cover type	By map location	By photo location--inches from photo center				
		0	1	2	3	4
	Percent	Percent				
Ponderosa pine	18.3	26.0	18.5	17.5	16.0	15.8
Douglas-fir	14.0	15.0	15.7	16.5	19.5	14.5
Spruce	7.5	9.0	11.2	8.7	1/ 12.5	13.0
Alpine fir	16.5	11.0	14.8	15.5	17.0	17.7
Lodgepole pine	24.2	16.0	19.5	19.2	1/ 14.7	15.0
Brush-other forest	9.5	13.0	10.5	7.8	9.7	12.8
Barren	3.3	5.0	5.7	1/ 7.2	1/ 6.3	7.5
Alpine meadow	2.2	2.0	1.8	1.8	0.8	2.2
Other open area	4.5	3.0	2.3	5.8	3.5	1/ 1.5
Total	100.0	100.0	100.0	100.0	100.0	100.0

1/ Significantly different from the map proportion by "t"-test, 5 percent level.

Note: Proportions based on 400 dots except at "0" (photo center) which is based on 100 dots.

Of the 45 possible comparisons, 6 show significant differences between photo and map-located dot samples.

Combination of key types which could be expected to be stratified by elevation indicated significant differences in only 4 of 25 possibilities.

Table 2.--Proportion of total dot sample by composite types and position on the aerial photo

Cover type	By map location	By photo location--inches from photo center				
		0	1	2	3	4
	Percent	Percent				
All nonforest	10.0	10.0	9.8	1/ 14.8	10.6	11.2
All commercial species	80.5	77.0	79.7	77.4	79.7	76.0
Pines and Douglas-fir	56.5	57.0	53.7	53.2	50.2	1/ 45.3
High-altitude types 2/	29.5	27.0	33.5	33.2	36.6	40.4
All sawtimber	35.5	1/ 48.0	39.8	38.1	1/ 42.6	40.5

Percent totaled from table 1.

1/ Significantly different from the map proportion by "t"-test, 5 percent level.

2/ Spruce, alpine fir, alpine meadow, and barren.

Note: Proportions based on 400 dots except at photo center.

Photo measurements (table 3) were significantly different in only one case out of a possible ten.

Table 3.--Mean stand height and mean cubic volume of sawtimber stands by position on aerial photo

Item Compared	By map location	By photo location--inches from photo center				
		0	1	2	3	4
	Feet	Feet				
Mean stand height	74.7	73.1	73.3	75.7	76.8	77.4
	Cu. Ft.	Cubic feet				
Mean cubic volume	1,557	1,518	1,472	1,608	1,625	1/ 1,776

1/ Significantly different from map sample by "t"-test, 5 percent level.

Note: Averages based on 400 measurements except at photo center.

DISCUSSION OF RESULTS

These data represent a practical test of a theory. The photo strips selected sample the most abrupt elevation changes in an area typical of many forest areas in the Rockies. The base maps and the aerial photos used are better than average for the region. The methods and the quality of photo interpretation were equal to any used in this area. With this background, why were the anticipated differences in photo and map samples so seldom significant?

Let's examine this basic theory and determine, if we can, the limiting factors which control its operation. The reasoning follows these lines:

1. Aerial photos are in perspective, therefore, objects closer to the aerial camera will photograph larger.

2. If photos are taken with a standard percentage of overlap, and if the plane flies at a consistent elevation above sea level, their centers will plot closer together and they will be larger scale over mountainous areas.

3. Dot samples located according to photo center will also plot closer together, and will therefore be biased in favor of higher elevations.

4. Foresters have often found cover types, and timber volumes to be roughly stratified by elevation.

5. Therefore, dot sampling by simple templet directly on aerial photos of mountainous areas will result in biased data.

This is the theory: its operation depends upon two limiting factors:

1. How well the cover types are stratified by elevation.

2. How consistent is the proportion of overlap and the flying height of the plane.

How well are the types stratified?

Unfortunately, little basic information on this subject is available. Detailed topographic maps have been compiled for only a few of the quadrangles studied, and even here a pinpoint comparison of cover types and elevation is rarely possible. Generalized information contributes little to a study of this type. Obviously, some types such as alpine meadow occur at high elevations. Others, such as lodgepole pine, are found from the valleys to the timberline and are far more closely correlated with fire history than elevation. Spruce, normally found at high elevations, may be hundreds of feet lower on cool north slopes, while both ponderosa pine and Douglas-fir are found much higher on south slopes than on north ones. Since either slope has an equal chance of being sampled, this variation between slopes may greatly reduce the over all effect. The degree of stratification is therefore difficult to prove in this area, although some stratification by elevation must be considered probable.

How consistent is the overlap?

It is not always possible or necessary to prove the consistency of camera height and of overlap. The interest lies in how well the distance between photos correlates with mean elevation of the ground. As the height of the mountains increases, the distance between photo centers will decrease, providing flying height and forward lap are consistent.

Two photo strips, located in quadrangles with detailed topographic maps, were studied to determine the extent of this correlation. Figure 1 shows the map plots of the actual photo centers, and the idealized flight lines with equidistant photo centers directly above profiles of the ground photographed. Distance between photo centers was correlated with average ground elevation for the photo (fig. 2). The expected shortening of the air base over high country failed to appear. It seems doubtful that the slight correlation found (-.28) would create much bias in the data from these two photo strips.

These findings were checked by studying the entire 10 flight lines each of which was divided into 2 strips of 5 photos each. The length of each of these 20 strips was then measured and the mean elevation determined from a standard aeronautical chart with 1,000-foot contour interval. The mean air base from each strip was correlated with the mean elevation (fig. 3). Here again the extremely low correlation (-.08) offers the most logical explanation for the lack of significance between data from photo and map located samples.

If in practice the photo centers do not fall closer together over high country, then the chain of reasoning on which this theory depends is broken, and we have no reason to expect biased data dot from sampling on photos of mountainous areas.

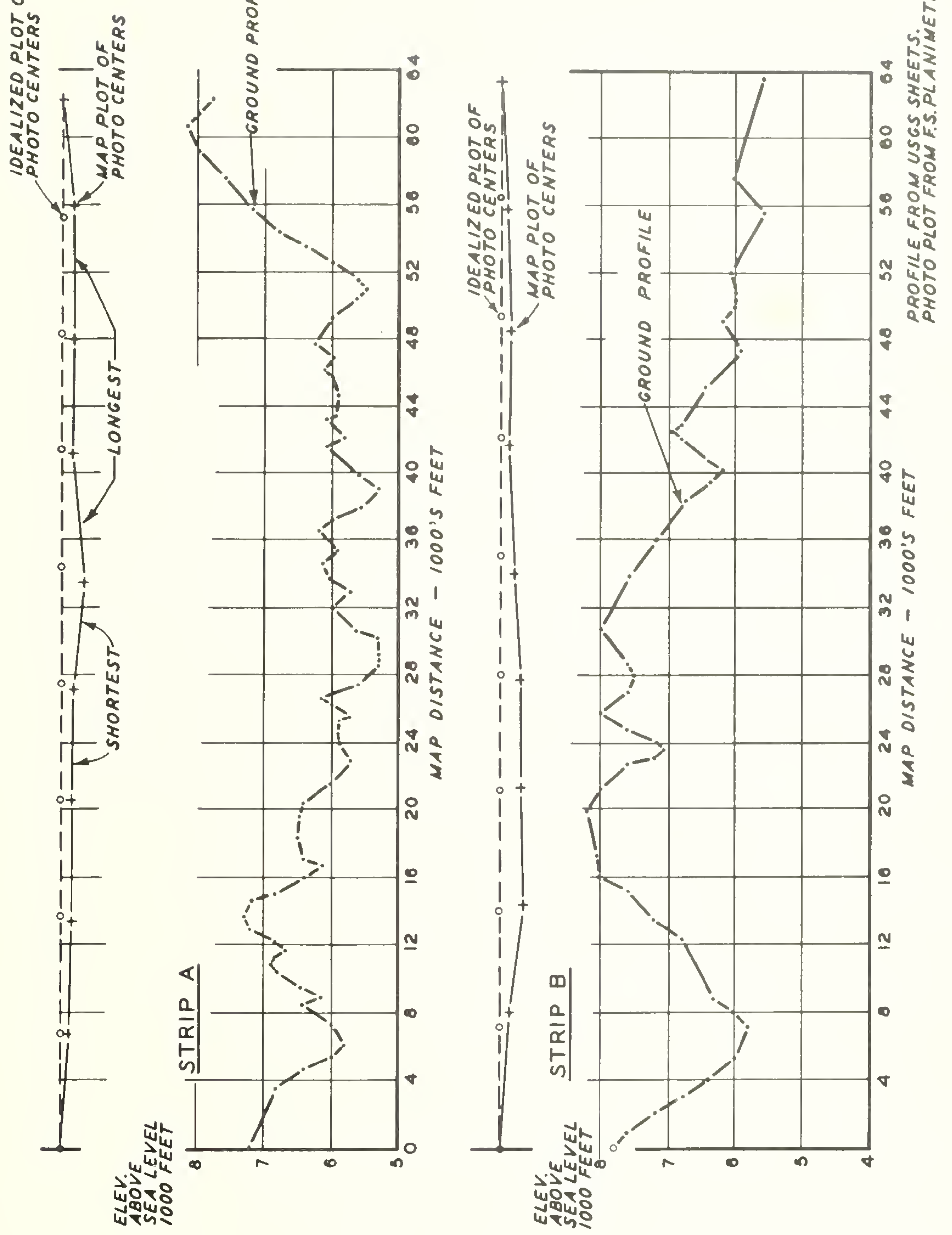

Figure 1.--Typical photo strips, showing map plot of photo centers, idealized flight line with equidistant centers and profile of ground photographed.

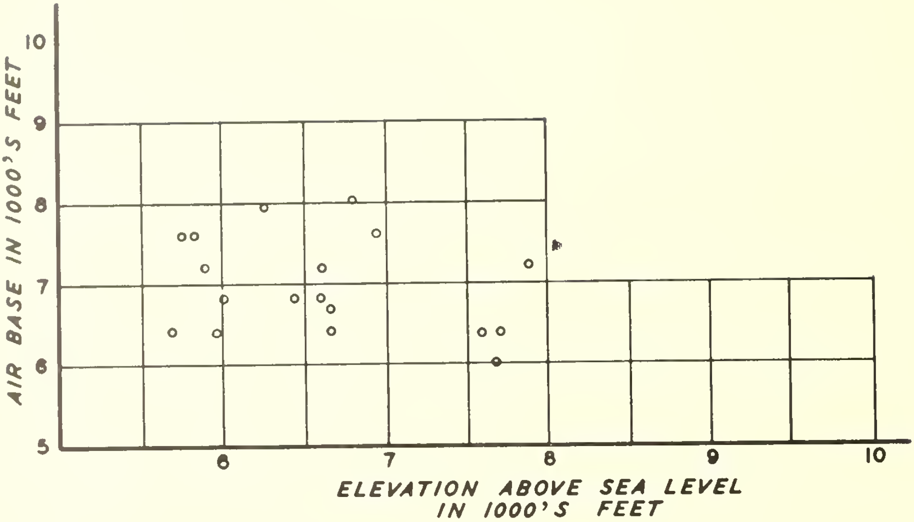

Figure 2.--The 18 samples from strips A and B show a correlation of -.28 between length of air base and elevation above sea level. Elevations obtained from USGS sheets and position from U. S. Forest Service planimetric maps.

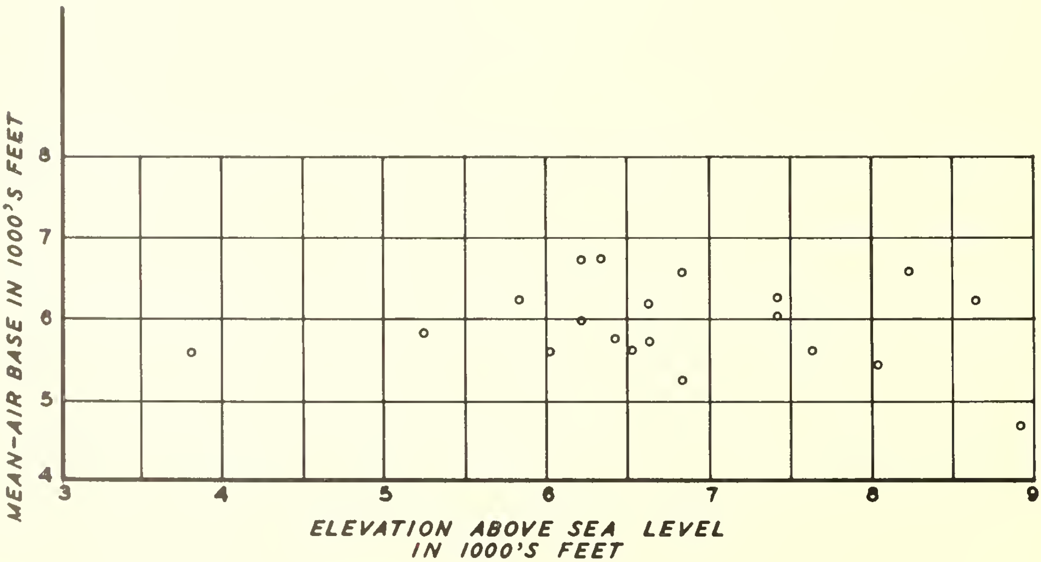

Figure 3.--The 20 samples of 5 photos each showed a correlation of -.08 between length of air base and elevation above sea level. Elevations obtained from Aeronautical Charts, positions from U. S. Forest Service planimetric maps.

When dot sampling on photos is used as a survey technique, the topography to be sampled should be studied carefully. Over high plateaus photo projects are laid out with datum planes which minimize the effect of elevation differences and indirectly the possible sampling bias. In areas like the one studied, deep narrow valleys and high sharp ridges follow one another in complete confusion. The best of photographic teams cannot get a consistent proportion of forward lap. Intervolometers are normally used, and setting changes when made seldom keep up with the rapidly changing ground elevation. The resulting variation in percent of overlap may well reduce the theoretical bias to insignificance.

How can we minimize the possibility of bias due to relief?

Numerous survey procedures have been recommended, most of which increase the cost of survey with little assurance of improving the data. Some of these are:

1. Delineating types over the entire area on photos and transferring these to good base maps by some form of stereo plotter before measurement. For small surveys covering but a few photos, this effort seems to be justifiable. In accuracy it should be comparable to the map location of all photo samples. For the type of area considered in this study, such precision could not be expected to greatly improve over all proportions. Unfortunately, the accuracy of this method hinges largely upon the procedure used to transfer type lines from photos to the map. If lines are transferred by reflecting projector or other nonstereo means, particularly if good base maps are not available, the final type maps are not likely to yield much more accurate data than the original photos. True, the few studies which have compared stereo and non-stereo plotting of forest types in this Region indicate no significant difference in proportions obtained from the final maps, but this probably indicates merely that sampling on the original photos would have resulted in equally valid proportions. In this study, at least, we can find no justification for mapping as a superior method of reducing error in forest types over mountainous areas.

2. Locate all dot samples on a map and transfer them to the photos by radial templet or radial line plotter. This might prove very expensive. In this study, the average cost of orienting the photo templet, interpreting and recording classification of 21 dots, and measuring those recorded as sawtimber was only 2.64 man-hours per 100 dots. When 4 dots per photo were located on a map and transferred by radial line plot, the cost of location alone was 7.65 man-hours per 100 dots. More efficient methods of transfer could reduce this cost difference, but at its best, this method will still be an expensive and inefficient one.

3. Scale ratio weighing procedure[3] consists of determining mean elevation of the entire sample and the mean elevation of the sample within each type. The type acreage (and possibly mean volume) is then adjusted by a factor based on the difference in scale. This method requires good topographic maps. For surveys over unmapped areas, or when many strata are used, this procedure is impractical and for the type of area studied, such a procedure would not be likely to result in improved data.

4. Concentrating the dots within 2 inches of photo center. All points within an aerial photo are considered to have equal opportunities to sample ground conditions. Since analysis of variance did not indicate significant difference between the photo center and other sampling points tested, for this area at least concentrating samples would have little beneficial effect.

THE PROCEDURE

This study compares data from dot samples located by simple photo templet with data obtained from samples located by map and then transferred to aerial photos by radial line plot.

Like comparisons could be made between areas delineated on photos and the same areas as shown on completed type maps. However, such comparisons would have inherent in them the errors introduced by the transfer of type lines and other mapping procedures, and would probably have less chance of showing significant differences than data from dot sampling.

Selection of Photos

Those portions of the Boise and Payette National Forests in southern Idaho which lie between 44° 15' and 45° 30' north and 115° 15' and 116° 15' west were selected for this study. This general area includes land typical of much of the Rocky Mountains, with elevations varying from 2,000 to 9,000 feet above sea level. Two inch to the mile planimetric maps carrying the plotted centers of the 1:20,000 scale resource photos were available for this area.

Ten of the 20 quadrangles within the area were selected at random. One flight line of 10 consecutive photos was selected from each of these 15-minute quadrangles. Insofar as possible, the selected strip of photos crossed the highest peaks and lowest valleys in the quadrangle. An additional photo was included at each end of the strip to give stereo coverage for the entire 10 photos.

3/ See footnote p. 2.

Location of the Dot Samples

The map samples were located first. The map locations of the centers of the first and tenth photos in each strip were connected by a straight line. This line was then subdivided into 9 equal parts, the resulting points being equivalent to the plotted centers of a strip of 10 equally spaced aerial photos. A 4-dot templet was oriented over each of the points in turn and the dots were pinpricked onto the base map. This gave a band of 40 dots spaced at equal map intervals within a strip covered by the original 10 photos.

Radial line plots were prepared on transparent film, connecting the dots with the map location of the original photo centers. These radial plots were then oriented over the proper aerial photos. When the photos were viewed in stereo the intersection of the radial lines marked the correct photo location of the mapped point. These intersections were pinpricked on the aerial photos. This map sample of 4 dots per photo, 400 dots in all, could thus be considered free from bias caused by topographic differences.

The photo samples were located at the time of photo interpretation by means of a transparent templet printed on photographic film (fig. 4). This templet consisted of 4 lines of 4 dots each at 1-inch intervals from photo center. Data from each of the 4 numbered groups could be paired with data from the previously located map samples. In addition, a single dot located over the principal point of the photo furnished a sample with one-fourth as many dots free from topographic displacement. This sample could be paired with those obtained from the numbered points as well as the map sample to study the effect of displacement within single photos.

Photo Interpretation

The templet was oriented over each photo in turn, and the interpreter classified the acre surrounding each dot while studying it stereoscopically. Stands classified as sawtimber were measured and their cubic volume per acre was estimated by means of these measurements and an aerial volume table.

The photo interpreter was able to study under stereo both the pinpricked map dots and the templet-located photo dots at one photo setup. Any technique errors in photo classification and in photo measurements would be consistent for both methods of dot location, and can therefore, be considered a nonsignificant factor in the study. Interpretations of cover types and size class were checked by reference to previously prepared stereograms and type maps of the area.

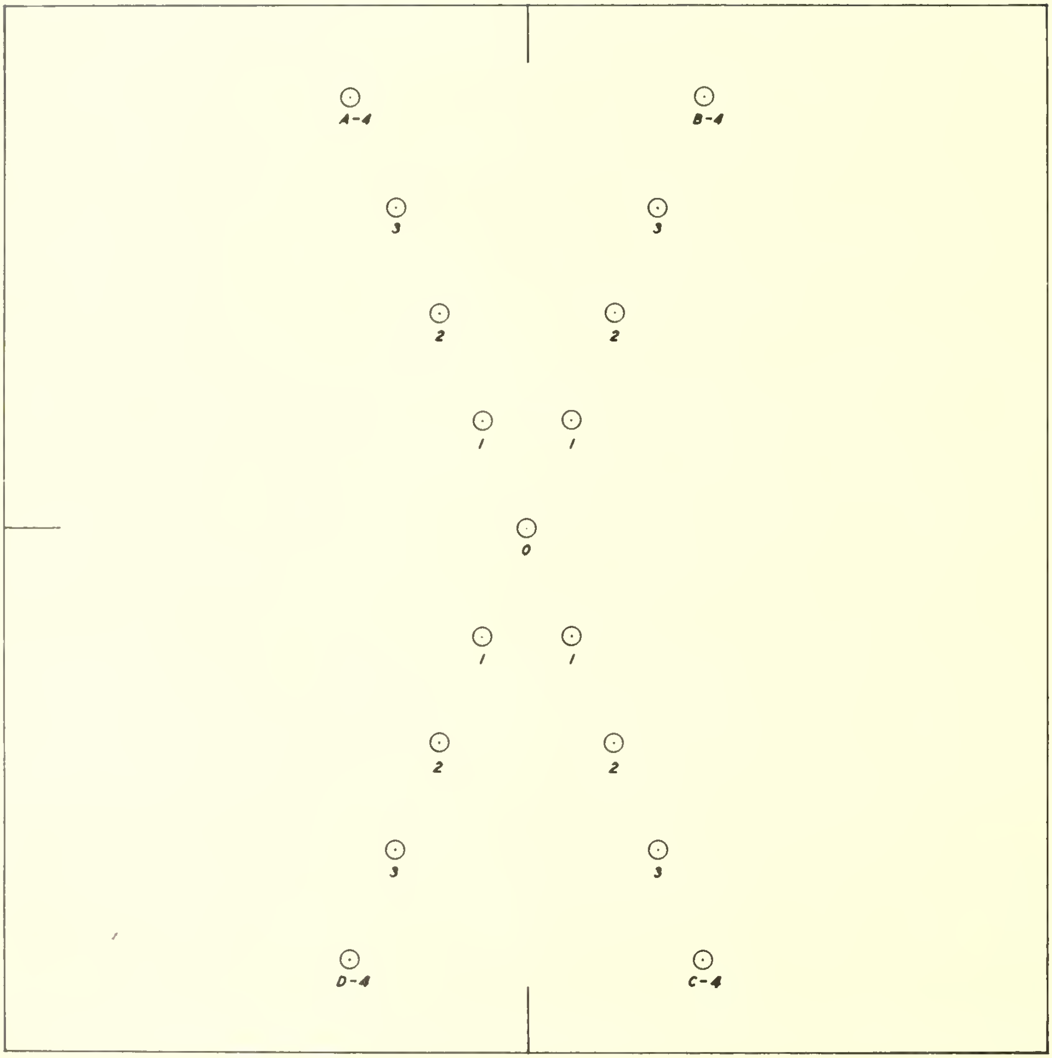

Figure 4.--The templet used on the aerial photos contained 17 dots arranged in 4 rows with a common dot at the center.

Classifications and other data for each plot were recorded individually on a tally form, one form for each of the 100 photos studied. Elapsed time to interpret all 21 dots was recorded for each aerial photo.

1. Cover types recognized were:

Forest types	Nonforest types
Ponderosa pine	Barren--rock and water
Douglas-fir	Alpine meadows
Spruce	Other open
Alpine fir	
Lodgepole pine	
Brush and other forest	

2. Stand-size classes recognized were:

   Sawtimber
   Other size classes

3. Measurements made on all sawtimber stands were:

   Mean height dominant stand--this measurement was made by parallax wedge.

   Mean crown diameter of dominant stand--this measurement was made by dot type crown wedge.

   Crown coverage--this measurement was made by comparison with a crown density scale.

   Cubic volume per acre--this estimate was made from an aerial volume table using the above photo measurements.

Computation of the Data

Data were summarized by photo and flight line and proportions were determined for each classification by flight line, and for the entire study. Analysis of variance was run for each classification recognized. The number of dots tallied at each templet position for each of 10 flight lines was used in this analysis. The dots for the map position were then paired with each of the 5 photo positions in turn and "t"-tests were made using the 10 flight lines.

In addition to these tests for individual classifications, like tests were made for broad groupings such as high altitude types and for mean measurements and photo volumes of sawtimber stands.

Correlations were then determined between elevations and distances between photo centers as plotted on available topographic maps.

Conclusions

For the area and type of photos studied, we conclude that:

1. The proportions obtained from dots located by photo center do not differ significantly from those obtained when dots are located by map.

2. Effects are comparable for cover types, stand-size class, and photo measurements.

3. Type stratification by elevation seemed to have little effect. Types occurring through a wide range of elevation showed occasional significant differences by "t"-test. Others generally considered to be well stratified by elevation showed no significant differences.

4. Proportions from dots located at photo center did not differ significantly from those from dots located throughout the photo.

5. Correlation between ground elevation and distance between photo centers was very low. This lack of significant correlation offers the best explanation for lack of significant sampling bias.

6. From these data, it seems unlikely that any of the commonly suggested methods of purifying dot sampling data, would prove necessary or worthwhile, in areas similar to the one tested.

A PROCEDURE FOR CONVERTING CONVENTIONAL TREE VOLUME TABLES (CUBIC) TO FORMULAE (PART 1)[1/]

Paul D. Kemp
Division of Forest Economics

The derivation of tree volume by formula facilitates volume computations, particularly when the formulae are adapted to automatic machine operations, and sharpens both volume and growth calculations. The conventional table with volumes by 1- or 2-inch diameter classes and 5- or 10-foot height classes is designed for deriving volume for a mass of approximate tree dimensions, i.e., numerous enough to give some assurance that discrepancies associated with grouping are compensating. But the trend, as in Forest Survey work and in other activities, is toward small carefully measured samples. The need, therefore, is for an expression of volume in a form adapted to diameter measurements to tenths of inches and height to feet. Conventional tables of such detail can be set up, but formula expressions of volume are more efficient.

TOTAL CUBIC FOOT VOLUME

Because trees are irregular solids there can be no perfect tree volume formulae such as have been derived for the calculation of the volume of regular geometric solids, e.g., the rectangle, cone, or sphere. Hence accurate tree volume determinations ordinarily can be made only for felled trees that permit diameter measurement and computation by small sections closely resembling regular solids. But for standing trees only one, or at best, several diameter measurements or approximations are practical. Furthermore, and again for practical reasons, diameters of standing trees ordinarily are measured outside bark for the determination of volume inside bark.

Of the many possible choices of formulae, tests indicated that, all things considered, the best total cubic volume formula for Rocky Mountain species is of the form $V = bX$ in which the regression coefficient "b" is varied by diameter class but assumed constant within diameter class. The "X" term is the product of D^2 (diameter in inches)^2 and H (total height in feet). To avoid blank decimal places in "b" the "X" terms are divided by 100 and the formula becomes $V = b(D^2H/100)$.

1/ This report is presented in two parts. The first part covers only the mechanics and pertinent information required to illustrate and understand the procedure; the second part deals with the development and more detailed discussion of the method.

Converting conventional cubic volume tables to formulae therefore, merely involves the determination of appropriate regression coefficients. A portion of table 35 from Haig's western white pine yield study[2] is used as an example in illustrating this procedure.

1. Set up a format as indicated in table 1. Columns 3 and 5 are merely the sum of table volumes and table heights. Calculate the average regression coefficients for each diameter class as entered in column 8.

2. Plot the average regression coefficients over diameter on ordinary cross section paper using a vertical scale that can be read three places and a horizontal scale to .1 inch. See upper portion of chart 1.

3. Fit a smooth curve to the plotted points. Read curved regression coefficients and enter as in column 9, table 1.

4. Check against tabular data by comparing the products of entries in column 9 and appropriate entries in column 7 with sums of volumes in column 3. Revise curve and coefficients as required until satisfactory correlation is obtained. For a table well harmonized between diameter classes the deviation will be within 1 percent for any diameter class. Greater differences generally indicate a poorly harmonized basic table.

5. Derive detailed regression coefficients as required by .1-inch diameter classes.

A further check against the individual items of the base table can be made by multiplying the appropriate regression coefficients by the entries in the table of $D^2H/100$.

Volumes calculated by formula will check closely with entries in base tables having straight line relationships within diameter class, i.e., volume proportioned to height. Western white pine volumes by base tables are curvilinear within diameter class, hence calculated volumes will be higher than base table volumes for tall trees and lower for short trees.

2/ Haig, I. T. 1932. Second-growth yield, stand, and volume tables for the western white pine type. U. S. Dept. Tech. Bull. 323.

Some cubic volume tables, as for example table 3 of Gevorkiantz and Olsen3/, are based on a uniform form factor--approximately .420. In other words, the regression coefficient of total cubic volume on $D^2H/100$ is the same for the entire table and can be derived by multiplying the average form factor by the constant .5454154. The average coefficient is therefore, .5454154(.420) = .229.

The relationship between form factor and regression coefficient of cubic volume on $D^2H/100$ is derived as follows:

$$\text{Stem form factor}^{4/} = \frac{\text{tree volume}}{\text{cylinder volume}}$$

$$\text{Tree volume} = b(D^2H/100)$$

$$\text{Cylinder volume} = .5454154(D^2H/100)$$

$$\text{Form factor} = \frac{b}{.5454154} \text{ or } b = .5454154 \text{ (form factor)}$$

$$\text{and form factor} = b(1.833346)$$

Hence, cubic volume can be derived by the use of either a regression coefficient on $D^2H/100$ or a form factor; however there are definite advantages in the use of the former, particularly in machine operations.

PARTIAL CUBIC FOOT VOLUME

The regression coefficients derived in the manner explained above and entered in column 9 of the table are for total cubic volume from ground to tip. Usually a discounted volume determination is desired as for Forest Survey estimates which include only cubic volume between a 1-foot stump and 4-inch (i.b.) top. Such volumes are commonly referred to as partial or merchantable cubic volumes.

Since the bark thickness factors for the major Rocky Mountain species have been determined, the regression of d.i.b. on d.o.b. provides a means of determining the zero point of the curve of merchantable volume factors over diameter if it is assumed that a bolt 4 inches inside bark diameter and 3½ feet long has zero merchantable volume.

3/ Gevorkiantz, S. R., and Olsen, L. P. 1955. Composite volume tables for timber and their application in the Lake States. U. S. Dept. Agr. Tech. Bull. 1104.

4/ There are several possible form factor variations. In this case it is the relationship between total stem volume inside bark and the volume of a cylinder of tree diameter outside bark (d.b.h.) and total tree height.

For example, the relation of diameter inside bark and diameter outside bark at breast height for western white pine is expressed by the formula .964X - .106, X being the diameter breast height. Hence, the inside bark diameter at breast height of a 5.0-inch tree is 5(.964) - .106, or 4.71 inches. The d.b.h. of a white pine tree that is just 4.0 inches inside bark at breast height can be computed from the same formula .964X - .106 = 4.0, or X = 4.26 inches.

From a curve (chart 1) set at zero percent merchantable volume for a 4.26-inch white pine tree and drawn through plotted merchantability factors shown in column 11 were derived. The products of items in columns 9 and 11 are the regression coefficients of partial cubic volume shown in column 10.

The ratio of partial or merchantable cubic volume and total cubic volume varies by tree height within diameter class. This ratio is generally somewhat higher for tall trees than short ones. Hence, the use of an average relationship tends to underestimate the merchantable cubic volume of tall trees and overestimate short trees. This bias is at least partially counteracted by the fact that, as previously stated, total cubic volume calculated as prescribed, i.e., an average regression coefficient by diameter class and $D^2H/100$ tends to overestimate the volume of tall trees and underestimate the volume of short trees.

Table 1.--Calculation of average regression coefficients of total cubic volume on $D^2H/100$--western white pine

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Diameter breast height	D^2	V	Height range	H	$\frac{H}{100}$	$D^2(\frac{H}{100})$	$V/D^2(\frac{H}{100})$	Regression coefficients of cubic volume on $D^2H/100$		Ratio partial to total
		Cu. ft.	Feet	Feet				Total	Partial	
4.0	16	13.9	20- 80	350	3.5	56.0	.249	.251	.000	-
5.0	25	21.7	20- 80	350	3.5	87.5	.248	.248	.079	.319
6.0	36	45.7	30-100	520	5.2	187.2	.244	.245	.158	.645
7.0	49	88.0	30-120	750	7.5	367.5	.239	.242	.190	.785
8.0	64	135.0	30-130	880	8.8	563.2	.240	.239	.207	.865
9.0	81	191.0	40-140	990	9.9	801.9	.238	.236	.215	.911
10.0	100	232.0	40-140	990	9.9	990.0	.234	.233	.219	.940
11.0	121	252.0	60-140	900	9.0	1,089.0	.231	.230	.220	.956
12.0	144	348.0	60-150	1,050	10.5	1,512.0	.230	.228	.219	.960
13.0	169	403.0	60-150	1,050	10.5	1,774.5	.227	.225	.217	.964
14.0	196	500.0	70-160	1,150	11.5	2,254.0	.222	.222	.215	.967
15.0	225	533.0	80-160	1,080	10.8	2,430.0	.219	.219	.212	.968
16.0	256	536.0	90-160	1,000	10.0	2,560.0	.217	.216	.210	.972
17.0	289	619.0	90-160	1,000	10.0	2,890.0	.214	.214	.208	.972
18.0	324	686.0	90-160	1,000	10.0	3,240.0	.212	.211	.206	.976
19.0	361	874.0	90-170	1,170	11.7	4,223.7	.207	.208	.203	.977
20.0	400	883.0	100-170	1,080	10.8	4,320.0	.204	.205	.200	.977

Table of $D^2H/100$

Total height classes (H)

10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230
1.6	3.2	4.8	6.4	8.0	9.6	11.2	12.8															
2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5														
3.6	7.2	10.8	14.4	18.0	21.6	25.2	28.8	32.4	36.0													
4.9	9.8	14.7	19.6	24.5	29.4	34.3	39.2	44.1	49.0	53.9	58.8											
6.4	12.8	19.2	25.6	32.0	38.4	44.8	51.2	57.6	64.0	70.4	76.8	83.2										
8.1	16.2	24.3	32.4	40.5	48.6	56.7	64.8	72.9	81.0	89.1	97.2	105.3										
10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	130.0	140.0									
12.1	24.2	36.3	48.4	60.5	72.6	84.7	96.8	108.9	121.0	133.1	145.2	157.3	169.4	181.5								
14.4	28.8	43.2	57.6	72.0	86.4	100.8	115.2	129.6	144.0	158.4	172.8	187.2	201.6	216.0	230.4							
	33.8	50.7	67.6	84.5	101.4	118.3	135.2	152.1	169.0	185.9	202.8	219.7	236.6	253.5	270.4	287.3						
	39.2	58.8	78.4	98.0	117.6	137.2	156.8	176.4	196.0	215.6	235.2	254.8	274.4	294.0	313.6	333.2	352.8					
	45.0	67.5	90.0	112.5	135.0	157.5	180.0	202.5	225.0	247.5	270.0	292.5	315.0	337.5	360.0	382.5	405.0	427.5				
	51.2	76.8	102.4	128.0	153.6	179.2	204.8	230.4	256.0	281.6	307.2	332.8	358.4	384.0	409.6	435.2	460.8	486.4	512.0			
	57.8	86.7	115.6	144.5	173.4	202.3	231.2	260.1	289.0	317.9	346.8	375.7	404.6	433.5	462.4	491.3	520.2	549.1	578.0	606.9		
	64.8	97.2	129.6	162.0	194.4	226.8	259.2	291.6	324.0	356.4	388.8	421.2	453.6	486.0	518.4	550.8	583.2	615.6	648.0	680.4	712.8	
	72.2	108.3	144.4	180.5	216.6	252.7	288.8	324.9	361.0	397.1	433.2	469.3	505.4	541.5	577.6	613.7	649.8	685.9	722.0	758.1	794.2	
	80.0	120.0	160.0	200.0	240.0	280.0	320.0	360.0	400.0	440.0	480.0	520.0	560.0	600.0	640.0	680.0	720.0	760.0	800.0	840.0	880.0	
		132.3	176.4	220.5	264.6	308.7	352.8	396.9	441.0	485.1	529.2	573.3	617.4	661.5	705.6	749.7	793.8	837.9	882.0	926.1	970.2	
		145.2	193.6	242.0	290.4	338.8	387.2	435.6	484.0	532.4	580.8	629.2	677.6	726.0	774.4	822.8	871.2	919.6	968.0	1016.4	1064.8	
		158.7	211.6	264.5	317.4	370.3	423.2	476.1	529.0	581.9	634.8	687.7	740.6	793.5	846.4	899.3	952.2	1005.1	1058.0	1110.9	1163.8	
		172.8	230.4	288.0	345.6	403.2	460.8	518.4	576.0	633.6	691.2	748.8	806.4	864.0	921.6	979.2	1036.8	1094.4	1152.0	1209.6	1267.2	
		187.5	250.0	312.5	375.0	437.5	500.0	562.5	625.0	687.5	750.0	812.5	875.0	937.5	1000.0	1062.5	1125.0	1187.5	1250.0	1312.5	1375.0	
		202.8	270.4	338.0	405.6	473.2	540.8	608.4	676.0	743.6	811.2	878.8	946.4	1014.0	1081.6	1149.2	1216.8	1284.4	1352.0	1419.6	1487.2	
		218.7	291.6	364.5	437.4	510.3	583.2	656.1	729.0	801.9	874.8	947.7	1020.6	1093.5	1166.4	1239.3	1312.2	1385.1	1458.0	1530.9	1603.8	
		235.2	313.6	392.0	470.4	548.8	627.2	705.6	784.0	862.4	940.8	1019.2	1097.6	1176.0	1254.4	1332.8	1411.2	1489.6	1568.0	1646.4	1724.8	
		252.3	336.4	420.5	504.6	588.7	672.8	756.9	841.0	925.1	1009.2	1093.3	1177.4	1261.5	1345.6	1429.7	1513.8	[illegible]	1682.0	1766.1	1850.2	
		270.0	360.0	450.0	540.0	630.0	720.0	810.0	900.0	990.0	1080.0	1170.0	1260.0	1350.0	1440.0	1530.0	1620.0	1710.0	1800.0	1890.0	1980.0	
			384.4	480.5	576.6	672.7	768.8	864.9	961.0	1057.1	1153.2	1249.3	1345.4	1441.5	1537.6	1633.7	1729.8	1825.9	1922.0	2018.1	2114.2	
			409.6	512.0	614.4	716.8	819.2	921.6	1024.0	1126.4	1228.8	1331.2	1433.6	1536.0	1638.4	1740.8	1843.2	1945.6	2048.0	2150.4	2252.8	
			435.6	544.5	653.4	762.3	871.2	980.1	1089.0	1197.9	1306.8	1415.7	1524.6	1633.5	1742.4	1851.3	1960.2	2069.1	2178.0	2286.9	2395.8	
			462.4	578.0	693.6	809.2	924.8	1040.4	1156.0	1271.6	1387.2	1502.8	1618.4	1734.0	1849.6	1965.2	2080.8	2196.4	2312.0	2427.6	2543.2	
			490.0	612.5	735.0	857.5	980.0	1102.5	1225.0	1347.5	1470.0	1592.5	1715.0	1837.5	1960.0	2082.5	2205.0	2327.5	2450.0	2572.5	2695.0	
			518.4	648.0	777.6	907.2	1036.8	1166.4	1296.0	1425.6	1555.2	1684.8	1814.4	1944.0	2073.6	2203.2	2332.8	2462.4	[illegible]	2721.6	2851.2	
			547.6	684.5	821.4	958.3	1095.2	1232.1	1369.0	1505.9	1642.8	1779.7	1916.6	2053.5	2190.4	2327.3	2464.2	2601.1	2738.0	2874.9	3011.8	
			577.6	722.0	866.4	1010.8	1155.2	1299.6	1444.0	1588.4	1732.8	1877.2	2021.6	2166.0	2310.4	2454.8	2599.2	2743.6	2888.0	3032.4	3176.8	
			608.4	760.5	912.6	1064.7	1216.8	1368.9	1521.0	1673.1	1825.2	1977.3	2129.4	2281.5	2433.6	2585.7	2737.8	2889.9	3042.0	3194.1	3346.2	
			640.0	800.0	960.0	1120.0	1280.0	1440.0	1600.0	1760.0	1920.0	2080.0	2240.0	2400.0	2560.0	2720.0	2880.0	3040.0	3200.0	3360.0	3520.0	
			672.4	840.5	1008.6	1176.7	1344.8	1512.9	1681.0	1849.1	2017.2	2185.3	2353.4	2521.5	2689.6	2857.7	3025.8	3193.9	3362.0	3530.1	3698.2	
			705.6	882.0	1058.4	1234.8	1411.2	1587.6	1764.0	1940.4	2116.8	2293.2	2469.6	2646.0	2822.4	2998.8	3175.2	3351.6	3528.0	3704.4	3880.8	
			739.6	924.5	1109.4	1294.3	1479.2	1664.1	1849.0	2033.9	2218.8	2403.7	2588.6	2773.5	2958.4	3143.3	3328.2	3513.1	3698.0	3882.9	4067.8	
			774.4	968.0	1161.6	1355.2	1548.8	1742.4	1936.0	2129.6	2323.2	2516.8	2710.4	2904.0	3097.6	3291.2	3484.8	3678.4	3872.0	4065.6	4259.2	
			810.0	1012.5	1215.0	1417.5	1620.0	1822.5	2025.0	2227.5	2430.0	2632.5	2835.0	3037.5	3240.0	3442.5	3645.0	3847.5	4050.0	4252.5	4455.0	
			846.4	1058.0	1269.6	1481.2	1692.8	1904.4	2116.0	2327.6	2539.2	2750.8	2962.4	3174.0	3385.6	3597.2	3808.8	4020.4	4232.0	4443.6	4655.2	
			883.6	1104.5	1325.4	1546.3	1767.2	1988.1	2209.0	2429.9	2650.8	2871.7	3092.6	3313.5	3534.4	3755.3	3976.2	4197.1	4418.0	4638.9	4859.8	
			921.6	1152.0	1382.4	1612.8	1843.2	2073.6	2304.0	2534.4	2764.8	2995.2	3225.6	3456.0	3686.4	3916.8	4147.2	4377.6	4608.0	4838.4	5068.8	
			960.4	1200.5	1440.6	1680.7	1920.8	2160.9	2401.0	2641.1	2881.2	3121.3	3361.4	3601.5	3841.6	4081.7	4321.8	4561.9	4802.0	5042.1	5282.2	
			1000.0	1250.0	1500.0	1750.0	2000.0	2250.0	2500.0	2750.0	3000.0	3250.0	3500.0	3750.0	4000.0	4250.0	4500.0	4750.0	5000.0	5250.0	5500.0	

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April 1957

INDUSTRIAL OPPORTUNITIES IN THE HEADWATERS TIMBER DEVELOPMENT UNIT

by S. Blair Hutchison

and John H. Wikstrom

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
United States Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

FOREWORD

The Headwaters Timber Development Unit is an odd-shaped area in southeastern Idaho, western Wyoming, and Northern Utah (figure 1). It includes all of the commercial quality timber land west of the Continental Divide in Wyoming. It takes in the northern edge of Utah which slopes into Wyoming from the Uinta and Wasatch Mountains, plus most of the forests in southeastern Idaho. All or part of nine national forests lie within the Unit. They are the Teton, Bridger, Targhee, Wasatch, Ashley, Caribou, Sawtooth, Salmon, and Challis.

The name "Headwaters" was chosen because the area lies in the upper reaches of three of the four major drainage basins west of the Continental Divide in the United States. The Bear River which drains into Great Salt Lake, the Green River which is a major tributary of the Colorado, and the Snake and Salmon River branches of the Columbia all rise within the Headwaters Unit.

The Headwaters Timber Development Unit is awakening from a period of industrial dormancy as far as the forests are concerned. To take advantage of the opportunities which appear to be knocking, the administrative branch of the Forest Service asked the Intermountain Forest and Range Experiment Station to make this study of the timber industry. Although the two forest economists listed as authors have done the principal work in this study, many people, both in and out of the Forest Service, have contributed information and counsel. The Division of Timber Management of the Forest Service in Ogden and the nine national forests have been particularly helpful.

One of the more important contributions of this study has been an appraisal of the water resources of western Wyoming and southern Idaho from the standpoint of the suitability of the streams for pulpmills. This excellent work was done by John Wiseman of the Robert A. Taft Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio. Wiseman's analysis is reported in detail in another publication referred to in this report.

C. J. OLSEN -- Regional Forester
U. S. Forest Service
Region 4

REED W. BAILEY -- Director,
Intermountain Forest and
Range Experiment Station

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(Illustrations drafted by Paul S. Bieler)

FOREST LAND AREA IN THE HEADWATERS TIMBER DEVELOPMENT UNIT

FIG. 1

INTRODUCTION

The Headwaters Timber Development Unit is outlined in the preceding map. The Unit is roughly the size of Pennsylvania and the forest alone occupies as much area as the State of New Jersey. There are 4.9 million acres of commercial forest in the Headwaters Unit. No accurate tally of the timber volume is available but the present sawtimber inventory is in the neighborhood of 24 billion board feet.

WE ARE STILL
PIONEERING 90
YEARS AFTER THE
FIRST LOGGING

Loggers have been cutting away at the forest here for at least 90 years, so this can hardly be called virgin territory. However, there are few if any large areas in the 48 states where some use has not been made of the timber. The Headwaters Unit does have the distinction of being one of the larger forest blocks not being utilized to full capacity. Even though the axe first rang in these woods many years ago, we are today starting almost from scratch in attempting to develop the timber product industries.

The story of logging in the Headwaters Unit during the early years has all but been forgotten. A few dabs of information are available here and there but like the remaining remnants of the logging communities which have come and gone, they leave much unsaid. Some of the additional facts necessary to make a coherent story have already been lost. Others remain only in the memories of old-timers and this information likewise will be lost unless someone soon attempts to put the pieces together.

We do know this: Utilization of local timber by the pioneers was so small as to be unimportant now except as a matter of historical interest. However, with the coming of the railroad in 1868, the tempo quickened. As the rails pushed into the wilderness at the rate of 2 miles a day, sawmills and the tie hacks moved west with the "gandy dancers." It probably took more than 300,000 ties to build the first track across the Headwaters Unit. Many of these ties and the ties required for replacements in the next few years were produced locally. How many we do not know. However, the evidence indicates that tie production in those days was an important enterprise.

Between 1872 and 1875, a 36-mile wooden flume, locally labeled "Sloan's Folly," was built in the mountains south of Evanston, Wyoming, to bring out timber products. Millions of board feet of sawlogs, hewed ties and charcoal wood were floated out of the hills in this flume and

Figure 2.--Relics of a vanished industry. These are remains of charcoal kilns apparently operated in the 1870's and 1880's at Hilliard, Wyoming. For some reason the industry faded away. One speculation is that the availability of coke for industrial purposes killed the charcoal business.

in the rivers. Elsewhere, logs were brought down by wagon and sleigh. A long-since-vanished logging town of 500, built along the flume, is one of several which blossomed for a short time and then faded away.

At one time, Evanston, Wyoming had 12 beehive-type charcoal kilns, Hilliard had 36 and there were others in nearby communities (figure 2). Information about these kilns is skimpy but apparently all or most of the charcoal went to copper smelters in the West. We are told there was once a small smelter at Hilliard that used some of the charcoal. In any case, this forest industry faded away after a time, for one reason or another. All that remains today is the abandoned kilns.

One historian tells us that in 1883 there were 30 or so little sawmills in southeast Idaho running about 8 months out of the year and cutting an average of 8 thousand board feet of lumber a day when they operated. These and a few sawmills in Wyoming supplied most of the lumber for local mines, homesteads, and communities.

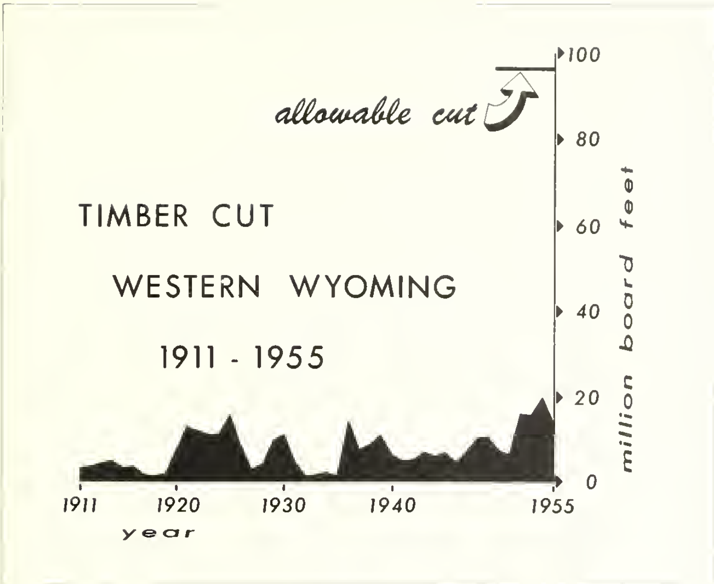

FIG 3

Skipping over several decades to the 1920's, we come to the next surge of timber development. Tie cutters moved in droves into the Bridger and Targhee National Forests and hewed hundreds of thousands of railroad ties. However, the depression and technological progress cut this boom short. The cheaper and more easily treated sawed tie began to crowd out the hewed tie and with it the picturesque "tie hack." In recent years, sawed ties have been produced locally by the portable sawmills but the tie market has been dominated by West Coast sawmills.

The story of the first nine decades can be summaried in a few words: During early years of settlement and development, local timber was largely relied upon to supply local needs. However, the charcoal and hewed tie markets became victims of progress. Improvements in transportation, which made industrial expansion possible in the first place, also brought in competing wood. As a consequence, the timber industry has never grown out of its swaddling clothes. Up to now, it has consisted mainly of small operators living off the fringes of the timber market.

Early timber-cut data are about as incomplete and fragmentary as the rest of our historical information. However, the essentials of the story are told in figure 3 which shows the trend of sawtimber cut in western Wyoming from 1911 to 1955. The cut has fluctuated with the passing years but even the "high years" have fallen far short of the production the forest could sustain.

The point to be underlined is that the heaviest cutting to date in the Headwaters Unit is still far short of the capacity of the forest to produce wood. In 1955, approximately 55 million board feet of timber were cut in the Unit which is less than one-fourth of the minimum "allowable cut" feasible at this time. Figure 4, on the following page, compares the 1955 sawtimber cut in the Headwaters Unit with the current allowable cut.

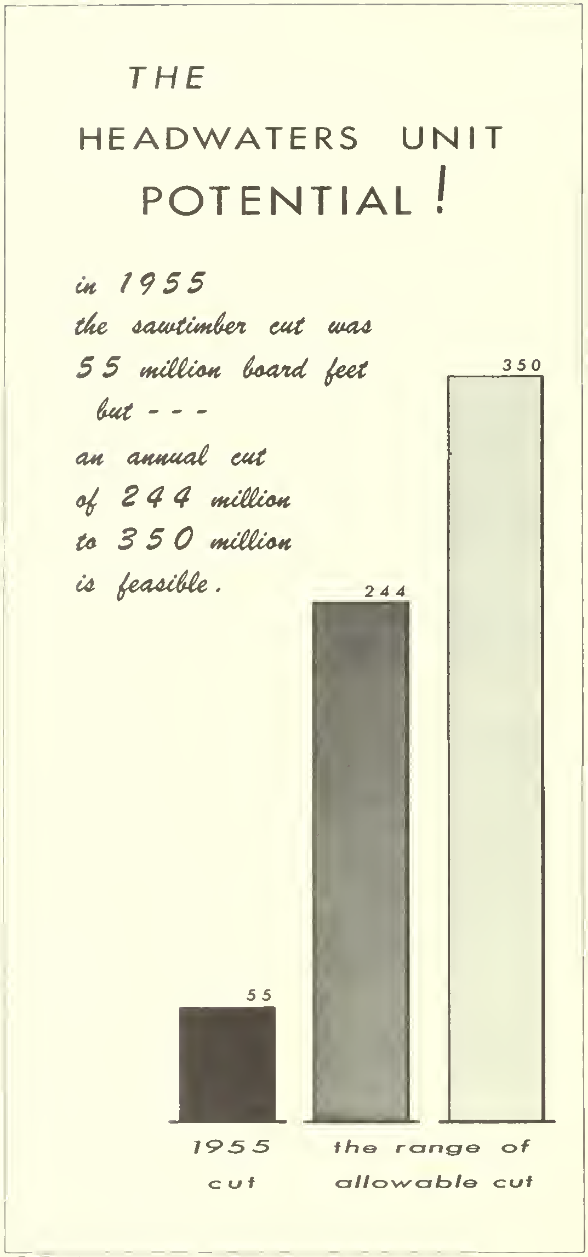

FIG. 4

HOW BIG IS THE OPPORTUNITY?

There are a number of reasons to suppose we are coming to the end of an era. Although the timber cut today is still relatively low, it is nevertheless higher than in former years. Because of declining supplies on the West Coast, the western lumber industry is searching elsewhere for timber. Barring a severe and prolonged economic recession, there should be substantial expansion of the timber cut in the Headwaters Unit during the next few years. The purpose of this report, therefore, is to review the local timber situation from the vantage point of 90 years' experience, to take stock of our assets, and to consider what general course of action might provide the greatest benefits in the long run.

In this analysis of the situation, there are six general questions to be considered:

- How much timber is there?
- What type of industrial development will the timber support?
- What type of industrial development appears most desirable?
- How much of the timber resource can be utilized economically?
- What can the timber resource contribute to the economy of the area
- What type of program will result in the best use of the timber resource?

IMPORTANCE OF THE FORESTS

THE NATION WILL NEED THE TIMBER IN THE HEADWATERS UNIT

Conscious as everybody is of 90 years or so of limited success in marketing timber from this area, we are more likely to underestimate than to overestimate the importance of the Headwaters Unit as a source of wood. Most of the 4.9 million acres here grow softwood. This timber is probably going to be in shorter supply than the hardwoods, thus, there should be a market for most of the wood we grow here. The present minimum allowable cut in the Unit is about 1 percent of the total softwood sawtimber growth in the United States. In the long run, when the forests of the Nation are all producing moderately well, it is to be expected that between one-half of 1 percent and 1 percent of the Nation's softwood growth will occur in the Headwaters Unit.

Like the rest of the Rocky Mountain States, the Headwaters Timber Development Unit has always been long on timber and short on markets. The primary reason for present optimism that this situation will change is the prospect that the Nation is going to continue to grow. A strong birth rate is increasing the population of the United States literally by leaps and bounds. It seems reasonable to suppose the number of people in the country may climb from the mid-1956 figure of 167 million to 275 million or more by the end of the century. The Forest Service has estimated that to supply the needs of a greatly expanded population the Nation should plan to grow between 79 and 105 billion board feet of timber annually.1/ (The 1952 sawtimber cut was 49 billion board feet.)

These long-range national needs should be looked at in the light of the fact that the total timber growing capacity in the United States is limited. In the second place, it will not be easy to get all owners to manage their lands as well as they should and in the third place, the East faces the long overdue task of building up its growing stock or forest capital, which will require some restrictions on the amount cut. When all angles are considered, it is hard to conceive that even the lower level of needs (79 billion board feet) can be met by the year 2000 without dipping deeply into the now lightly used timber stands of the Rocky Mountains.

There would appear to be six specific reasons for optimism:

1/ "Timber Resource Review," U. S. Dept. of Agriculture, Forest Service, 1955. (Preliminary draft.)

- The United States does not have enough forest land that it can supply anticipated future wood needs without utilizing all or nearly all of the forest in the country.

- The forests of other regions have not kept up with timber product demands of recent years.

- Changing population patterns are bringing the markets closer to the Rocky Mountain timber, thereby reducing the competitive handicap.

- Liquidation of the virgin timber on the West Coast is lessening the once oppressive competitive pressure from that area.

- The Nation probably faces a particular shortage of soft-textured woods of which the Rocky Mountains have several important species.

- Recent experience with Engelmann spruce shows that with proper promotion the less-used Rocky Mountain species can become best-sellers overnight.

This encouraging picture points to a new opportunity for timber industry development in the Headwaters Unit. It also indicates that the timber in this unit, not much needed in the past, will become increasingly important to the Nation as the years go by.

THE TIMBER HERE CAN
BE A BIG HELP TO
LOCAL COMMUNITIES

Although the Headwaters Unit is the size of Pennsylvania, it has about the same population as Erie, that state's third largest city. In 1950 there were approximately 140,000 people in the Headwaters Unit --3 per square mile. At that time the labor force in the Unit was 50,000 people, so even a moderate increase of industrial activity will have considerable repercussions. We estimate that relatively full use of the present minimum allowable timber cut would provide employment to 4,500 or more persons. That is roughly nine times the present employment by the timber industries.

Some idea of the ramified effects of expansion of basic industries may be had by applying factors derived by the New Jersey Development Council. According to their figures, 4,000 new jobs in a basic industr would add 28,000 people to the local population. Taxable valuation would expand by 50 million dollars; 660 new stores and shops would open for business, and there would be another 6,400 cars on the road.

TABLE 1.--PERCENT OF LABOR FORCE IN AGRICULTURE 1950

	Percent
United States	13
Utah, Idaho, Wyoming	18
Headwaters Unit	29

TABLE 2.--PERCENT OF LABOR FORCE IN MANUFACTURING 1950

	Percent
United States	25
Utah, Idaho, Wyoming	9
Headwaters Unit	4

More jobs, more people, and more money will not necessarily make the Headwaters Unit a better place to live and, therefore, is not an end in itself. However, there appear to be several reasons why industrial expansion is desirable. In the first place, it is likely that a larger population would reduce the cost of essential community services to the taxpayer.

Growth of the nonagricultural basic industries also appears desirable as a means for diversifying and thus strengthening the income base. This area leans very heavily on its agricultural resource. For example, the proportion of the labor force engaged in agriculture is more than twice as high as for the United States as a whole and higher than for the states of Utah, Idaho, and Wyoming as a whole (table 1).

Conversely, the Headwaters Timber Development Unit has few manufacturing enterprises. This is shown in table 2.

American agriculture has for many years been more unstable than the rest of the economy. As a matter of fact, fluctuating farm income is one of the most important political and economic problems in the country today. While the purchasing power of the average individual was increasing 15 percent from 1947 to 1955, the farmer's purchasing power dropped 13 percent. Farmers had 12 percent of the national income in 1947 and 6 percent in 1955. The farm income problem will probably be with us for a long time yet. Thus, it is to the advantage of areas with heavy dependence upon farming to encourage other types of development where they are feasible. Any sound industrial expansion based on the timber or mineral or other resources will certainly strengthen the economy of the Headwaters Unit in the long run.

THE FOREST RESOURCE

THIS UNIT HAS A SUBSTANTIAL FOREST AREA--MOSTLY PUBLICLY OWNED

Seventeen percent of the area in the Headwaters Unit is commercial forest land. The colored map in the forepart of this report shows the general location of this resource. Following are some of the salient forest statistics:

- There are 4,870,000 acres of commercial forest in the Headwaters Unit.

- 41 percent of the commercial forest is lodgepole pine type and 34 percent is Douglas-fir type.

Lodgepole pine	2,018,000 acres	
Douglas-fir	1,645,000 acres	
True firs	295,000 acres	
Spruce	427,000 acres	
Ponderosa pine	123,000 acres	
Aspen-cottonwood	362,000 acres	A-1 2/

- 95 percent or more of the commercial forest is publicly owned in the national forests. No segregation was made by owners so this figure is an approximation. The map in figure 5 shows the location of the national forests. Following is the forest area in each national forest, including all ownerships.

Bridger	731,000 acres	
Teton	588,000 acres	
Ashley	130,000 acres	
Wasatch	293,000 acres	
Cache	94,000 acres	
Caribou	302,000 acres	
Targhee	859,000 acres	
Salmon	948,000 acres	
Challis3/	925,000 acres	A-1

2/ These and following numbers prefixed with "A" refer to appendix tables where more detailed statistics may be found.

3/ Includes a small part of the Sawtooth National Forest.

NATIONAL FORESTS IN THE
HEADWATERS TIMBER DEVELOPMENT UNIT

FIG. 5.

THE FORESTS HERE CAN SUPPORT A FAIRLY LARGE TIMBER CUT

Earlier in this report we mentioned that the cut of timber is far below even the minimum level which is presently feasible. How much beyond that minimum the cut could be safely raised depends on how selective or choosy the sawmills and other plants are in their wood requirements. It depends also on how much management work is done in the forest.

In years past, harsh economic facts have forced the sawmills to concentrate on "T-bone steak" timber leaving the "hamburger" unused. Obviously, if loggers have to continue to pass up some species of timber and leave behind dead and cull trees their annual take will have to be less than if they use everything.

Oddly enough, the forester's big headaches in the past have been caused by the wood left behind by the logger rather than by the timber he has taken. In some cases so much timber has been left that it has been almost impossible to do anything constructive. Figure 6, on the following page, illustrates the problem. The timber stand shown has been logged for railroad ties plus such side lumber as the tie trees would produce. The trees smaller than 11 inches were not taken so a rather heavy stand remained. Such highly selective logging creates reproduction and disease problems. Lodgepole pine is an intolerant species, that is, it does not reproduce well under shade. Thus, where the canopy isn't opened up adequately, the species does not reproduce itself. The much more tolerant alpine fir takes over instead. Unfortunately, the alpine fir in some localities is commercially almost worthless because of its scrubbiness. The other problem occurs in localities where the old stand is infected with mistletoe. In these cases when trees are left behind they scatter mistletoe seed on the young stand below, causing deformities which will greatly reduce the yield of usable timber in years to come.

While national forest administrators are optimistic over the timber industry opportunities in the Unit, they are quick to point out that problems such as these should not be ignored in the rush to develop industry. They emphasize that it would be a mistake to build industry up to full capacity without taking parallel action to properly finance the forest operation itself. Timber growing in the Headwaters Unit is potentially a big and profitable business. As with any business, one of the prerequisites to profitable operation is adequate financing.

Figure 6. A partially logged lodgepole pine stand. Only the trees larger than 11 inches were removed. This still leaves a heavy canopy which will prevent young lodgepole pine trees from being established. Unless something is done, this area will be taken over by scrubby alpine fir.

It will take tens of millions of dollars to buy the kind of highly flexible management this area needs. If forest managers are to be able to log the millions of board feet of overmature timber scattered throughout the area before it dies they will need a complete primary network of roads. Likewise to produce merchantable timber in 100- to 160-year rotations will require considerable effort in thinning and weeding young stands.4/

4/ The rotations assumed for each type are:

	Years		Years
Lodgepole pine	100	Spruce	140
Douglas-fir	160	Alpine fir	100
Ponderosa pine	160	Hardwoods	60

ALLOWABLE CUT o o o o o

The allowable cut may be described as the desirable annual cut for a particular period considering the nature of the present stand, the degree of anticipated utilization, and the management being undertaken.

If it is properly developed, the timber stand of the Headwaters Unit can support a good size industry. The allowable annual cut of sawtimber during the next 70 to 80 years should be somewhere between 244 and 350 million board feet annually.5/ In addition to this volume, an allowable cut of 250 to 400 thousand cords of smaller trees is possible (figure 7). In subsequent years it should be possible to raise the cut to ½ billion board feet plus 267 thousand6/ cords annually.

The methods of deriving the upper and lower allowable cut estimates are described in the appendix. It is sufficient to say here that the 244 million board feet and the 250 thousand cords are safe levels of cut to start with. On the other hand, we will have to do a really good job of management to sustain a cut of 350 million board feet and 400 thousand cords in the coming decades. During the next few years it would be satisfactory to obtain all of the cut from the harvesting of present merchantable timber providing the cut is concentrated in high-risk stands. However, before long, progressively more of the cut will have to come from other sources than the final harvest. For example, if the total sawtimber cut 70 to 80 years from now is to be maintained at 350 million board feet, about one-third of it will have to come from thinnings and the salvage of dead and dying trees.

5/ Except for lodgepole pine, sawtimber includes sound trees 11 inches in diameter breast high and larger. Lodgepole pine trees larger than 9 inches d.b.h. are classed as sawtimber. Poletimber includes trees between 5 inches d.b.h. and sawtimber size. All sawtimber volumes in this report, unless otherwise specified, are Scribner log rule. Scribner rule volumes run about 12 percent less than International ¼-inch rule.

6/ Through better forestry, we would expect to take a smaller part of the cut from pole-size trees after the first rotation.

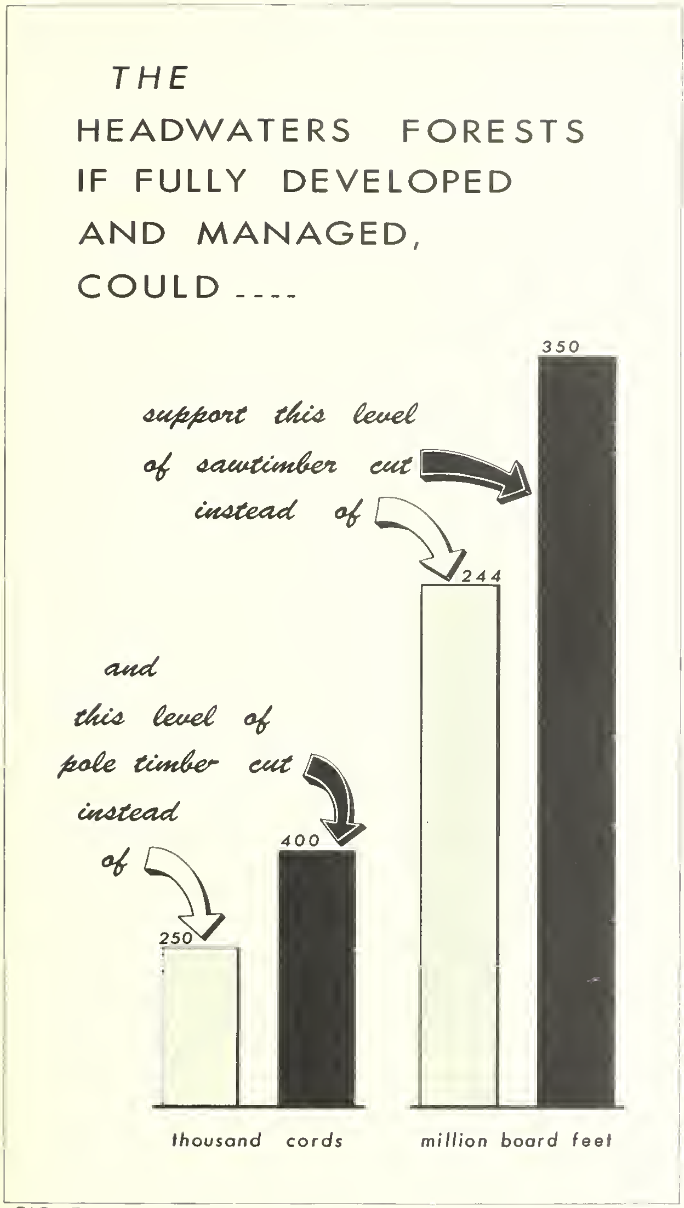

FIG 7

The allowable cuts discussed in the balance of this report are minimums. Because of the heavy losses due to insects and diseases, national forest administrators anticipate that the actual cut during the next few decades will be greater than these minimums. Following are some of the salient features of the minimum allowable cut:

- Minimum allowable cut for the entire Headwaters Unit:

  Sawtimber
  244,000,000 bd. ft.

  Poletimber
  250,000 cords

  All timber
  69,000,000 cu. ft.

A-2, A-3, A-4

The geographic distribution of the cut is shown in figure 8.

- Sixty-nine percent of the timber could best be delivered to sawmill sites in Idaho, 25 percent to Wyoming points, and 6 percent to a site in Montana. Figure 9 shows the allowable cut available to nine sawmill sites.

A-5, A-6, A-7

- Sixty-five percent of the allowable cut is tributary to pulpmill sites along the Upper Snake River in Idaho, 29 percent is

MINIMUM ALLOWABLE
ANNUAL SAWTIMBER CUT
HEADWATERS TIMBER DEVELOPMENT UNIT
1956

LEGEND
EACH DOT = 100,000 BOARD FEET
FOREST LAND AREA

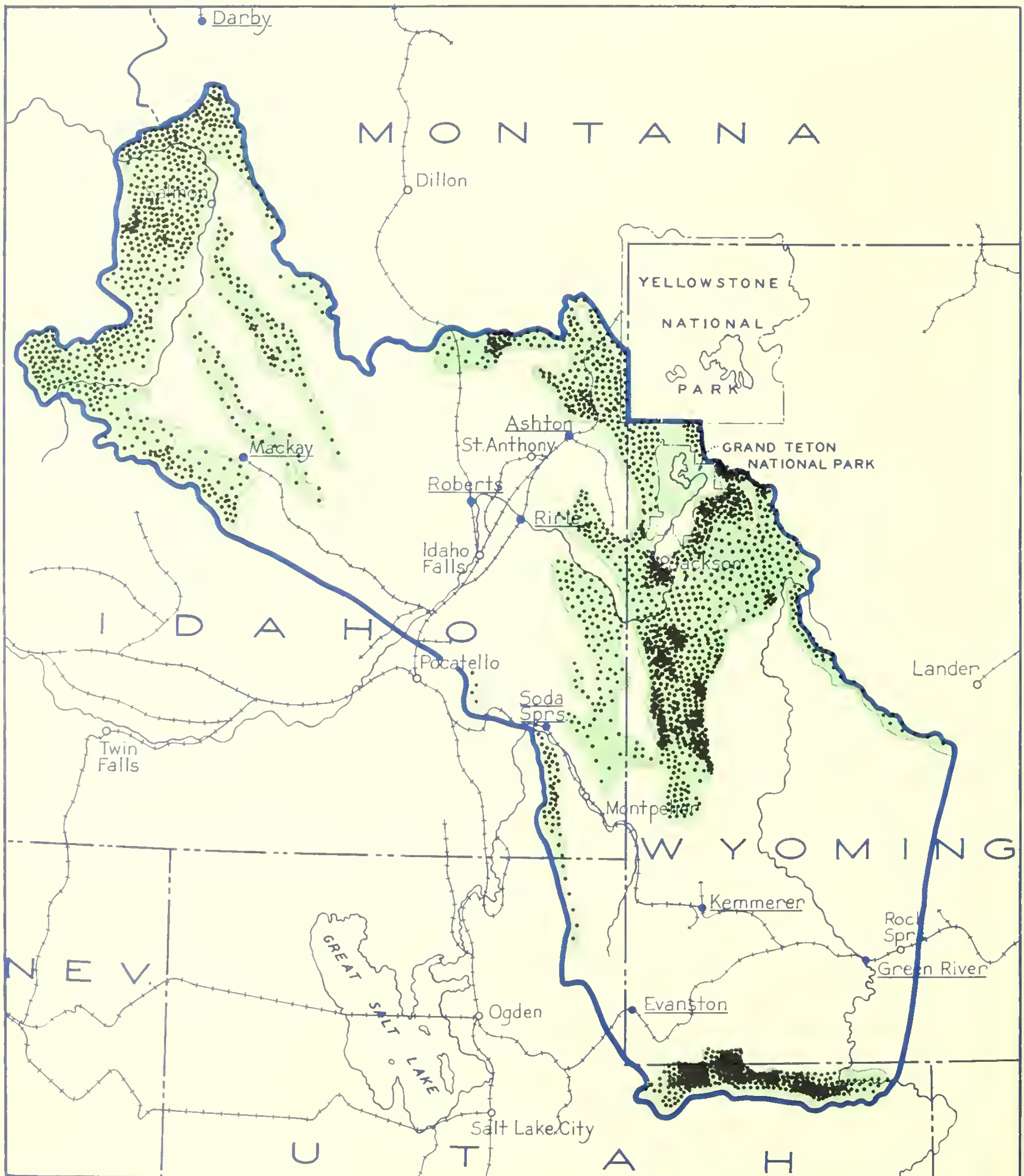

FIG. 8

(AGRICULTURE - OGDEN)

MINIMUM ALLOWABLE TIMBER CUT TRIBUTARY TO POSSIBLE SAWMILL SITES

HEADWATERS TIMBER DEVELOPMENT UNIT

1956

LEGEND

FOREST LAND AREA

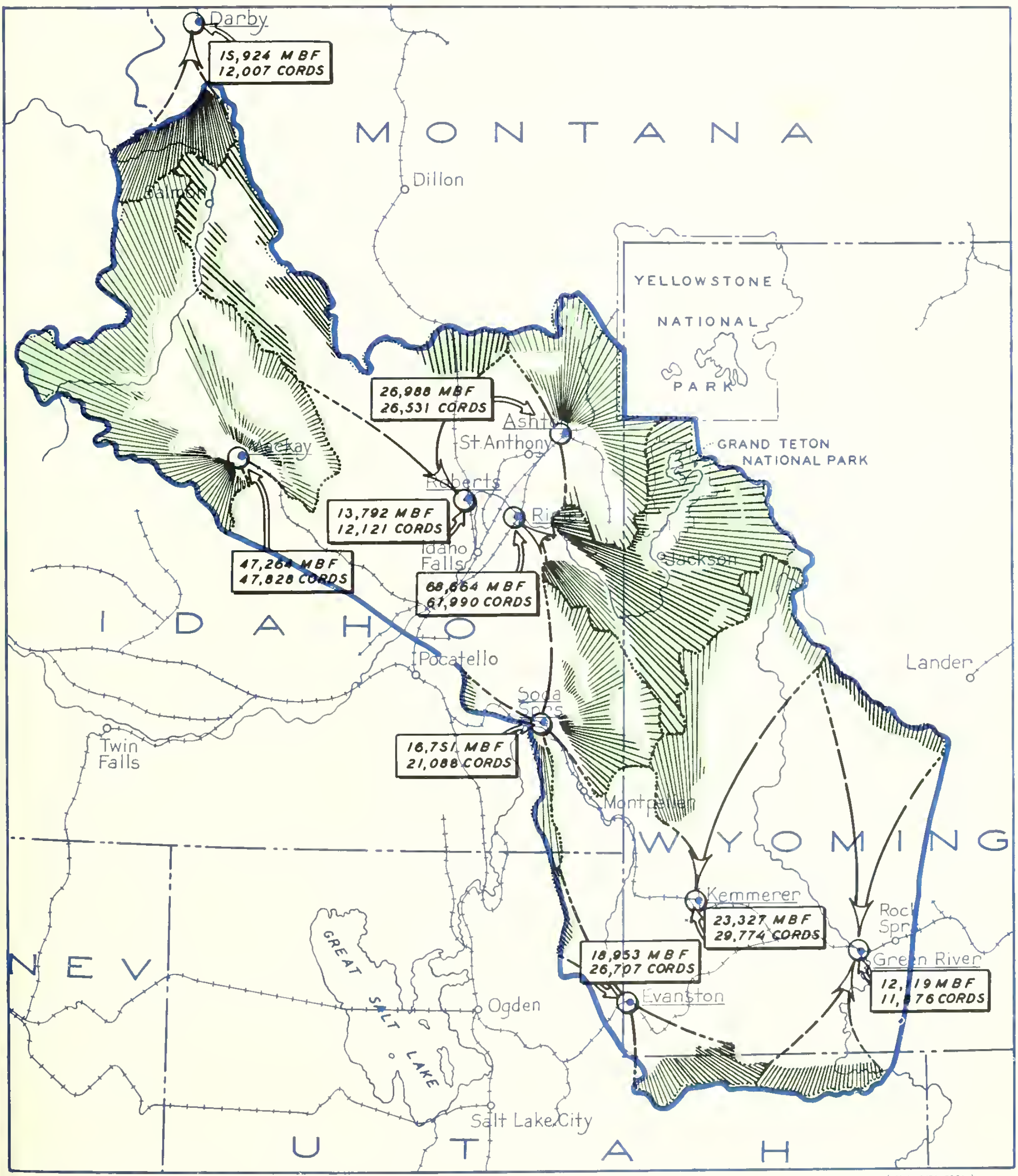

FIG. 9

tributary to Green River, Wyoming and 6 percent to a Montana pulpmill site. The amount of allowable cut at three pulpmill sites is shown in figure 10.

A-8, A-9, A-10

- Thirty-eight percent of the allowable annual cut is lodgepole pine and 21 percent is Douglas-fir.

	Million cubic feet
Lodgepole pine	26.4
Douglas-fir	14.5
True fir	8.9
Spruce	9.8
Ponderosa pine	1.1
Aspen-cottonwood	4.2
Other	4.1
Total	69.0

To keep the record straight, we should emphasize that it is not the purpose of this report to decide where the timber should be manufactured but rather to indicate the feasibility of industrial expansion. However, to make the cost calculations which will be discussed later, specific plant locations had to be assumed. The communities mentioned in figures 9 and 10 are by no means the only sites for industrial development, but they are representative of general vicinities where plants might be located.

MINIMUM ALLOWABLE TIMBER CUT TRIBUTARY TO POSSIBLE PULPMILL SITES

HEADWATERS TIMBER DEVELOPMENT UNIT

1956

LEGEND

FOREST LAND AREA

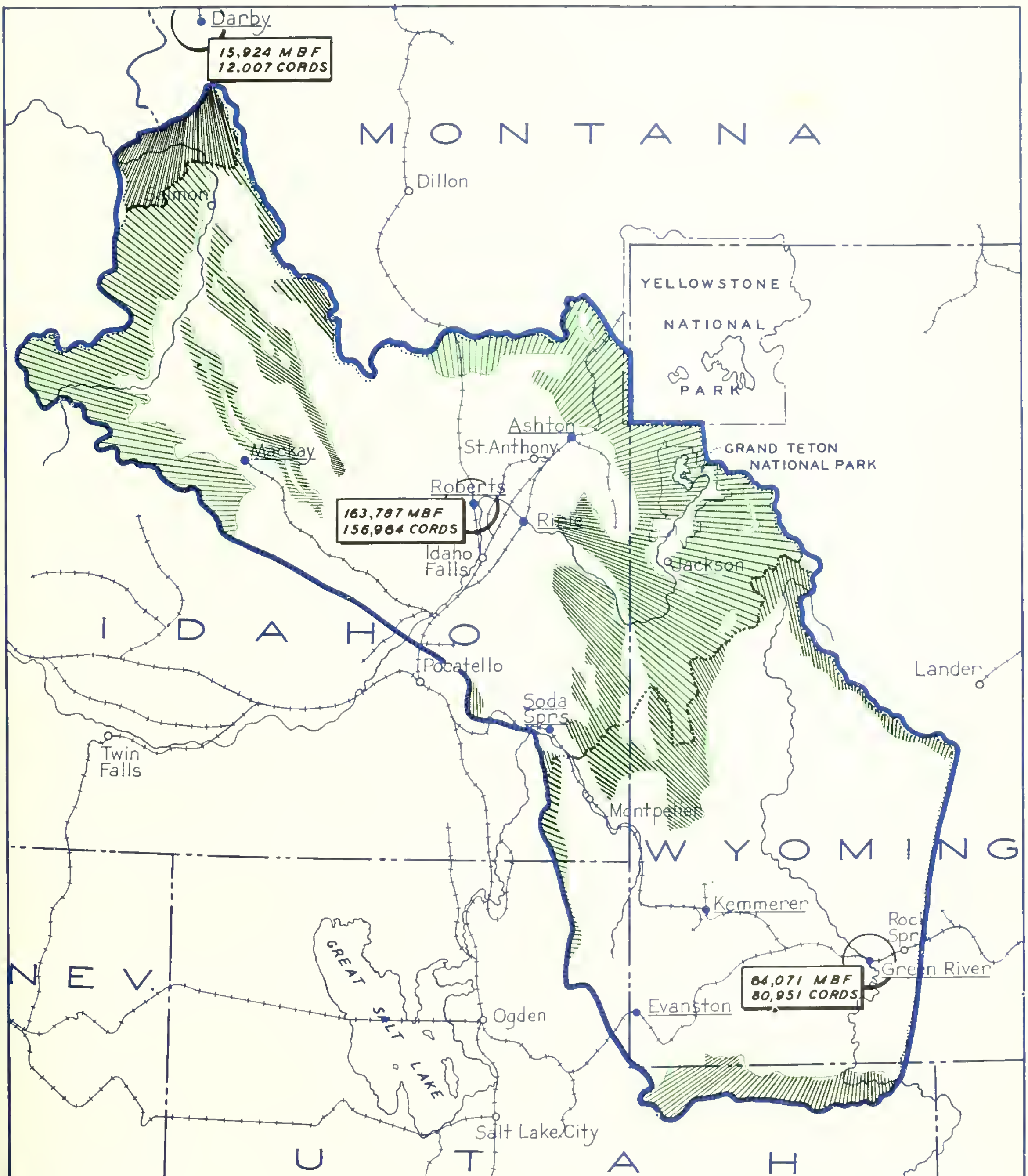

FIG. 10

INDUSTRIAL OPPORTUNITIES

The timber industry problem in the Headwaters Unit is to break with the past and to develop types of use which meet the following general criteria:

- Stable income to the community.
- Maximum employment at reasonable wages.
- Full utilization of the timber.
- A high-grade product.

At the present time the most hopeful prospects from these standpoints are (1) sawmills of a larger and more permanent sort than have been typical in the past, (2) pulpmills and paper mills, (3) composition-board mills.7/ The timber in this locality is well suited for all three types of use. However, no one of the industries is in itself the complete answer to the utilization problem. In the long run, best use will be made of the timber if all three industries are here.

EACH ONE THOUSAND BOARD
FEET OF TIMBER WILL PROVIDE
FROM 2 TO 6 MAN-DAYS' WORK

Kind of plant, the process used, degree of manufacturing, and efficiency all have bearing on employment opportunities. Sawmills have very different labor requirements than pulpmills. As a matter of fact, two plants of the same type and output may differ substantially in this respect, depending on efficiency and degree of mechanization. There are several pulping and composition-board processes, and there are many types of paper and composition-board products. Thus, we can speak only in generalities in discussing employment opportunities. However, it appears that:

- Sawmills and composition-board plants provide about the same amount of employment per unit of wood.

- Both sawmills and composition-board plants provide more employment from a unit of wood than pulpmills.

7/ The term "composition-board" is a collective term which includes a variety of low, medium, and high-density boards made from wood fibers and wood particles by several different processes. "Masonite" is the trade name of one of the high-density hardboards. "Celotex" is one of the low-density boards.

- A pulpmill and paper mill combination will provide considerably more employment per unit of wood than either a sawmill or composition-board plant which does not have an associated remanufacturing plant.

- A combination lumber and composition-board operation would provide more employment per unit of wood than either alone but less than a pulp and paper mill.

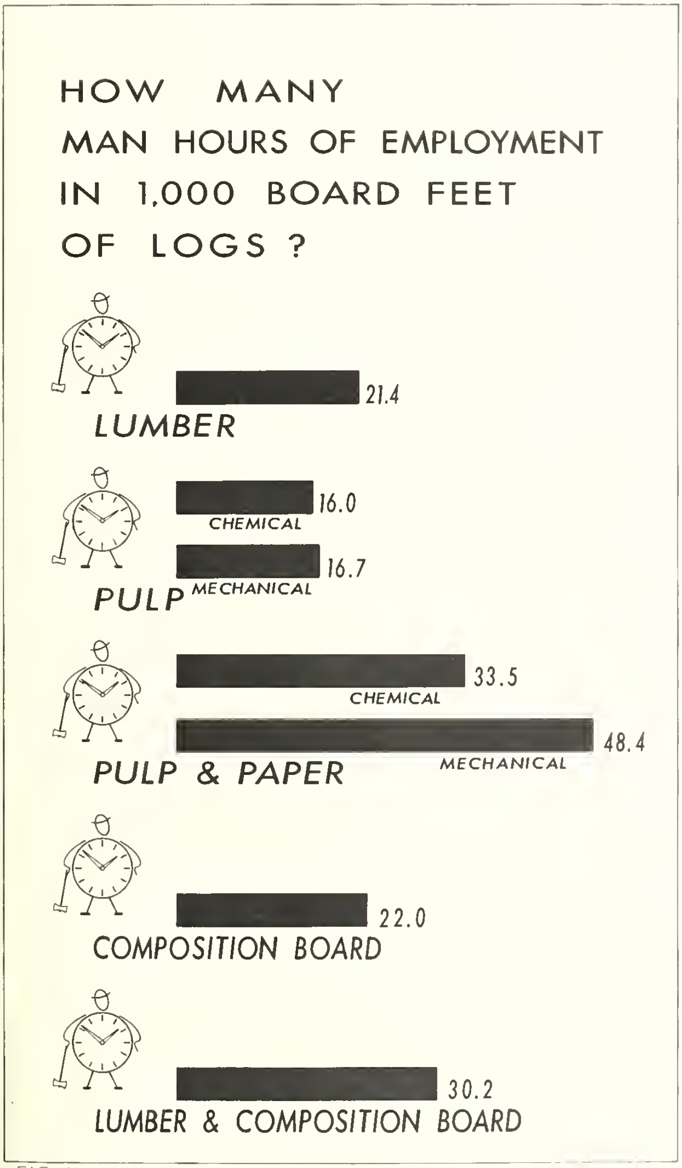

FIG 11

Figure 11 presents man-hour requirements which seem to be realistic for various types of operations.

The number of people a plant would employ involves the additional factor of size. As with all types of production, each of the timber industries has its own most efficient size. In the case of pulpmills using chemical processes, it is generally thought that a plant must produce at least 100 tons of pulp daily if it is to be reasonably efficient. Plants two or three times this size are generally desired. The minimum efficient size of mechanical pulpmills is 50 tons per day. With present processes, composition-board plants probably should have at least 40 or 50 tons' capacity. Under most circumstances, sawmills would have to produce at least 45,000 to 60,000 board feet of lumber daily to justify dry kilns, planers, and other facilities required to do the best job of utilization and manufacturing. Table 3 on the next page shows the manpower needs of various type plants.

TABLE 3.--EMPLOYMENT BY IDEAL-SIZE PLANTS (from stump to end product of the plant)

Type of plant	Daily capacity	Employment
Sawmill	60 M bd. ft.	160
Chemical pulp	200 tons	345
Mechanical pulp	50 tons	50
Chemical pulp and paper	200 tons	720
Mechanical pulp and paper	50 tons	140
Composition-board	50 tons	40

TABLE 4.--INVESTMENTS REQUIRED FOR IDEAL-SIZE PLANTS

Type of plant	Capital investment (Million dollars)
Sawmill	3/4
Chemical pulp	10 to 15
Mechanical pulp	1 to 1½
Chemical pulp and paper	16 to 25
Mechanical pulp and paper	2½ to 4
Composition-board	1½ to 2½

IDEAL-SIZE PLANTS WILL COST FROM LESS THAN $1 MILLION TO $25 MILLION DEPENDING ON THE INDUSTRY

One big advantage of the lumber industry is that efficient sawmilling units are less costly than efficient units of other industries. Pulpmills and paper mills are many times more expensive. As a matter of fact, several past efforts to promote pulpmills and paper mills have failed because the large investment required made financing too difficult.

Table 4 shows the capital investment which might be required for different type plants. The composition-board plant in this instance is a continuous wet process hardboard mill. Certain other types of composition-board plants would be cheaper to build.

UP TO NOW THE LUMBER INDUSTRY HAS NOT MET THE CRITERIA MENTIONED ON PAGE 18.

So many sawmills have come and gone after operating a few months or few years that the lumber industry can hardly be called stable.

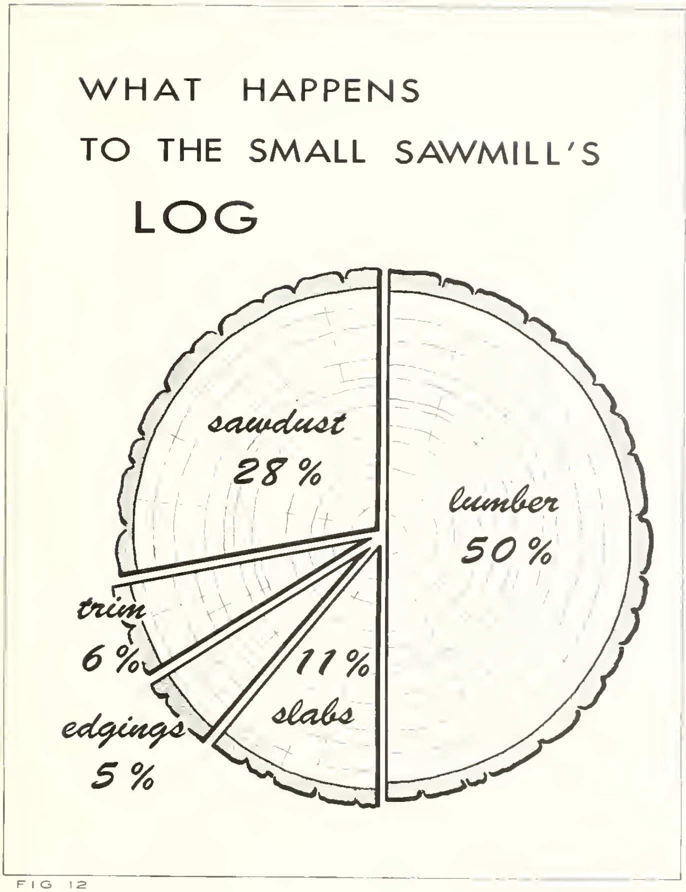

FIG 12

TABLE 5.--VOLUME IN MERCHANTABLE LODGEPOLE PINE STANDS WHICH IS IN TREES 11 INCHES IN DIAMETER AND LARGER	
National forests	Percent
Teton, Bridger, Ashley and Wasatch	64
Targhee	63
Sawtooth, Challis, and Salmon	40

Nor, has it paid its workers as well as sawmills in the larger lumber centers of the West. Comparative statistics are not available for the Headwaters Unit. However, the industry here is very much the same as the industry in Utah and Wyoming as a whole. The 1947 Census of Manufactures shows the average yearly income per lumber industry worker in Washington was half again higher than in Utah and one-third higher than in Wyoming.

Another age-old problem in the lumber industry has been its inability to use a large part of the timber. It is fair to say that this utilization problem is as acute in the Headwaters Unit as anywhere. The picture on page 22 (figure 13) shows a common sight in this area--piles of slabs and sawdust left behind by roving sawmills as they move from one spot to the next. In some instances as much as 50 percent of the logs entering the sawmill become unused residue (figure 12). Many of the mills here have cut railroad ties. When the market for standard lumber has been good they have sawed it from the outer portions of the log. When the lumber markets have been poor they have confined

Figure 13. A small sawmill on the Bridger National Forest. The mountains of slabs and sawdust at such mills bear witness to the need for better utilization.

their production to ties, and as a consequence the slabs have been that much thicker.

The utilization problem is aggravated by the fact that logging has in many cases been highly selective. Situations like the one pictured in figure 6 where only the larger trees have been cut are all too common. To confine utilization to trees 11 inches in diameter and larger, as in that case, not only creates an almost impossible management task for the forester, it also wastes much good wood. In the spruce and Douglas-fir sawtimber stands in this locality, 90 percent or more of the usable volume is in trees larger than 11 inches in diameter. However, in some areas, the <u>merchantable</u> lodgepole pine stands have less than half of their volume in 11-inch and larger trees as table 5 shows: Counting the trees not taken and the wood wasted in the manufacturing process, a typical small sawmill cutting to an 11-inch diameter limit in lodgepole pine on the Sawtooth, Challis, or Salmon National Forests would be wasting 80 percent of the timber--which is hardly a satisfactory situation.

THE DIFFICULTIES OF THE LUMBER INDUSTRY HERE ARE PARTLY RELATED TO SIZE OF ESTABLISHMENT

It is hard to generalize about sawmills as there are efficient and inefficient operators among all classes. Nevertheless, it is true that the features we regard as undesirable in the industry are more common among small plants than among larger ones. For example, there are more low-paid workers at small sawmills than at large ones. One analysis made a few years ago in Montana showed the average hourly wage at the biggest mills to be almost twice as high as at the smallest.[8/] Furthermore, there has been more waste at small mills and they have turned out a generally poorer product than the larger mills.

While it may be possible to develop an efficient and desirable lumber industry around the very small sawmill the chances of being able to do so are much less than if a substantial number of the plants are large enough to produce 10 million board feet or more annually. Small portable sawmills as a group have proved to be inefficient units of production for three reasons:

- Managerial ability is a scarce commodity. It is hard enough to find the skills and leadership necessary for effective operation of one large mill let alone a dozen small ones.

- Locations where residues are available in large quantities (that is at large mills) have been the ones attracting pulpmills and other plants looking for sources of fiber material. Even on the West Coast where great progress has been made in the utilization of sawmill and veneer mill residues there has been very little use of residue from small or medium-size plants. Certainly if the principal source of slabs, edging, sawdust, etc. continues to be at widely scattered portable sawmill sites, progress in utilizing this fiber material will be slow.

- Individually, small mills have insufficient production to justify the additional facilities necessary to make high-grade lumber and to utilize residues. They likewise are not able to take full advantage of lumber grading. In the case of new installations designed for efficient operation, a minimum annual output of 10 million board feet is probably necessary to justify installing a planer, dry kiln, mechanical debarker, and chipper.

8/ The Forest Situation in Lincoln County, Montana by S. Blair Hutchison. Forest Survey Release 20, Northern Rocky Mountain Forest and Range Experiment Station, 1942.

TABLE 6.--UNITS OF CHIPS[1/] PER THOUSAND BOARD FEET OF LOGS SAWED FOR LUMBER	
With no barker	0.2
With slab barker	.4
With log barker	.6-.75

1/ A unit of chips contains 200 cubic feet and has about the same solid wood content as a cord of groundwood.

We can perhaps best illustrate the small sawmill's handicap by considering the investment it must make to produce chips as a by-product. Chipping wood into the small pieces necessary in pulping would seem to be a simple process. However, good chips cannot be produced from sawmill residues without substantial investment. Surprisingly enough, chips used by sulphate pulpmills must meet certain quality requirements. They should be uniform in size and cleanly cut rather than being crushed or pinched at the ends. This factor affects liquor absorption in the cooking process. A chipping plant which will produce precision chips costs about $50,000. Composition-board plants are less demanding in the matter of chip quality so a chipper serving that market might cost $35,000.

Bark is not acceptable in most pulp so if maximum chip yields are to be obtained, debarking is necessary. This is shown in table 6 which presents chip yield data compiled by the Western Pine Association. Unfortunately, there is no such thing as a good, cheap debarker. Satisfactory hydraulic log debarkers cost upward of $300,000 and mechanical log debarkers from $100,000 to $150,000. Machinery for debarking slabs would cost less.

In the South, the handicap of size in the small mill has been partially overcome by the development of the concentration yard system. In its simplest form, the concentration yard is nothing more than a planing mill which buys rough lumber from small sawmills, processes it to a finished product, and then sells it. Since it handles the output of several sawmills, the yard has sufficient production to justify planers and dry kilns, and in some cases a selling organization. The concentration yard system could be adopted in the Headwaters Unit. However, it would not help the problem of widely scattered residues nor would it increase the efficiency of rough lumber remanufacture. In more than a few instances, the concentration yard has been a device to exploit the small mill owner and his employees.

Small portable mills have their place in the industrial picture along with larger more permanent ones. Each has its own advantages. Nevertheless, it seems clear that the interests of the community and the resource will be best served if most of the lumber production is by plants individually producing 10 million board feet or more annually.

TABLE 7.--COMPARISONS OF LUMBER GRADE RECOVERY

Grade	Ponderosa pine Percent	Lodgepole pine Percent
Selects	14	½
#1 & 2 common	11	48
#3 common	23	37
#4 common	18	12
#5 common	6	½
Shop	15	-
Box, molding, and shorts	13	2
	100	100

THERE SEEMS TO BE AN EXCELLENT OPPORTUNITY TO DEVELOP A DESIRABLE LUMBER INDUSTRY

Recent events give us reason to be encouraged about the lumber industry prospects in the Headwaters Unit. The most important of these events has been the establishment and apparently successful operation of two medium-size sawmills in eastern Montana. Both plants principally cut lodgepole pine timber. One produces about a million board feet of lumber monthly, the other twice that amount. Each has a dry kiln and planer and sells its lumber in the national market. Lodgepole pine lumber from these two mills has gone to all parts of the United States.

Lodgepole pine has been avoided by the larger mills in the past because it is characteristically a small tree even at maturity. Being small it is more expensive to handle and it has less top quality lumber than bigger species like ponderosa pine. Therefore, one of the more encouraging features of these new mills is that they have demonstrated an ability to use trees of very small size without being at too much of a disadvantage.

These two pioneering mills have shown that lodgepole pine will produce good lumber. A shortage of clear knot-free boards is partially offset by the fact that there are not many low-grade boards. The species produces a superior knotty paneling for which there is a good market. Table 7 presents a comparison of representative lumber grade recovery data for lodgepole pine and old growth ponderosa pine.

A drawback of small trees is the high proportion of narrow boards they produce. Fifty to sixty percent of the output of mills sawing lodgepole pine boards is in the hard-to-sell 6-inch and narrower widths. However, there is a mill in eastern Washington which glues lodgepole pine into panels and pieces for table tops, other furniture parts, and caskets. One of the two Montana mills mentioned above has been gluing experimentally. There is reason to expect narrow widths will ultimately be less of a handicap than now.

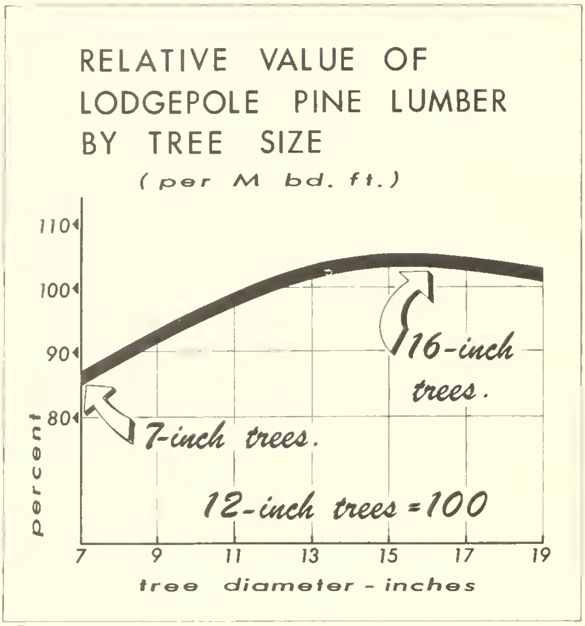

FIG 14

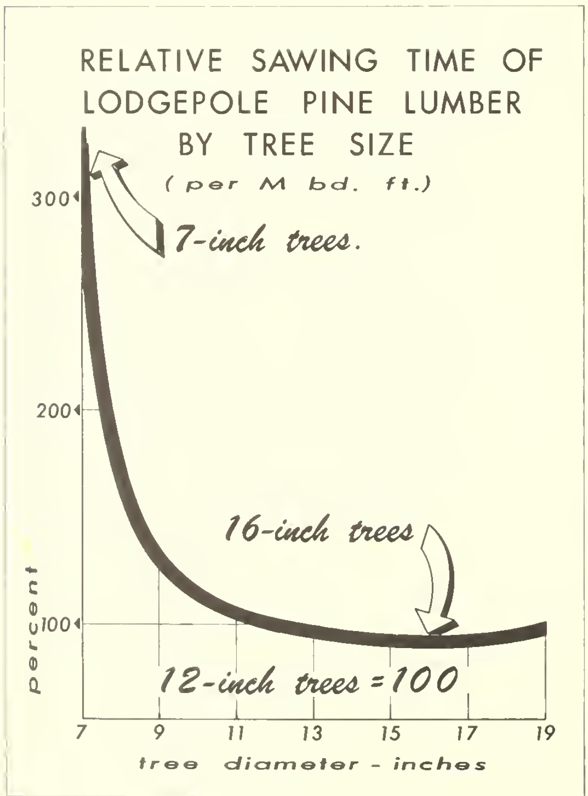

FIG 15

In looking into the problem of widths, we find that even though neither of the Montana mills sells a significant amount of glued-up stock, they receive a fairly good price for their lumber. Grade for grade the price is about the same as for ponderosa pine. For one of the mills the average price for all grades has run about $10.00 a thousand board feet less than the average price for ponderosa pine lumber.

A FIBER PRODUCTS INDUSTRY IS NEEDED TO ROUND OUT THE PICTURE

A lumber industry consisting mainly of fairly large and well-equipped sawmills would be a big step forward. However, it still would not be the complete answer to the utilization problem. In the first place the conventional sawmill is a selective establishment. It uses something like half the log. In the second place, while well-equipped mills can use more little trees than they once did, they cannot use such timber in the proportion it occurs in some merchantable stands today.

The problem of the sawmill is well illustrated by figures 14 and 15 which show two things:

- Lumber from 7-inch trees has only eight-tenths the value per 1,000 board feet as lumber from 16-inch trees.

- It takes more than three times as long to produce 1,000 board feet of lumber from 7-inch trees as from 16-inch trees.

In the last several decades, the lumber industry has made considerable progress in the handling of small timber and there is every reason to suppose ways will be developed for more economical handling of 7- and 8-inch trees in years to come. Likewise, through gluing and other procedures, it should be possible to increase the value of narrow boards. Nevertheless, there is nothing to indicate that the lumber industry can make more than partial use of the timber resource in this area. Much of the wood is suitable only for fiber. The paper industry with its multitude of different papers and cardboards is made to order for the situation here. So also is the newer and closely associated composition-board industry.

One might ask, if fiber products plants can use trees and wood which sawmills cannot, why not bypass the sawmill and concentrate the development efforts in attracting pulpmills, paper mills, and composition-board plants? The answer to this question is partly an economic one which will be discussed later. However, there are some other reasons why much of the public timber at least should be directed to the sawmill. Every sign points to the fact that as timber shortages become more acute--and they will-- the most difficult problem will be to meet lumber needs. The lumber pinch will be greatest in the better quality items such as clear boards and the better common grades. Therefore, since almost any wood can be used for fiber, it will be good public policy and good business too, to direct as much as possible of the timber suitable for lumber to lumber production.

TABLE 8.--CONSUMPTION OF PAPER AND PAPER BOARD IN THE UNITED STATES (Excluding composition board)

	Million tons
1920	7.6
1953	29.8
1975	54.5 +
2000	89.2 +

A LOT OF PAPER IS USED IN THE MOUNTAIN STATES BUT LITTLE IS PRODUCED HERE

The pulp and paper industry in the United States has grown by fantastic leaps and bounds in the last several decades and all signs indicate a substantial future growth. In 1920, the total consumption of paper and paper board[9/] in the country was 7.6 million tons. By 1953, it

9/ Timber Resource Review, United States Department of Agriculture, Forest Service, 1955 (Preliminary Draft).

had almost quadrupled that figure and by the end of the century, it should at least triple again. An analysis in the Timber Resource Review indicates the demand for paper and paper board will be at least 89 million tons by the year 2000 (table 8).

As this is written, there are only two pulpmills in the eight Mountain States and two more are in the process of construction (figure 16). However, if the people of the United States expand their use of paper to the degree anticipated, it will be only a matter of time before there are a number of pulpmills in the Rocky Mountains. Distance to the main United States markets and other factors have slowed down the expansion of paper industry in these states. But it hardly seems that the Nation's future paper needs can be met without seeking out new timber supplies. Already a decline of available wood in the South and West Coast has caused the industry to look elsewhere. Alaska is now enjoying a pulpmill boom. Both of the existing plants in the Rocky Mountains are new--and there will be more plants along in the next decade or so.

The prospects that some of the new plant capacity will come to the Mountain States are enhanced by the fact that these states use much more paper than they produce. As nearly as can be told, the eight states use something over 3 percent of the paper and paperboard consumed in the United States. In 1956, they had less than 1 percent of the pulpmill capacity. This excess of consumption over production is equivalent to the output of eleven or twelve 200-ton plants.

The Mountain States are a growing market. There were 5 million people living here in 1950 but the number may climb to 14 million or more in the next half century. Thus, any new pulpmills would have the opportunity to compete in a substantial and expanding nearby market.

Two processes are used in making wood pulp--mechanical and chemical. The principal outlet for mechanical pulp is newsprint which makes up 10 to 15 percent of the paper used in the Mountain States. A newsprint mill is reported to be under construction in Colorado. If it is constructed it will take the edge off that market. However, there are other uses for mechanical pulp and the larger market for chemical pulp products is still wide open.

WOOD PULP MILLS IN THE UNITED STATES - 1956

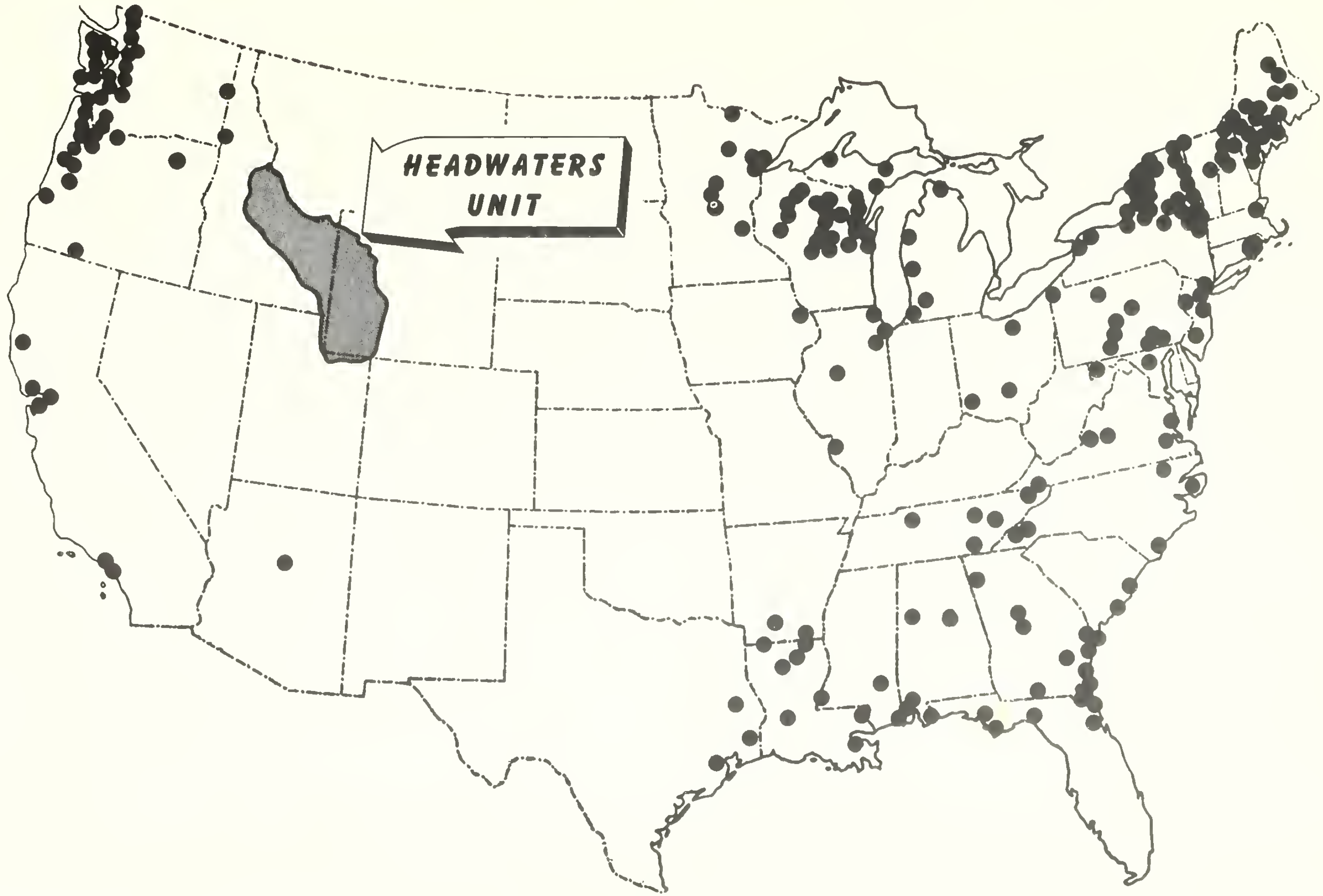

FIG. 16

ALL OF THE ROCKY MOUNTAIN SPECIES CAN BE PULPED

Table 9 summarizes the information available on the pulping characteristics of the several species. All three of the more common pulping processes--sulphate chemical, sulphite chemical, and mechanical--are feasible in this area. However, the sulphite process has some disadvantages which make it a less attractive process here than the other two. In the first place, Douglas-fir does not pulp readily by the sulphite process. Secondly, although pines are readily pulped by this process, they do not make the high-grade papers which sulphite pulping produces from other species such as spruce. Thirdly, the most commonly used sulphite process has the drawback of being a bad stream polluter. Mechanical mills cause the least pollution of all, but mechanical pulp cannot be used for as many different products as chemical pulp. These factors have caused most people suggesting pulpmill development to recommend the sulphate process for this region.

WATER IS ONE OF THE KEY FACTORS IN PULPMILL DEVELOPMENT

There are many streams in the Rocky Mountains--many streams in fact with enough water to keep pulpmills running. A 200-ton sulphate plant producing bleached pulp requires 18 to 19 million gallons of water daily. This use is largely nonconsumptive, that is it results in but little reduction of streamflow. Most of the water is used for washing the pulp and then is returned to the stream. As a matter of fact, because of the moisture in the wood some pulpmills actually return more water to the streams than they take out. The problem comes from the fact that the water returned to the streams from a chemical pulpmill is usually heavy-laden with organic material and some chemicals. Waste water or effluent from a 200-ton sulphate pulpmill may have an oxygen demand equivalent to the sewage from a city of 80,000 people. Consequently, pulpmills not only should take advantage of every device to minimize pollution, they should be located on streams large enough to dilute adequately any chemicals to harmless proportions and to dilute adequately the concentration of organic residues.

Pulpmill pollution is a complicated subject, but it is sufficient to say here that there are relatively few streams in the Rocky Mountains which are large enough to handle the effluent from a 200-ton sulphate plant. There are many places however, where mechanical mills would be feasible because the grinding process does not produce as much waste as when the fibers are separated by chemicals and because mechanical mills tend to be smaller than chemical pulp plants.

Table 9. SUITABILITY OF ROCKY MOUNTAIN TIMBER FOR PAPER PULP

Process	Species	Difficulty of pulping	Quality of unbleached pulp	Suitability of pulp
Sulphate	Lodgepole pine	Reduces readily	Very strong. Good color.	High grade Kraft and specialty wrapping papers and fiber board.
	Douglas-fir	Reduces readily	Fairly strong. Poor color.	Kraft wrapping papers and fiber board not requiring maximum strength.
	White spruce	Reduces readily	Very strong. Excellent color.	High grade Kraft wrapping papers and fiber board.
	Engelmann spruce	Reduces readily	Strong. Excellent color.	High grade Kraft wrapping papers and fiber board.
	Alpine fir	Reduces readily	Very strong. Excellent color.	High grade Kraft wrapping papers and fiber board.
	Limber pine	Reduces readily	Strong. Good color.	High grade wrapping papers and fiber board. (No commercial use to date.)
	Aspen	Reduces readily	Low strength. Excellent color.	Excellent for mixture with lodgepole, limber, and ponderosa pine pulp in quantities up to 25 percent.
Sulphite	Lodgepole pine	Reduces fairly readily	Strong. Excellent color.	Wrapping, book, and printing papers.
	Douglas-fir	Reduces with difficulty	Fair strength. Poor color.	Limited by poor color and content of pitch.
	White spruce	Reduces readily	Strong. Excellent color.	News, wrapping, book, high grade printing and bond papers. Dissolving and nitrating pulps.
	Engelmann spruce	Reduces readily	Strong. Excellent color.	News, wrapping, book, high grade printing and bond papers. Dissolving and nitrating pulps.
	Alpine fir	Reduces readily	Very strong. Excellent color.	News, wrapping, book, high grade printing and bond papers. Dissolving and nitrating pulps.
	Limber pine	Little known of properties		
	Aspen	Reduces readily	Low strength. Excellent color.	Book and tissues.
Mechanical	Lodgepole pine	Reduces readily	Standard strength. Excellent color.	Blending with chemical pulp in making newsprint, wallpaper, toilet tissue, toweling, and paper board.
	Douglas-fir	Reduces readily	Fair strength. Poor color. Likely to contain pitch.	Papers and boards not requiring maximum strength and color. Use limited because of pitch.
	White spruce	Reduces readily	Standard strength. Excellent color.	All uses requiring groundwood.
	Engelmann spruce	Reduces readily	Standard strength. Excellent color.	All uses requiring groundwood.
	Alpine fir	Reduces readily	Standard strength. Excellent color.	Practically all uses requiring groundwood.
	Limber pine	Reduces readily	Standard strength. Good color. Likely to contain pitch.	Use limited because of pitch. Otherwise suitable for all normal uses.
	Aspen	Reduces readily	Fair strength. Excellent color.	Coarse grades insulating board, finer grades news, book, and specialty papers.

To get an expert appraisal of the water situation, the Robert A. Taft Sanitary Engineering Center[10] of the Public Health Service, U. S. Department of Health, Education, and Welfare was asked to make a reconnaissance survey of the streams in and near the Headwaters Unit. The survey was made in cooperation with the Departments of Health of Idaho, Wyoming, Utah, and Oregon. It shows there are four stretches of stream in southern Idaho and western Wyoming that are suitable for sulphate pulpmills by virtue of volume of flow and proximity to railroads (figure 17). The details of this survey are covered in the reports mentioned in footnote 10. However, the following highlights are worth repeating here. The four locations are:

- The Snake River immediately below Weiser, Idaho. At this point the river is large and there are no communities or water uses for some distance downstream. An up-to-date pulpmill or pulpmill and paper mill of from 500 to 1,000 tons daily capacity could safely be installed in this area if adequate precautions were taken to abate pollution.

- The Snake River in the vicinity of Bliss and Hammett, Idaho. This is also a stretch of large streamflow. A 500- to 1,000-ton pulpmill or pulpmill and paper mill could be located here with the same qualifications as above.

- The Snake River in the vicinity of Roberts, Idaho. This is one of the only two locations in the Headwaters Unit which should be considered for chemical pulpmill or pulpmill and paper mill sites. No chemical pulpmill should be located at Roberts until certain changes are made. Present plants and communities using the river for waste disposal have already loaded it down with residues. However, it is possible to drastically reduce this pollution. Once it is reduced adequately, the U. S. Public Health Service feels that a 250-ton sulphate pulpmill or pulpmill and paper mill is feasible. If special measures are taken to reduce the toxicity of the wastes a 500-ton plant could be operated without undue risk.

10/ Report on Sites for Potential Pulpmills in the Snake and Green River Basins in Relation to Water Supply and Disposal of Wastes, by Robert A. Taft, Sanitary Engineering Center, Public Health Service Department of Health, Education, and Welfare, Cincinnati, Ohio. The above report is summarized in Research Note 43, Intermountain Forest and Range Experiment Station, Suitable Sulphate Chemical Pulpmill Sites in Southern Idaho and Western Wyoming from the Standpoint of Waste Disposal.

POTENTIAL SULPHATE PULPMILL SITES IN SOUTHERN IDAHO & WESTERN WYOMING AND TONS OF DAILY PLANT CAPACITY STREAMFLOW COULD SUPPORT

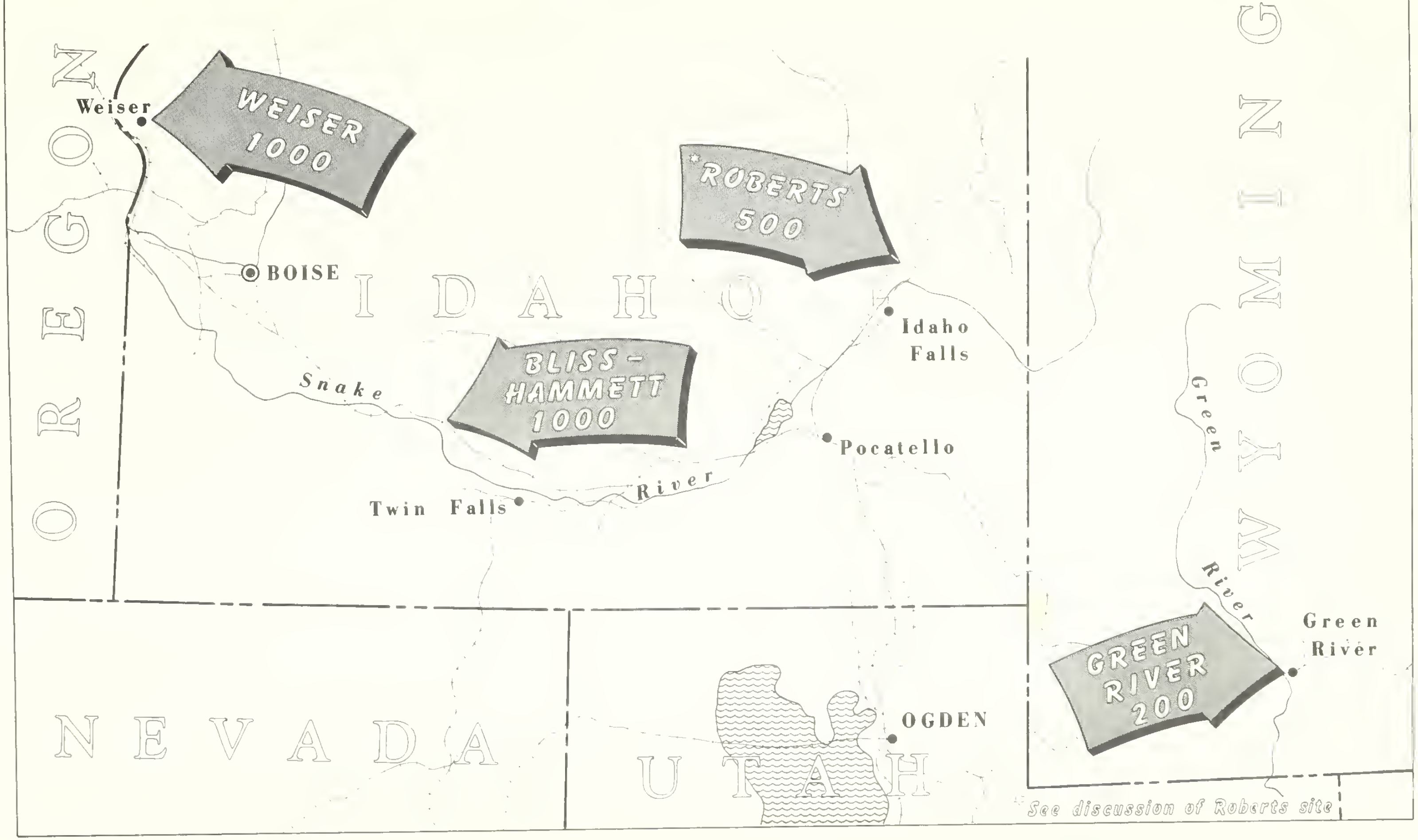

FIG. 17

The Green River below Green River, Wyoming. This river is much smaller than the Snake River but a 150-ton sulphate mill could be located here if means were provided to store the waste in ponds or lagoons during the long periods of low streamflow. With proper provisions to reduce toxicity of the wastes a 200-ton sulphate pulpmill or pulpmill and paper mill could be built. Because the river is small, any new consumptive use upstream might reduce its flow to the point where a chemical pulpmill would not be desirable below the town of Green River.

In suggesting these pulpmill sites, the Public Health Service makes some important qualifications. It has recommended in all cases that settling ponds or lagoons be built to reduce the volume of waste entering the rivers (some of it would oxidize in the lagoons). Lagoons of substantial capacity would also permit withholding the waste from the rivers during periods of extreme low flow.

It is also well to remember that the Public Health Service recommends the Roberts site only if existing pollution is considerably reduced. No stream anywhere is more heavily used than the Upper Snake River. It is the main source of domestic, industrial, and irrigation water. In at least two places, the withdrawal of irrigation water practically dries it up during certain periods. The Snake River is so vital to existence in this area that any developments affecting either quality or quantity of water should be considered with care.

Like all the major waterways in the Nation, the Snake River also serves to carry away domestic and industrial wastes. This is a necessary and important function. Also, like all of these waterways, there is a limit to the amount of waste material the Upper Snake River can carry without impairing the quality of the water for consumptive uses. At present, most of that carrying capacity is being used by existing industries and communities. The volume of pollutants can be reduced by adequate sewage disposal. To the extent it is reduced, there will be room for more industries with waste disposal problems. To the extent it is not reduced, existing stream pollution may retard industrial expansion.

The pulp and paper industry has made great progress in coping with the stream pollution problem which has dogged chemical mills these many years. Improvements in pulpmill design and operating procedures will result in even better waste control in years to come. However, the estimates of desirable pulpmill capacity presented here are based on presently practical plants and techniques. Until more efficient ways of waste disposal are proved and there is assurance they will be adopted, these present estimates should be used to guide development.

PULPMILL DEVELOPMENT MAY BE SLOW

This appraisal of the situation would be less than candid if an essential difference in the outlook for lumber and pulp development were not mentioned. In the case of sawmills, a period of expansion seems to be immediately ahead. In the case of pulpmills, however, the prospects are not so definite nor perhaps so immediate. The Headwaters Unit lies fairly close to Denver and Salt Lake City which are the hub of the Mountain States market. The Unit enjoys direct rail connections with four-tenths or more of the market in these eight states. Thus, we can be sure there is a place and an opportunity for pulpmills in this locality but it remains to be seen how long it will be before someone with the necessary money will feel the opportunities here are as great as they are elsewhere. This is not said to minimize the advantages of the Headwaters Unit but rather to emphasize that development may be slow.

The water situation is tighter here than in some other parts of the Rocky Mountains. Until such time as existing pollution on the Upper Snake River is diminished adequately there is room for only one 200-ton chemical plant in the Unit so far as stream pollution is concerned. This amounts to about 4 tons of capacity per million acres of commercial forest. In contrast the ratio is 25 tons per million acres in western Montana. The encouraging feature, of course, is that if the Upper Snake River is cleaned up there will be room for an additional 500 tons of chemical pulpmill capacity, which is more than enough to handle the available resource.

At present, the Headwaters Unit has very little sawmill residue available for pulping. This is important because most of the pulpmill expansion in the West in recent years--and there has been a lot of it --has been based on wood residues from sawmills and veneer mills. Slabs, edgings, and other waste wood from these plants have provided a relatively cheap supply of pulpable material. Today, more than half of the sulphate pulp production in the West is from such residues. There is still much unutilized sawmill residue in the Western States. Until such time as most of that supply is soaked up, it seems likely that concerns intending to build sulphate pulpmills will favor locations where they can obtain chips from sawmills and veneer mills. About 140,000 units of chips are required annually to keep a 200-ton chemical pulpmill operating. If the logs were barked, 350 million board feet of lumber production would be required to produce that volume of residue. Thus, it obviously will be sometime before large pulpmills are attracted to the Headwaters Unit on the strength of the residue supply.

We pointed out earlier that barkers and chippers are expensive items. It probably will take 10 million board feet of lumber production to justify such installations. Several larger sawmills are being built here but in 1954 there was no sawmill in the Headwaters Unit producing more than 4 million board feet per year.

The Headwaters Unit also has a fairly long timber haul to contend with. The average distance between the timber and chemical pulpmill sites is probably no longer than in eastern Montana but longer than in western Montana, northern Idaho, and southwestern Idaho.

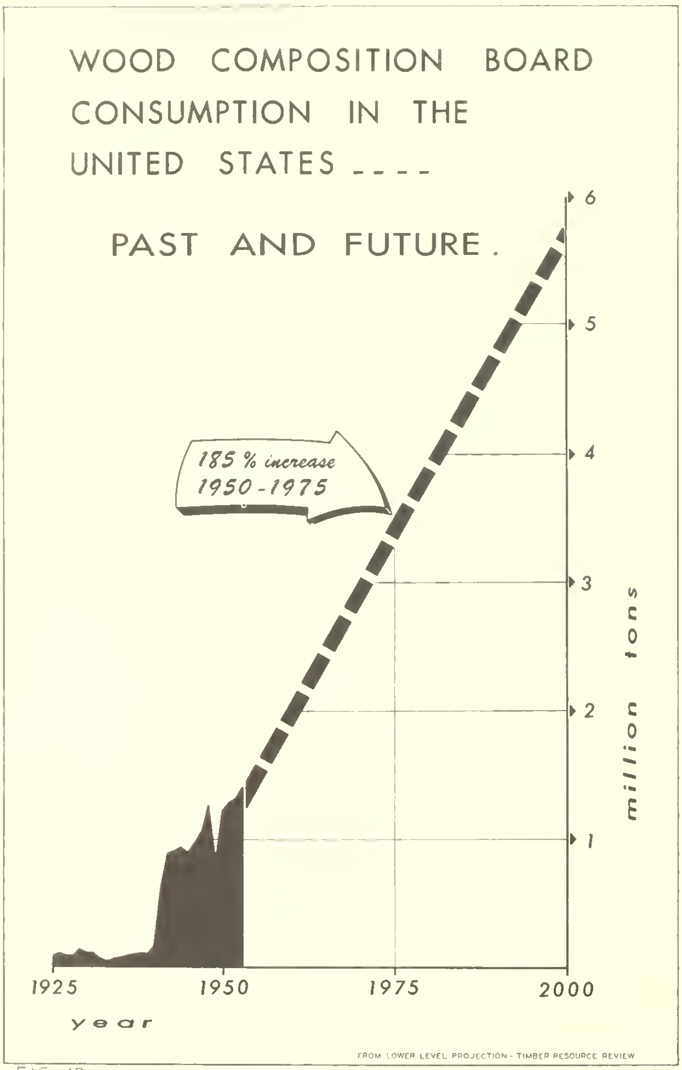

FIG 18

Some pulp companies might be disturbed by the fact that there is probably less chance for them to acquire timber holdings of their own in the Headwaters Unit than in some other parts of the Rocky Mountains. It isn't absolutely necessary that a pulpmill own land but inability to acquire timber holdings as a safeguard for supply, constitutes something of a mental hazard to companies planning to invest large sums in plants.

COMPOSITION BOARDS ARE A GOOD INDUSTRIAL PROSPECT

Composition boards are one of the "hottest" wood items in the American market today. The total consumption of these products in 1953 was 17 times higher than in 1925 and 9 times higher than in 1940 (figure 18). In 1953,

Figure 19. More and more composition-board is used in the outside walls of homes. Low labor costs for installation are a strong sales feature for this material.

the consumption was 1.4 million tons. An analysis by the Timber Resource Review indicates the American people will be consuming 5.8 million tons or more annually by the year 2000.

There are three good reasons for the past rapid expansion of composition-board use and the bright outlook.

- In the first place, composition boards offer several important advantages for building construction, furniture, and other purposes (figure 19). One of these advantages is relative cheapness. Another is ease of application.

- In the second place, composition boards are far from fussy in their raw material requirements. Almost any tree species can be used. So can defective logs unsuitable for lumber and plywood. Composition boards can be made from the residues of sawmills, plywood mills, mill work plants, and furniture plants.

- A third very important advantage in relation to the pulp and paper mills is that the plant investment is relatively small.

The outlook for composition board development in the Mountain States is enhanced by the fact that as this is written in 1956, there is only one operating composition-board plant in the eight states (figure 20). Composition-board plants in this area should be able to operate as cheaply as anywhere, and to the extent that they are closer to Mountain States and Prairie States markets than plants elsewhere they should enjoy a competitive advantage in these markets. This appears to be a golden opportunity.

Very little composition board is made in the West directly from logs or bolts. Practically all of it comes from the residues of sawmills and veneer mills. Because residue wood is cheap wood, we may expect most of the new composition-board plants in the coming few years to be built where such raw material is available. If that is the case, it is premature to seek to bring these plants into the Headwaters Unit until such time as there is an assured source of sawmill or plywood residue.

One can hardly overestimate the desirability of the composition-board industry. The long-run market outlook for composition boards, and the present lack of plant capacity in the Rocky Mountains are both encouraging factors. From a utilization standpoint, such an industry is ideally suited to the needs of the Headwaters Unit. The fact that 40-ton-per-day plants are feasible makes the financing much easier than for large pulpmills and paper mills. Groups which might find it is impossible to raise 10 or 15 million dollars for a sulphate plant might be able to round up the 1 or 1½ million dollars or even less needed for a composition-board plant. Depending on the processes used, composition-board plants do little or no polluting of streams.

In a region of low-per-acre yields like this, a 200-ton pulp plant might be somewhat handicapped because it has to reach out a long way to obtain all the wood it needs, thus incurring heavy procurement costs. By contrast, a composition-board plant may need as few as 14,000 cords of wood or units of chips per year. That amount of wood can be obtained from a relatively small area. Any community with one sawmill or several sawmills producing a total of 30 million board feet annually could support a composition-board plant from the residues and thus increase its timber-based employment by one-fourth. Ultimately, it is to be expected that such a composition-board plant would also make use of small trees and logging residues, thus increasing employment and income still more.

COMPOSITION BOARD PLANTS IN THE UNITED STATES - 1956

(INCLUDING SOME PROPOSED PLANTS)

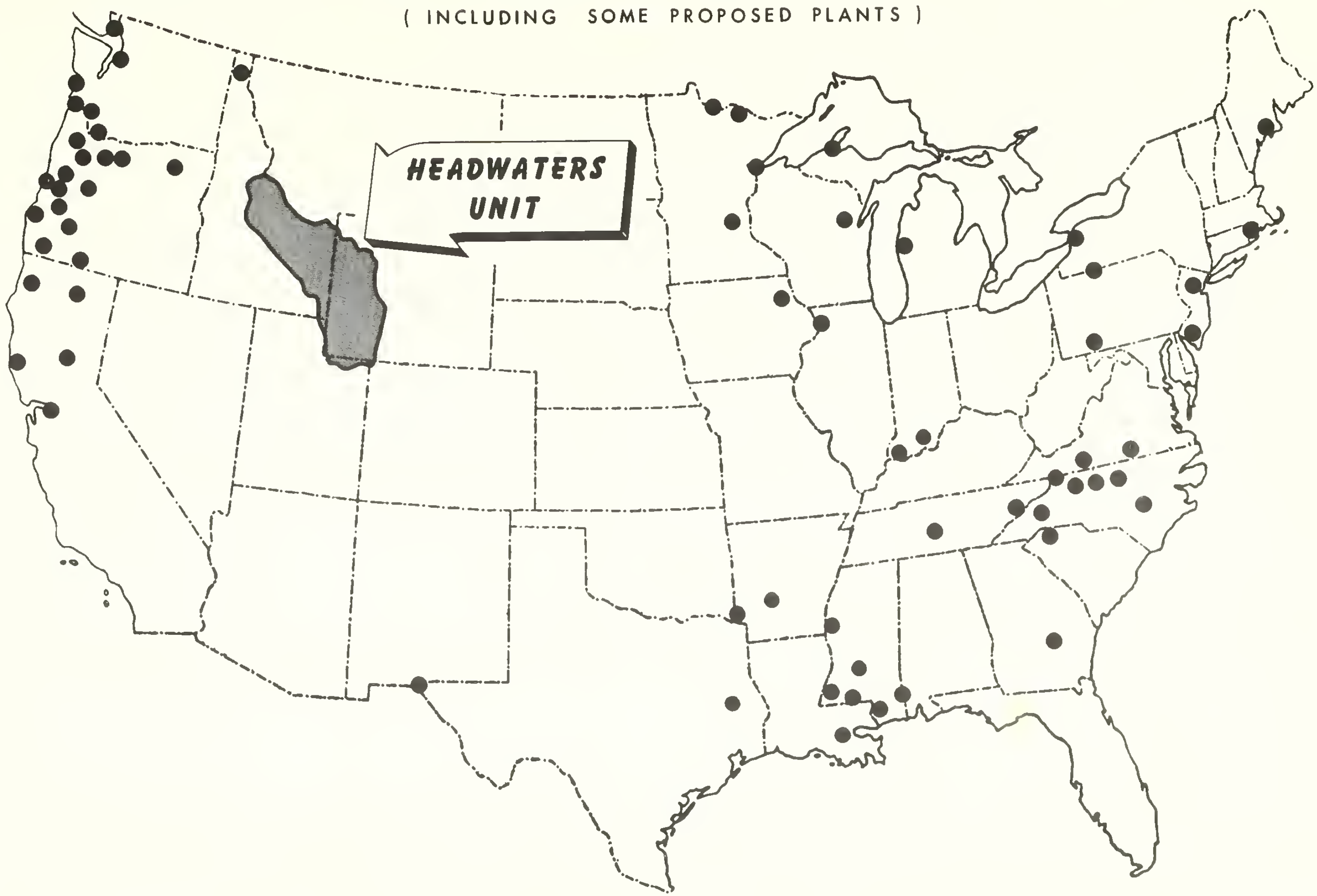

FIG 20

ECONOMIC FEASIBILITY[11]

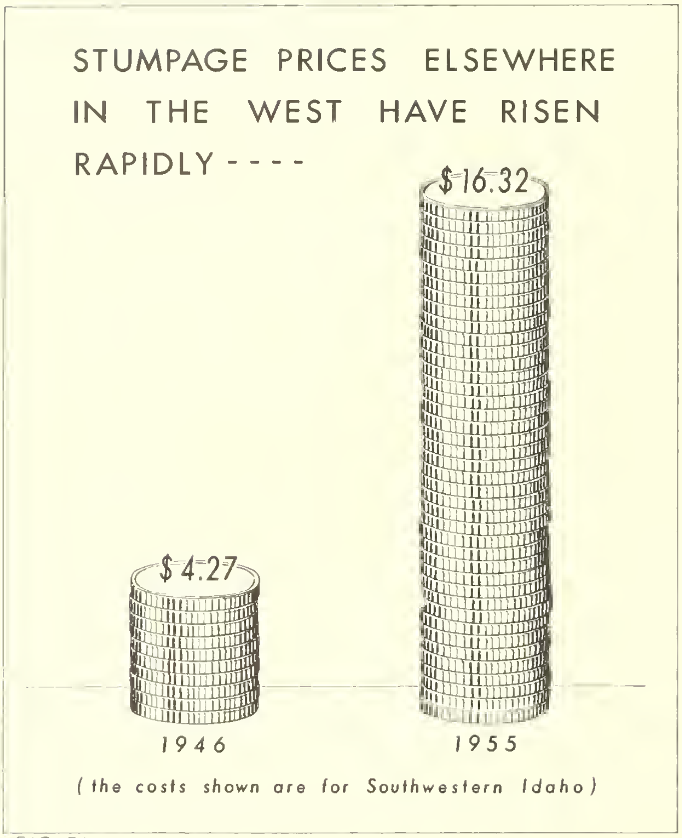

FIG 21

THE RISING COST OF WOOD ELSEWHERE GIVES THE HEADWATERS UNIT ITS LUMBER OPPORTUNITY

When the lumber industry sent its scouts west to find new timber supplies, they passed up the Headwaters Unit without a second look. Among other things, they foresaw logging would be expensive. It was, and it still is.

The thing that has changed in recent years, is that stumpage has ceased to be the dirt-cheap commodity it once was in other regions. In southwestern Idaho, for example, the larger national forest timber sales in 1955 averaged a little over $16 a thousand board feet. This is in contrast with an average sale value of $4.27 in 1946 (figure 21). Throughout the older producing areas of the West, the trend has been

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11/ Sawmills will have to use some under-sawlog-size timber as the price of operating in this area. For the purpose of calculating costs, we have assumed 20 percent of the cubic volume of wood going to sawmills would come from under-sawlog-size trees. We have assumed that 47 percent of the roundwood intake of chemical plants would be from sawtimber trees, the rest from smaller trees. Mechanical pulpmills are limited in the size of material they can use and composition-board mills using roundwood would probably be strongly integrated with sawmill operations. For that reason, it has been assumed any roundwood used by these two industries' mills would come from pole-size trees.

the same. Some recent sales of timber have, in fact, brought prices that would have been regarded as fantastic and impossible only a few years ago.

As a consequence, stumpage prices are no longer a small item of end cost to be passed over lightly. In southwestern Idaho, sawtimber stumpage prices are now about two-thirds as high as the cost of logging from stump to mill. Out on the Coast, in many instances, stumpage price equals or exceeds the logging cost. An extreme case occurred in northern Idaho where the bid price on one sale of white pine was about three times the logging cost. Timber values have not increased to the same degree on the Headwaters Unit. The only substantial volume of timber sold here during 1955 brought $4.71 a thousand board feet, which is only 10 percent of the logging cost.

The situation is briefly described in figure 22. In other regions rises in stumpage costs have gone a long way toward offsetting the advantages of lower logging costs so far as sawmills are concerned. Stumpage prices will probably rise in the Headwaters Unit but they will also rise elsewhere so the favorable situation shown can be expected to continue.

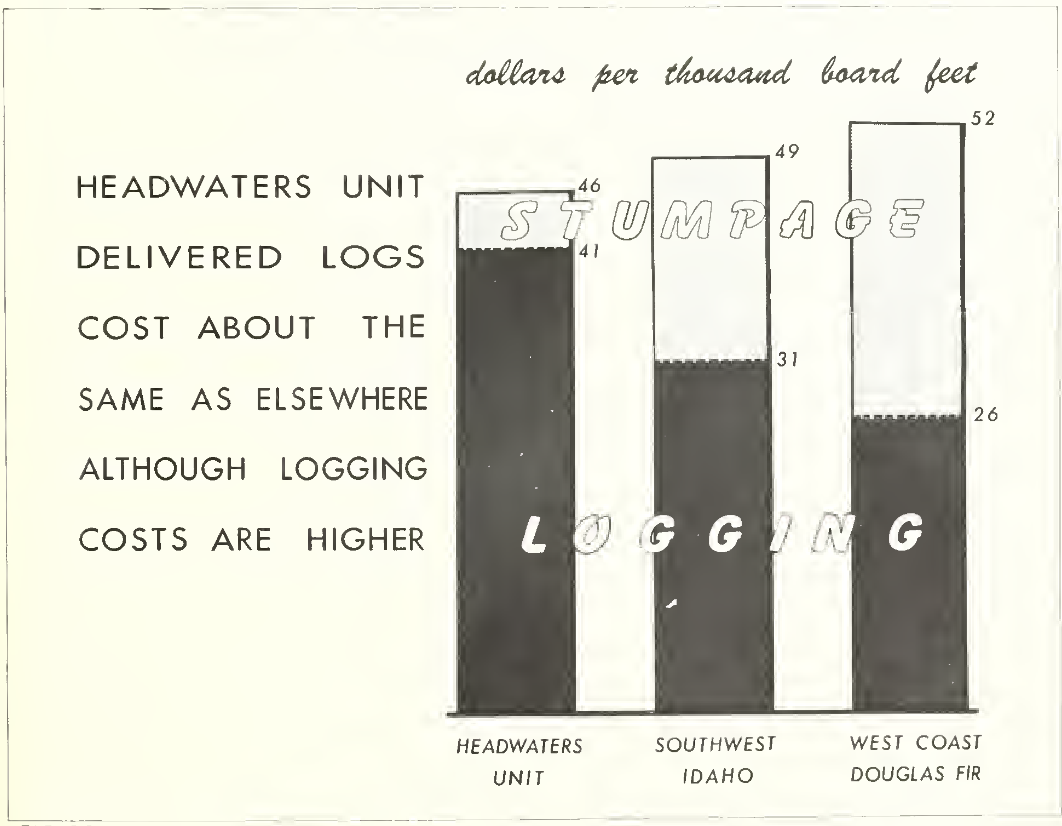
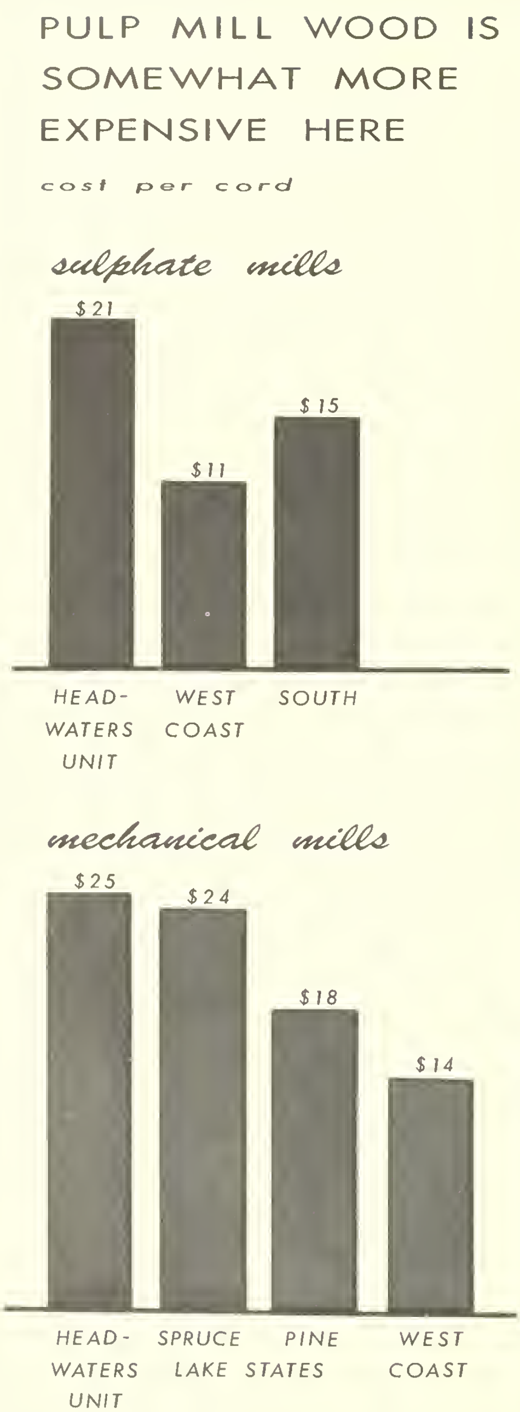


FIG 22



PULPWOOD COSTS ELSEWHERE HAVE NOT RISEN GREATLY

Pulpwood stumpage has been easier to get than saw-timber stumpage and the price consequently has not been bid up as much in other regions. Secondly, sulphate pulpmills have made increasing use of sawmill residues which up to the present at least has been a cheap raw material. In any case, the higher logging costs in the Headwaters Unit will probably be more of a deterrent to pulpmills than to sawmills. Figure 23 compares delivered pulpwood costs in this Unit with other regions.

• • • • •

Table 10 shows that if utilization is complete, the lumber industry may expect its wood to cost about $51 per thousand board feet. Pulpmills might have to pay $25 per cord for round wood.12/ However, during the first decade or two of an industrial plant's life, its costs may be lower than the table 10 estimates because of the possibility of shorter hauling distances than the averages we have computed.

12/ For calculation purposes, minimum stumpage values of $5 a thousand board feet and $1.25 a cord were assumed. Except for figure 22, costs presented are for utilization as outlined in footnote 11.

TABLE 10--AVERAGE COST OF ROUND WOOD IN THE HEADWATERS UNIT	Sawmills	Chemical pulpmills	Mechanical pulp & composition-board plants
	Per MBF	Per cord	Per cord
Logging cost stump to mill	$46.60	$23.54	$23.96
Minimum stumpage including TSI	4.81	1.64	1.25
Total procurement cost	51.41	25.18	25.21

WHY LOGGING COSTS ARE HIGH

Three factors account for the high cost of logging. First and most important is the distance between the stump and the better plant sites. Pulpmills and efficient-size sawmills must be located on railroads to market their wares effectively. The map in figure 8 shows that the Headwaters Unit is traversed by the barest skeleton of a rail network. Thus, much timber is a long way from desirable plant sites. For some sites suitable for sawmills, mechanical pulpmills or composition-board plants, the hauling distance would be fairly short. At Ashton, for example, the average haul would be 44 miles (figure 24). In other instances, the closest timber is far from the mill site and transportation becomes a full-scale problem. A plant at Kemmerer, for example, would be 42 miles from its closest wood supply and 145 miles from its farthest for an average haul of 101 miles.

Transportation looms up particularly large in the case of chemical pulpmills. Plants of a reasonable size would have to draw from such a large area that one at Green River might expect to have an average haul of 138 miles. One at Roberts would have a 154-mile haul (figure 24). Appendix tables A-11, A-12, A-13, and A-14 give additional data on hauling distances.

The shortage of rail facilities which makes hauling distances long in the first place aggravates the transportation problem in another way. In many localities, it is possible to make some use of railroads in getting the timber to the manufacturing plants. In the Headwaters Unit, only 1 percent of the haul to sawmills, mechanical

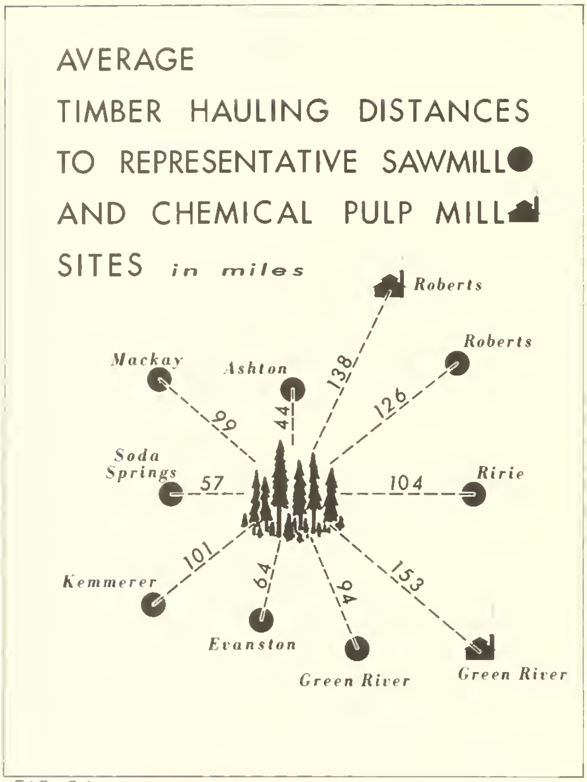


FIG 24

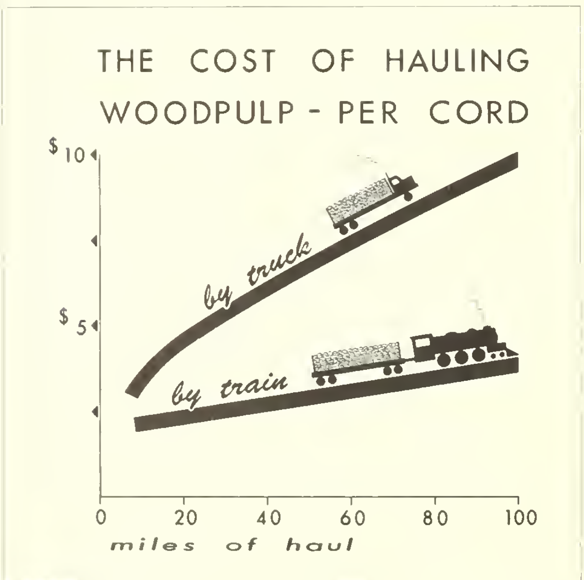


FIG 25

pulpmills, or composition-board plants and 30 percent of the haul to chemical pulpmills can be made by rail. This is a disadvantage because trucking is more expensive than rail haul. Figure 25 compares the cost of hauling pulpwood by truck and by rail for various distances. It shows, for example, that if the wood is to be hauled 100 miles at current rates, the cost would be $6.03 less per cord by rail.

As a consequence of distance and the necessity of relying heavily on trucks, hauling is the biggest single item of logging cost. For some sites, it amounts to more than half the total cost of logging (table 11).

The second reason for high logging costs is low timber volumes per acre. The average merchantable stand in the Headwaters Unit has less than 8,000 board feet per acre which is much lower than in the other important timber-producing areas of the West. It takes about the same amount of road to open up an area regardless of the yield; thus road costs in the Headwaters Unit are higher than in most other locations. Roads here will cost about $4 a thousand board feet and $1.50 a cord[13/] (table 11).

13/ These costs cannot be compared with road costs from timber sales. In making sale appraisals, arterial roads are charged against the initial sale. In this study roads are charged against all the timber to be cut in the next 100 years.

TABLE 11.--LOGGING COST--STUMP TO MILL

Cost item	Cost to sawmills	Cost to chemical pulpmills	Cost to mechanical pulp & composition-board plants
	Per MBF	Per cord	Per cord
Transportation	$21.72	$12.97	$12.40
Logging, stump to truck	20.97	9.06	10.12
Road development	3.91	1.51	1.44
Total	46.60	23.54	23.58

Small timber size is the third reason for high logging costs. Loggers in the Headwaters Unit are faced with the necessity of cutting more trees and hauling more pieces per thousand board feet and per cord than if they were favored with larger timber. For example, to fell, buck, skid, and load sawlog timber here costs 35 percent more than in southwest Idaho. This is a particular handicap to sawmills because they are competing with plants in other regions with bigger logs. It is not so much of a handicap to pulpmills because the size differential between regions is less. Table 11 gives a breakdown of logging costs for the Headwaters Unit as a whole. More detailed logging costs by national forests and plant sites are presented in tables A-15 to A-21 in the appendix.

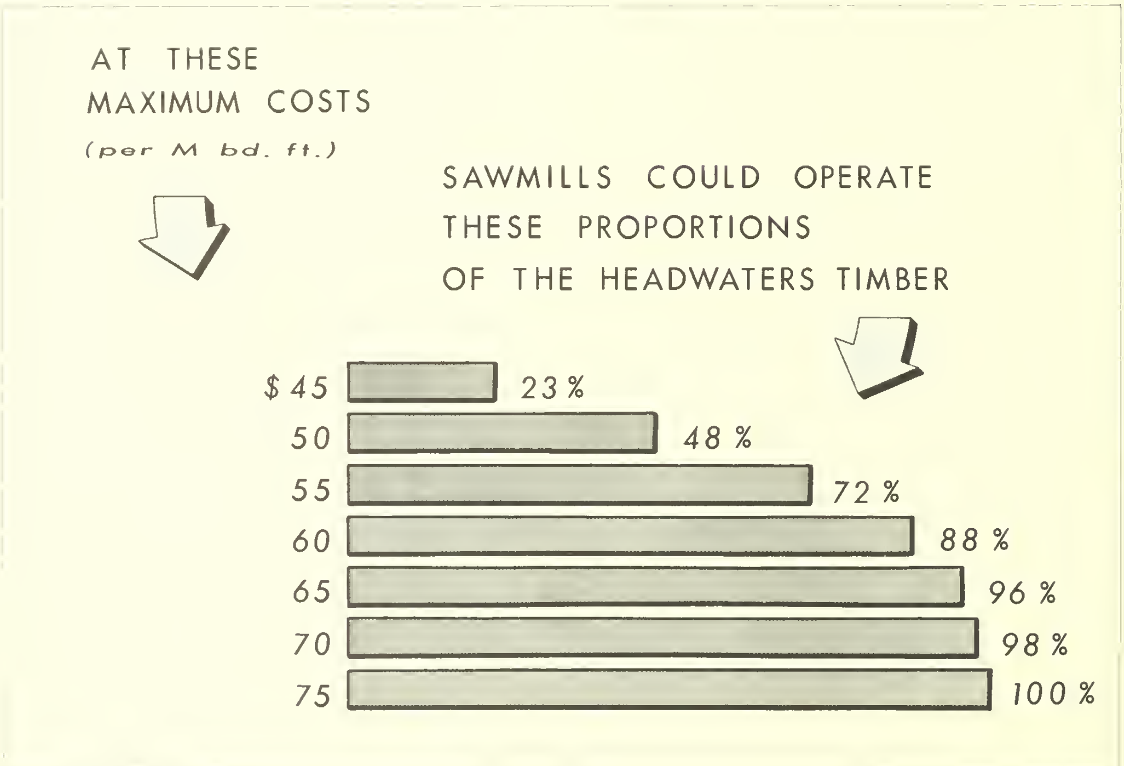
THE LUMBER INDUSTRY CAN
OPERATE VIRTUALLY ALL
THE FOREST IN THE UNIT

The most important sign pointing to expansion of the lumber industry in the Headwaters Unit is the success of sawmills cutting the same type of timber in other localities. They have proved that this timber will make good salable lumber. They have also proved that with the right mill design and equipment it is possible to hold down lumber manufacturing costs.

The best statistics available are summarized in table 12. These are not average figures in any sense. They are cost estimates that are merely indicative of the opportunity in this area. They show that with present markets and present manufacturing practices, sawmills probably could afford to pay up to $56.50 for lodgepole pine logs delivered at the plant. They probably could afford to pay up to $61.90 for mixed species. The average wood cost in the Headwaters Unit is considerably below these break-even points. As a matter of fact, in the Headwaters Unit as a whole, nearly 90 percent of the wood can be delivered to sawmills at costs below the break-even point (figure 26). Appendix tables A-18 and A-19 present data on the range of costs to the different sawmill sites.

TABLE 12.--LUMBER VALUE AND PRODUCTION COST PER THOUSAND BOARD FEET (Log Scale)

	Lodgepole pine	Mixed species
Net lumber value	$104.60	$104.60
Sawing costs	48.10	42.70
Balance for wood procurement	56.50	61.90
Av. wood procurement cost Headwaters Unit	51.41	51.41



PULPMILLS FACE A LESS FAVORABLE COST SITUATION THAN SAWMILLS

Detailed information on the cost of manufacturing pulp is not available. Consequently, it is not possible to calculate the profit opportunity for this industry. However, the differential in wood procurement costs in comparison with other regions indicates that chemical pulpmills here would operate at a cost disadvantage. The average wood procurement costs are $6 to $10 a cord above costs in either the South or the West Coast. Not even the cheapest wood available to chemical pulpmill sites in the Headwaters Unit could compete with prices in those areas. Detailed statistics on the average cost of pulpwood and the range of costs are shown in tables A-20 and A-21 in the appendix.

Opportunities for chemical pulpmills will improve with the development of a lumber industry--providing the type of lumber industry is established that can produce and market chipped sawmill residues. Chips suitable for sulphate pulp are currently selling for $7 to $7.50 a unit at sawmills in the West. If sawmills are built in the Headwaters Unit to utilize all the timber now available, there would be an opportunity to recover 94,000 units of chips. With these as a nucleus of supply, pulpmills could reduce their wood costs and the whole feasibility picture would improve. Table 13 shows the volume of chips which under these circumstances would be available to Roberts and Green River and an estimate of delivered cost.[14] The estimates are based on the assumption that sawmills would receive $7.50 a unit for their chips, the rest of the cost being for transportation.

TABLE 13.--VOLUME AND COST OF PULPABLE CHIPS IN THE HEADWATERS UNIT

	Volume	Average delivered cost
	Units	Per unit
Roberts	66,600	$10.76
Green River	21,100	10.42
Total	87,700	10.68

TABLE 14.--COST OF ROUNDWOOD AND ROUNDWOOD PLUS CHIPS TO CHEMICAL PULPMILLS per cord or unit

	Roundwood	Roundwood plus chips
Roberts	$25.87	$21.27
Green River	23.84	21.01

14/ About 6,000 units would be available to a pulpmill in Montana.

TABLE 15.--AVERAGE WOOD PROCUREMENT COSTS TO MECHANICAL PULPMILLS

Possible site	Average cost per cord pole timber
Mackay, Idaho	$30.48
Roberts, Idaho	29.70
Ashton, Idaho	20.21
Soda Springs, Idaho	21.40
Ririe, Idaho	25.84
Evanston, Wyoming	21.53
Green River, Wyoming	24.05
Kemmerer, Wyoming	24.91

Chemical pulpmills have such a large appetite for wood that their needs could not be met from sawmill residues alone. Plants of an efficient size would also have to depend heavily on roundwood. Unfortunately, the economics of residue use would not entirely offset the high roundwood procurement costs presented earlier. Table 14 shows that even by utilizing chips the cost of wood to both chemical mill sites would be over $21 per cord.

Mechanical pulpmills, likewise, would get few breaks in the Headwaters Unit at this time. The big obstacle again is the cost of wood. West Coast operators enjoy nearly a $10 a cord advantage in wood procurement costs. Costs to eight possible mechanical pulpmill sites are shown in table 15. The price of wood at even the lower-cost sites is $5 to $7 a cord above what at least some of the western pulpmills are paying. Additional information on wood costs is presented in table A-15 in the appendix.

Up to the present, mechanical pulpmills have been limited to roundwood because they were unable to grind residue material. Recent successes in grinding chips may make it possible for mechanical mills to take advantage of that cheap source of wood. Should this happen, the resource picture for this type of pulpmill would greatly improve. As a matter of fact, the opportunity from a cost standpoint would be about the same as that described for composition-board plants in the following paragraphs.

COMPOSITION-BOARD PLANTS COULD OPERATE HERE IN CONJUNCTION WITH SAWMILLS

Manufacture of composition-board is essentially a secondary industry in the West. Virtually all of the production is from sawmill and veneer mill residues. For that reason, roundwood procurement costs are not particularly significant so far as feasibility of composition-board plants is concerned. The main raw materials question in this case is the availability and cost of sawmill residues.

TABLE 16.--COST OF CHIPPED SAWMILL RESIDUES TO COMPOSITION-BOARD PLANTS

Plant site	Source of chips	Average cost per unit
Mackay	Mackay	$6.00
Ririe	Ririe	6.00
Ashton	Ashton, Roberts	7.14
Kemmerer	Kemmerer, Soda Springs	7.74
Green River	Green River, Evanston	8.43

It should cost no more to debark logs and to chip sawmill residues in the Headwaters Unit than it does anywhere else. Chips suitable for composition-board manufacture could probably be produced for $6 a unit. However, not enough chippable residue would be available in some sawmill communities to justify composition-board plants. For that reason, some transportation of chips from one community to another would be necessary. Table 16 shows how much chips would cost at sites where composition-board plants might be built.

If the assumptions we have made about the cost of producing chips are correct, the most expensive wood would not be over $8.43 a unit. While this is a little more than West Coast mills apparently are paying now, composition-board plants here would have a small freight advantage from being closer to the midwestern markets. This and whatever local markets there are should give composition-board plants in the Headwaters Unit the advantage they need to operate.

INTEGRATED UTILIZATION IS DESIRABLE

Not only would integrated utilization provide a broader industry base; it would improve the stability and competitive position of the lumber industry in three ways:

- Reduce sawmilling costs. Apparently no specific study has been made of the cost of disposing of sawmill residues. However, it takes money to operate a waste burner. Estimates of disposal costs run as high as $1.50 a thousand board feet for smaller plants. If the sawmill residues can be utilized profitably, lumber manufacturing costs can be whittled by the amount of the disposal expense.

- Increase quantity and quality of lumber yield. As far as we know, no studies have been made to determine the effect of debarking on lumber recovery. However, sawmill operators using debarkers report they get more lumber and higher quality lumber as a result. One estimate is that debarking will increase lumber values by $1 to $1.50 a thousand board feet of logs sawed.[15/]

Increase the total revenue to sawmills by giving residues value. If chips suitable for composition-board manufacture are sold for $6 a unit, sawmills might expect to make $1 to $1.50 per unit produced. This, in effect, would increase their profit per thousand board feet of lumber sawed by 40 to 60 cents.

The profit sawmills would make from producing chips is only a fraction of the total gain which would result from establishing a market for this material. A hardboard plant, for example, might net $33.30 per thousand square feet of board if sawmill residues were the raw material.[16/] This is equivalent to about $15 per unit of chips. If four-tenths of a unit of chips were recovered from each thousand board feet of logs sawed into lumber, this would amount to an added return of $6 a thousand board feet.

15/ Economics of Debarking-Sawmills, W. H. Rambo and H. A. DeRice Proceedings of the Seventh Annual Northwest Wood Products Clinic. 1952.

16/ Hardboard--The Forest Industries Latest Major Development; The Lumberman 78(3): 103; March, 1951.

A DESIRABLE INDUSTRY DEVELOPMENT

For many years the Forest Service has had to stand by and watch large quantities of wood in the Headwaters Unit be consumed by insects and decay. Much of the timber that was sold could not be harvested in a way that would achieve forest management objectives. Now the timber has come of age economically speaking, and the time is here to begin courting industry for industrial partners who can help in developing the resource. The problem is to attract the right type of industry that can best serve the long-term needs of the area.

An industry establishing in the Headwaters Unit should be expected to do more than consume wood. The plants coming here should be of types which have a good chance for success and they should play an effective part in solving the utilization problems.

INTEGRATED UTILIZATION IS NECESSARY

The cost figures we have been able to bring together indicate that all of the timber in the Headwaters Unit can be logged profitably by sawmills. Obviously, though, the lumber industry will be no panacea for the ills of the region. As already pointed out, sawmills waste from one-third to one-half of the wood in the logs they take. In addition, there is much wood in trees too small for sawmills to use. The problem of handling these small trees when they are not utilized is particularly difficult. They have to be destroyed to make way for a new crop. Clearly, a fiber industry which would utilize the wood now wasted would be highly desirable.

The economic information assembled in this report shows that the problem of getting full use of the wood in the Unit will not be solved overnight. The time may not yet be ripe for the establishment of pulp- and composition-board mills. However, we can hasten the arrival of such plants by establishing the right type of primary sawmilling industry.

FIRST ATTENTION SHOULD BE GIVEN TO EXPANDING THE LUMBER INDUSTRY

Since the lumber industry will probably be the keystone to utilization in the area, it is important to attract the type of sawmills that will truly pave the way for future improvements in utilization. The characteristics a sawmill must have to accomplish this should be considered carefully. Right now, we see three requirements that are all important:

- Most of the mills should be large enough to be able to justify planers, drykilns, and other equipment required for the manufacture of a first-class product. Furthermore, they should be large enough to justify installation of debarkers and chippers whenever a market becomes available for chips.

- Most of the sawmills should be so located as to facilitate use of their residues bv fiber industries. This means they should in most cases be on railroads so transportation of residues to fiber-using plants will not be unduly expensive. Needless to say, this precludes principal reliance upon portable sawmills with their widely scattered slab piles.

- The sawmills should be able to take part of their logs from trees smaller than sawtimber size. In the absence of other outlets for small trees, sawmills will have to take more of them than they might like to as part of the price of operating in this area. To do otherwise would only perpetuate the type of management problem we mentioned earlier in this report.

PERHAPS SOME FIBER INDUSTRY CAN BE ESTABLISHED SOON

We have pointed out in the preceding chapter that one of the drawbacks of this area is the lack of consolidated supplies of wood residues, but this is a situation which could change overnight with the establishment of the right type of sawmills. An ideal solution would be to establish plants which produce both lumber and fiber products from the start. In the past, some lumbermen have harbored the belief that it would be difficult to market lumber and fiber products through the same sales outlets. Experience has shown this need not be the case for in modern markets most of these products complement each other. Integrated plants are certainly feasible so it would be highly desirable to promote them.

THE PUBLIC HAS A BROAD RESPONSIBILITY

The Forest Service in addition to being a land-managing agency, is an arm of government concerned with public welfare. There is nothing new about this thought. We merely repeat it here to emphasize that in the Headwaters Unit with nearly all of its timber in national forests, the latter responsibility becomes particularly important. No matter what direction future policies and programs of the Forest Service take, they will have a major influence in the molding of the future timber economy. If the timber is sold in small parcels, small mills will be favored. If the sales are larger, larger mills will be encouraged to enter the picture. If degree of utilization is made a requirement of timber purchase, up-to-date plants will have an advantage and so on. This influence upon developments is an inescapable fact. It can be exercised by default or it can be recognized and used purposefully to help attract the types of industry which will bring the greatest benefit to the communities and the best use of the timber. If haphazard timber industry growth is to be avoided and if plants which will do the best job of using the timber are to be encouraged, a clear-cut industrial development program will be needed before any major commitments are made on the national forests.

One immediate problem in this area is how to insure a degree of industrial stability. In most regions wood-using plants are able to acquire some timber holdings of their own as insurance in case the breaks go against them in getting other timber. In the Headwaters Unit this is not possible and continued operation of any plant requires successful bidding for public timber. Many a lumberman has laid awake nights wondering if his investment might be jeopardized by someone outbidding him. Such a situation does not favor plants requiring a heavy capital investment. It is obvious, therefore, that desirable types of industry will find the Headwaters Unit more attractive if they can be assured of timber for a long enough period to amortize investments rather than having to operate on a hand-to-mouth basis.

Another problem is to increase forest management know-how. The past 90 years have not provided the experience needed for the job ahead. Relatively little experimental work has been done with the timber types in this area and nowhere have foresters been able to do a complete job of management. There has been relatively little cutting and finances have not permitted much more than protection. Consequently in addition to accelerating research it might be well to undertake a complete forest management program on some areas even though finances are inadequate for an intensive effort on all the land. Such "pilot plant" operations would give forest administrators a running start on the job of raising the allowable cut.

Attention should also be given to some of the broader phases of resource development. Perhaps the most important problem in this category is how to overcome the distance factor so far as local transportation is concerned. Over the years, since the transcontinental railroads opened up the Mountain States, branch lines have sprouted in all directions. As we have shown earlier, the manner of rate-making has shrunk distances for those localities served by railroads. Highways have paralleled the railroads and trucks have taken away some of their business. Nevertheless, they still form the basic framework of the transportation system.

Unfortunately, there are wide open spaces in the Headwaters Unit and elsewhere in the Rocky Mountains where rail service is not available. It is in these areas where highway trucks carry the total load of freight that the full problem of distance is felt. The conventional truck has not measured up to the task of providing low-cost transportation of sawlogs and cordwood for long distances. The challenge under these circumstances is to find ways and means to make the highways serve the functions of the absent railroads. In the case of the forests, the problem can be stated specifically as: How can the cost of hauling wood long distances by truck be reduced substantially?

Revolutionary thinking about highway transportation is necessary if the distance factor is to be licked. Perhaps the answer lies in developing entirely new equipment that is bigger, faster, or otherwise different to the point of being more efficient. Perhaps the answer is to design a different type of highway system to meet the special needs of areas without railroads. In any case, the facts we have to contend with are these:

- Full use of resources in isolated areas is not likely to be achieved until transportation facilities are developed which measure up to the need.

- It may take a very different type of highway transportation to serve areas where rail services are not available. The highways may have to be wider and have greater load-carrying capacity than present roads. Perhaps the whole traffic handling system will have to be changed.

It seems fair to suggest that the time has come for an imaginative new look at this transportation problem if the more remote areas are to make their full contribution to this country's welfare.

Figure 27. The forests of the Headwaters Unit have wood the Nation needs. How much this 5 million acre enterprise contributes to the economy of the Unit in years to come depends on the wisdom and foresight of our plans and programs today.

APPENDIX TABLES

AND EXPLANATION OF ALLOWABLE CUT CALCULATIONS

Table A-1. Commercial forest area--by national forest and forest type

Headwaters Timber Development Unit

National forest	Type						
	Douglas-fir	True firs	Spruce	Lodgepole pine[1]	Ponderosa pine	Aspen-cottonwood	Total
	Acres						
Bridger	135,642	111,221	162,717	234,122	-	87,597	731,299
Teton	46,486	36,864	161,909	316,961	-	25,608	587,828
Ashley	11,000	-	9,000	82,000	26,500	1,000	129,500
Wasatch	6,000	-	25,476	227,059	-	34,840	293,375
Cache	43,065	22,732	5,448	22,840	-	-	94,085
Caribou	95,818	10,903	808	71,105	-	123,730	302,364
Targhee	259,408	31,840	18,104	465,533	-	84,497	859,382
Salmon	459,172	33,031	19,793	338,588	94,845	2,131	947,560
Challis	588,550	48,180	23,520	259,940	2,170	2,170	924,530
Total	1,645,141	294,771	426,775	2,018,148	123,515	361,573	4,869,923

1/ Includes whitebark pine and limber pine types

Table A-2. Minimum allowable annual sawtimber[1] cut by national forest and species

Headwaters Timber Development Unit

National forest	Species[2]							
	Douglas-fir	True firs	Spruce	Lodgepole pine	Ponderosa pine	Aspen cottonwood	Other	Total
	Thousand Board Feet							
Bridger	7,363	7,170	11,526	15,401	-	302	3,760	45,522
Teton	3,073	4,488	11,841	18,456	-	94	4,084	42,036
Ashley	584	495	1,156	4,388	1,635	5	924	9,187
Wasatch	506	1,309	3,230	12,260	-	123	2,494	19,922
Cache	2,259	1,137	1,168	998	-	-	71	5,633
Caribou	4,982	988	523	3,379	-	596	85	10,553
Targhee	14,609	2,695	2,980	17,678	-	407	268	38,637
Salmon	17,349	2,772	4,272	8,418	4,467	10	218	37,506
Challis	19,764	2,968	4,702	7,040	94	10	208	34,786
Total	70,489	24,022	41,398	88,018	6,196	1,547	12,112	243,782

1/ Lodgepole pine trees 9 inches d.b.h. and larger, other species of trees 11 inches d.b.h. and larger.

2/ Minor differences between tables are due to rounding off.

Table A-3. Minimum allowable annual cut from pole-size trees[1] by national forest and species

Headwaters Timber Development Unit

National forest	Species 2/							
	Douglas-fir	True firs	Spruce	Lodgepole pine	Ponderosa pine	Aspen-cottonwood	Other	Total
	Cords							
Bridger	1,204	9,281	6,103	11,515	-	22,818	4,170	55,091
Teton	613	7,139	6,263	15,431	-	6,764	4,634	40,844
Ashley	151	1,255	779	3,968	6	290	751	7,200
Wasatch	236	3,288	2,169	10,987	-	9,126	2,048	27,854
Cache	235	907	66	1,195	-	39	49	2,491
Caribou	606	746	10	6,246	-	4,895	102	12,605
Targhee	1,669	2,693	219	25,164	-	3,782	288	33,815
Salmon	7,876	7,226	1,889	16,787	482	82	1,734	36,076
Challis	8,798	7,139	2,237	13,817	9	84	1,862	33,946
Total	21,388	39,674	19,735	105,110	497	47,880	15,638	249,922

1/ Lodgepole pine trees 5 - 9 inches d.b.h., other species of trees 5 - 11 inches d.b.h.

2/ Minor differences between tables are due to rounding off.

Table A-4. Minimum allowable annual cut from all trees 5.0" d.b.h. & larger by national forests and species

Headwaters Timber Development Unit

National forest	Species 1/							
	Douglas-fir	True firs	Spruce	Lodgepole pine 2/	Ponderosa pine	Aspen-cottonwood	Other	Total
	Thousand cubic feet							
Bridger	1,529	2,479	2,910	4,090	-	1,901	1,217	14,126
Teton	654	1,669	2,949	5,065	-	565	1,337	12,239
Ashley	130	227	299	1,233	281	24	278	2,472
Wasatch	129	591	835	3,444	-	761	753	6,513
Cache	396	373	240	297	-	3	19	1,328
Caribou	899	334	109	1,201	-	541	25	3,109
Targhee	2,622	927	604	5,653	-	404	76	10,286
Salmon	3,824	1,114	900	2,949	760	9	183	9,739
Challis	4,350	1,148	1,001	2,442	16	9	192	9,158
Total	14,533	8,862	9,847	26,374	1,057	4,217	4,080	68,970

1/ Minor differences between tables are due to rounding off.

2/ Includes whitebark pine and limber pine types.

Table A-5. Minimum allowable annual sawtimber cut [1/] by species in areas tributary to selected sawmill sites

Headwaters Timber Development Unit

Mill site	Species [2/]							
	Douglas-fir	True firs	Spruce	Lodgepole pine	Ponderosa pine	Aspen-cottonwood	Other	Total
	Thousand Board Feet							
Darby	7,336	851	1,151	2,531	3,981	6	68	15,924
Mackay	25,341	4,012	6,614	10,536	455	12	294	47,264
Ashton	8,283	1,516	1,789	15,037	-	217	146	26,988
Roberts	7,244	1,614	1,701	2,942	126	41	124	13,792
Ririe	12,484	7,770	16,254	26,249	-	420	5,487	68,664
Soda Springs	5,981	2,371	2,013	5,298	-	524	564	16,751
Kemmerer	2,545	3,709	7,179	7,863	-	172	1,859	23,327
Green River	682	861	1,586	6,050	1,635	32	1,273	12,119
Evanston	592	1,318	3,111	11,513		122	2,297	18,953
Total	70,488	24,022	41,398	88,019	6,197	1,546	12,112	243,782

1/ Lodgepole pine trees 9 inches d.b.h. and larger, other trees 11 inches d.b.h. and larger.

2/ Minor differences between tables are due to rounding off.

Table A-6. Minimum allowable annual cut from pole-size trees [1/] by species in areas tributary to selected sawmill sites

Headwaters Timber Development Unit

Mill site	Species [2/]							
	Douglas-fir	True firs	Spruce	Lodgepole pine	Ponderosa pine	Aspen-cottonwood	Other	Total
	Cords							
Darby	3,053	2,227	556	5,148	412	46	565	12,007
Mackay	11,464	9,963	3,004	20,752	58	100	2,487	47,828
Ashton	985	1,654	149	21,440	-	2,154	149	26,531
Roberts	2,442	2,791	571	5,324	22	366	605	12,121
Ririe	1,886	11,154	8,172	23,711	-	10,984	6,083	61,990
Soda Springs	743	2,314	537	7,204	-	9,818	472	21,088
Kemmerer	399	4,589	3,674	5,697	-	13,026	2,389	29,774
Green River	184	1,871	1,081	5,410	6	2,310	1,014	11,876
Evanston	232	3,110	1,990	10,423	-	9,078	1,874	26,707
Total	21,388	39,673	19,734	105,109	498	47,882	15,638	249,922

1/ Lodgepole pine trees 5 - 9 inches d.b.h., other trees 5 - 11 inches d.b.h.

2/ Minor differences between tables are due to rounding off.

Table A-7. Minimum allowable annual cut from all trees 5.0" d.b.h. and larger by species in area tributary to selected sawmill sites

Headwaters Timber Development Unit

Mill site	Species 1/							
	Douglas-fir	True firs	Spruce	Lodgepole pine	Ponderosa pine	Aspen-cottonwood	Other	Total
	Thousand Cubic Feet							
Darby	1,587	343	247	894	673	5	59	3,808
Mackay	5,593	1,575	1,395	3,664	80	11	259	12,577
Ashton	1,509	533	362	4,819	-	227	41	7,491
Roberts	1,484	586	361	990	24	40	73	3,558
Ririe	2,444	2,818	4,008	7,332	-	984	1,777	19,363
Soda Springs	1,099	804	456	1,677	-	916	166	5,118
Kemmerer	525	1,258	1,810	2,060	-	1,085	630	7,368
Green River	153	364	412	1,695	281	193	381	3,479
Evanston	141	581	794	3,243	-	757	692	6,208
Total	14,535	8,862	9,845	26,374	1,058	4,218	4,078	68,970

1/ Minor difference between tables are due to rounding off.

Table A-8. Minimum allowable annual sawtimber1/ cut by species in areas tributary to selected pulpmill sites

Headwaters Timber Development Unit

Species2/	Pulpmill sites			
	Green River	Roberts	Missoula	Total
	Thousand Board Feet			
Douglas-fir	6,592	56,560	7,336	70,488
True firs	7,614	15,557	851	24,022
Spruce	13,546	26,701	1,151	41,398
Lodgepole pine	28,277	57,212	2,531	88,020
Ponderosa pine	1,634	580	3,981	6,195
Aspen-cottonwood	469	1,072	6	1,547
Other	5,939	6,105	68	12,112
Total	64,071	163,787	15,924	243,782

1/ Lodgepole pine trees 9 inches d.b.h. and larger, other trees 11 inches d.b.h. and larger.

2/ Minor differences between tables are due to rounding off.

Table A-9. Minimum allowable annual cut from pole-size trees[1] by species in areas tributary to selected chemical pulpmill sites

Headwaters Timber Development Unit

Species[2]	Pulpmill sites			
	Green River	Roberts	Missoula	Total
	- - - - - - - - - - - - - C o r d s - - - - - - - - - - - - -			
Douglas-fir	1,172	17,162	3,054	21,388
True firs	11,384	26,063	2,227	39,674
Spruce	7,276	11,903	556	19,735
Lodgepole pine	24,331	75,630	5,148	105,109
Ponderosa pine	6	80	411	497
Aspen-cottonwood	31,098	16,736	46	47,880
Other	5,684	9,390	565	15,639
Total	80,951	156,964	12,007	249,922

1/ Lodgepole pine trees 5 - 9 inches d.b.h., other trees 5 - 11 inches d.b.h.

2/ Minor differences between tables are due to rounding off.

Table A-10. Minimum allowable annual cut from trees 5.0 inches d.b.h. and larger by species in areas tributary to selected chemical pulpmill sites

Headwaters Timber Development Unit

Species[1]	Pulpmill sites			
	Green River	Roberts	Missoula	Total
	- - - - Thousand Cubic Feet - - - - - -			
Douglas-fir	1,339	11,609	1,587	14,535
True firs	2,788	5,731	343	8,862
Spruce	3,400	6,197	247	9,844
Lodgepole Pine	7,815	17,666	894	26,375
Ponderosa pine	281	103	673	1,057
Aspen-cottonwood	2,605	1,608	5	4,218
Other	1,853	2,167	59	4,079
Total	20,081	45,081	3,808	68,970

1/ Minor differences between tables are due to rounding off.

Table A-11. Minimum allowable annual sawtimber[1/] cut from 9 national forests tributary to selected sawmill sites and average hauling distance to each

Headwaters Timber Development Unit

Sawmill sites	Ashley Volume	Ashley Av. haul	Bridger Volume	Bridger Av. haul	Cache Volume	Cache Av. haul	Caribou Volume	Caribou Av. haul	Challis Volume	Challis Av. haul	Salmon Volume	Salmon Av. haul	Targhee Volume	Targhee Av. haul	Teton Volume	Teton Av. haul	Wasatch Volume	Wasatch Av. haul	Total Volume	Total Av. haul
	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.	M bd.ft.	Mi.
Ashton	-	-	-	-	-	-	-	-	-	-	-	-	26,988	45	-	-	-	-	26,988	45
Mackay	-	-	-	-	-	-	-	-	34,786	89	12,478	119	-	-	-	-	-	-	47,264	97
Ririe	-	-	15,987	85	-	-	3,680	49	-	-	-	-	6,961	44	42,036	124	-	-	68,664	103
Roberts	-	-	-	-	-	-	-	-	-	-	9,104	148	4,688	69	-	-	-	-	13,792	121
Soda Springs	-	-	4,958	80	4,920	43	6,873	48	-	-	-	-	-	-	-	-	-	-	16,751	56
Evanston	-	-	-	-	713	50	-	-	-	-	-	-	-	-	-	-	18,240	66	18,953	65
Green River	9,187	95	1,250	109	-	-	-	-	-	-	-	-	-	-	-	-	1,682	72	12,119	93
Kemmerer	-	-	23,327	102	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23,327	102
Darby	-	-	-	-	-	-	-	-	-	-	15,924	83	-	-	-	-	-	-	15,924	83
Total	9,187	95	45,522	94	5,633	44	10,553	48	34,786	89	37,506	111	38,637	48	42,036	124	19,922	67	243,782	88

1/ Lodgepole pine trees 9 inches d.b.h. and larger; other species of trees 11 inches d.b.h. and larger.

Table A-12. Minimum allowable annual poletimber[1/] cut from 9 national forests tributary to selected sawmill sites and average hauling distances to each

Headwaters Timber Development Unit

Sawmill sites	Ashley Volume	Ashley Av. haul	Bridger Volume	Bridger Av. haul	Cache Volume	Cache Av. haul	Caribou Volume	Caribou Av. haul	Challis Volume	Challis Av. haul	Salmon Volume	Salmon Av. haul	Targhee Volume	Targhee Av. haul	Teton Volume	Teton Av. haul	Wasatch Volume	Wasatch Av. haul	Total Volume	Total Av. haul
	Cords	Mi.	Cords	Mi.	Cords	Mi.	Cords	Mi.	Cords	Mi.	Cords	Mi.	Cords	Mi.	Cords	Mi.	Cords	Mi.	Cords	Mi.
Ashton	-	-	-	-	-	-	-	-	-	-	-	-	26,531	44	-	-	-	-	26,531	44
Mackay	-	-	-	-	-	-	-	-	33,946	95	13,882	120	-	-	-	-	-	-	47,828	103
Ririe	-	-	12,505	85	-	-	3,291	49	-	-	-	-	5,350	38	40,844	123	-	-	61,990	104
Roberts	-	-	-	-	-	-	-	-	-	-	10,187	152	1,934	68	-	-	-	-	12,121	138
Soda Springs	-	-	9,746	74	2,028	43	9,314	46	-	-	-	-	-	-	-	-	-	-	21,088	58
Evanston	-	-	-	-	463	51	-	-	-	-	-	-	-	-	-	-	26,244	62	26,707	62
Green River	7,200	95	3,066	109	-	-	-	-	-	-	-	-	-	-	-	-	1,610	72	11,876	96
Kemmerer	-	-	29,774	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29,774	100
Darby	-	-	-	-	-	-	-	-	-	-	12,007	85	-	-	-	-	-	-	12,007	85
Total	7,200	95	55,091	92	2,491	44	12,605	47	33,946	95	36,076	117	33,815	44	40,844	123	27,854	63	249,922	89

1/ Lodgepole pine trees 5 - 9 inches d.b.h., other trees 5-11 inches d.b.h.

Minimum allowable annual cut of all trees 5.0 inches d.b.h. and larger from 9 national forests tributary to selected sawmill sites and average hauling distance to each

Headwaters Timber Development Unit

Sawmill sites	Ashley		Bridger		Cache		Caribou		Challis		Salmon		Targhee		Teton		Wasatch		Total	
	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul	Volume	Av. haul
	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.	M cu.ft.	Mi.
Ashton	-		-	-	-	-	-	-	-	-	-	-	7,491	44	-	-	-	-	7,491	44
Mackay	-		-	-	-	-	-	-	9,158	91	3,419	119	-	-	-	-	-	-	12,577	99
Ririe	-		4,393	85	-	-	982	49	-	-	-	-	1,749	42	12,239	124	-	-	19,363	104
Roberts	-		-	-	-	-	-	-	-	-	2,512	150	1,046	69	-	-	-	-	3,558	126
Soda Springs	-		1,847	77	1,144	43	2,127	47	-	-	-	-	-	-	-	-	-	-	5,118	57
Evanston	-		-	-	184	50	-	-	-	-	-	-	-	-	-	-	6,024	65	6,208	64
Green River	2,472	95	518	109	-	-	-	-	-	-	-	-	-	-	-	-	489	72	3,479	94
Kemmerer	-		7,368	101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,368	101
Darby	-		-	-	-	-	-	-	-	-	3,808	84	-	-	-	-	-	-	3,808	84
Total	2,472	95	14,126	93	1,328	44	3,109	48	9,158	91	9,739	113	10,286	46	12,239	124	6,513	66	68,970	89

Table A-14. Minimum allowable annual cut from 9 national forests tributary to selected chemical pulpmill sites and average hauling distance to each

Headwaters Timber Development Unit

Chemical pulp mill site	Ashley		Bridger		Cache		Caribou		Challis		Salmon		Targhee		Teton		Wasatch		Total	
	Volume	Mi.	Volume	Mi.	Volume	Mi.	Volume	Mi.	Volume	Mi.	Volume	Mi.	Volume	Mi.	Volume	Mi.	Volume	Mi.	Volume	Mi.
Sawtimber[1] volume in thousand board feet																				
Roberts	-	-	15,987	109	968	152	9,791	97	34,786	218	21,582	206	38,637	100	42,036	148	-	-	163,787	[illegible]
Green River	9,187	95	29,535	163	4,665	166	762	165	-	-	-	-	-	-	-	-	19,922	111	64,071	[illegible]
Total	9,187	95	45,522	144	5,633	164	10,553	102	34,786	218	21,582	206	38,637	100	42,036	148	19,922	111	227,858	148
Poletimber[2] volume in cords																				
Roberts	-	-	12,505	109	317	152	11,468	105	33,946	221	24,069	208	33,815	102	40,844	147	-	-	156,964	[illegible]
Green River	7,200	95	42,586	158	2,174	166	1,137	167	-	-	-	-	-	-	-	-	27,854	119	80,951	139
Total	7,200	95	55,091	147	2,491	164	12,605	111	33,946	221	24,069	208	33,815	102	40,844	147	27,854	119	237,915	151
Volume of all trees[3] in thousand cubic feet																				
Roberts	-	-	4,393	109	208	152	2,866	100	9,158	220	5,931	206	10,286	100	12,239	148	-	-	45,081	[illegible]
Green River	2,472	95	9,733	161	1,120	166	243	166	-	-	-	-	-	-	-	-	6,513	114	20,081	[illegible]
Total	2,472	95	14,126	145	1,328	164	3,109	105	9,158	220	5,931	206	10,286	100	12,239	148	6,513	114	65,162	148

1/ Lodgepole pine trees 9 inches d.b.h. and larger, other trees 11 inches and larger
2/ Lodgepole pine trees 5 to 9 inches d.b.h., other trees 5 to 11 inches
3/ All trees 5 inches and larger

Table A-15. Minimum allowable annual cut tributary to selected sawmill sites and cost of wood procurement to each

Headwaters Timber Development Unit

Mill site	National forest	Sawtimber							Pole Timber						
		Volume	Average cost per thousand board feet -- dollars						Volume	Average cost per cord -- dollars					
		M bd. ft.	Stumpage & T.S.I 1/	Roads	Stump to truck 2/	Transportation	Profit	Total	(cords)	Stumpage & T.S.I 1/	Roads	Stump to truck 2/	Transportation	Profit	Total
Ashton	Targhee	26,988	5.00	2.47	16.50	10.58	3.79	38.34	26,531	1.25	0.88	8.88	6.98	2.22	20.21
Mackay	Challis	34,786	5.00	6.29	16.50	21.68	5.34	54.81	33,946	1.25	2.42	8.88	15.78	3.45	31.78
	Salmon	12,478	5.00	3.27	16.50	18.91	4.96	48.64	13,882	1.25	1.24	8.88	12.87	3.04	27.28
Subtotal		47,264	5.00	5.49	16.50	20.95	5.24	53.18	47,828	1.25	2.08	8.88	14,94	3.33	30.48
Ririe	Bridger	15,987	5.00	3.21	16.50	14.57	4.35	43.63	12,505	1.25	1.26	8.88	9.68	2.59	23.66
	Caribou	3,680	5.00	3.06	16.50	10.80	3.82	39.18	3,291	1.25	1.17	8.88	7.28	2.26	20.84
	Targhee	6,961	5.00	5.34	16.50	9.97	3.71	40.52	5,350	1.25	1.89	8.88	6.30	2.12	20.44
	Teton	42,036	5.00	4.03	16.50	19.37	5.02	49.92	40,844	1.25	1.53	8.88	12.90	3.05	27.61
Subtotal		68,664	5.00	3.92	16.50	16.84	4.67	46.93	61,990	1.25	1.49	8.88	11.39	2.83	25.84
Roberts	Salmon	9,104	5.00	4.63	16.50	22.35	5.44	53.92	10,187	1.25	1.70	8.88	15.87	3.46	31.16
	Targhee	4,688	5.00	2.18	16.50	13.22	4.16	41.06	1,934	1.25	0.89	8.88	8.56	2.44	22.02
Subtotal		13,792	5.00	3.80	16.50	19.25	5.00	49.55	12,121	1.25	1.57	8.88	14.70	3.30	29.70
Soda Springs	Bridger	4,958	5.00	3.17	16.50	13.10	4.14	41.91	9,746	1.25	1.24	8.88	8.34	2.41	22.12
	Cache	4,920	5.00	2.78	16.50	9.29	3.61	37.18	2,028	1.25	1.22	8.88	6.29	2.12	19.76
	Caribou	6,873	5.00	4.63	16.50	10.39	3.76	40.28	9,314	1.25	1.87	8.88	6.81	2.19	21.00
Subtotal		16,751	5.00	3.65	16.50	10.87	3.83	39.85	21,088	1.25	1.52	8.88	7.46	2.29	21.40
Evanston	Cache	713	5.00	3.47	16.50	10.95	3.84	39.76	463	1.25	1.35	8.88	7.43	2.28	21.19
	Wasatch	18,240	5.00	2.77	16.50	12.20	4.02	40.49	26,244	1.25	1.10	8.88	7.96	2.35	21.54
Subtotal		18,953	5.00	2.80	16.50	12.15	4.01	40.46	26,707	1.25	1.10	8.88	7.95	2.35	21.53
Green River	Ashley	9,187	5.00	1.85	16.50	15.13	4.43	42.91	7,200	1.25	0.66	8.88	10.25	2.67	23.71
	Bridger	1,250	5.00	4.11	16.50	16.48	4.62	46.71	3,066	1.25	1.83	8.88	11.04	2.79	25.79
	Wasatch	1,682	5.00	3.20	16.50	12.64	4.08	41.42	1,610	1.25	1.22	8.88	8.50	2.43	22.28
Subtotal		12,119	5.00	2.27	16.50	14.92	4.40	43.09	11,876	1.25	1.04	8.88	10.21	2.67	24.05
Kemmerer	Bridger	23,327	5.00	2.80	16.50	16.38	4.60	45.28	29,774	1.25	1.09	8.88	10.92	2.77	24.91
Darby	Salmon	15,924	5.00	4.29	16.50	14.51	4.34	44.64	12,007	1.25	1.66	8.88	9.96	2.63	24.38
All sites		243,782	5.00	3.79	16.50	16.01	4.55		249,922	1.25	1.44	8.88	10.88	2.76	25.21

1/ T.S.I. refers to the portion of stumpage receipts the Forest Service is authorized to use for Timber Stand Improvement Work.
2/ Felling, bucking, skidding, and loading.

Table A-16. Minimum allowable annual cut available[1/] for lumber by tree size class tributary to selected sawmill sites and the average wood procurement cost to each

The Headwaters Timber Development Unit

Mill site	Pole trees		Sawtimber		All timber	
	Volume in M bd. ft.	Cost per M bd. ft.	Volume in M bd. ft.	Cost per M bd. ft.	Volume in M bd. ft.	Cost per M bd. ft.
Darby	2,278	$76.19	12,739	$44.64	15,017	$49.43
Mackay	7,000	95.25	37,812	53.18	44,812	59.75
Roberts	2,070	92.81	11,034	49.55	13,104	56.38
Ashton	4,295	63.16	21,591	38.34	25,886	42.46
Soda Springs	2,745	66.87	13,400	39.85	16,145	44.44
Ririe	11,523	80.75	54,930	46.93	66,453	52.79
Evanston	3,257	67.28	15,163	40.46	18,420	45.20
Green River	2,024	75.16	9,695	43.09	11,719	48.63
Kemmerer	3,989	77.84	18,662	45.28	22,651	51.01
Total	39,181	$79.11	195,026	$45.85	234,207	$51.41

1/ For the purpose of making cost calculations, we have assumed 20 percent of the cubic volume of wood going to sawmills would come from pole-size trees.

Table A-17. Minimum allowable annual cut tributary to selected chemical pulpmill sites and cost of wood procurement to each

Headwaters Timber Development Unit

Mill site	National forest	Sawtimber: Volume M bd. ft.	Sawtimber: Average cost per thousand board feet -- dollars: Stumpage & T.S.I.1/	Roads	Stump to truck 2/	Transportation	Profit	Total	Pole timber: Volume cords	Pole timber: Average cost per cord -- dollars: Stumpage & T.S.I.1/	Roads	Stump to truck 2/	Transportation	Profit	Total
Roberts	Bridger	15,987	5.00	3.21	16.50	17.41	4.75	46.87	12,505	1.25	1.26	8.88	11.67	2.87	25.93
	Cache	968	5.00	2.68	16.50	14.32	4.32	42.82	317	1.25	1.02	8.88	9.57	2.58	23.30
	Challis	34,786	5.00	6.29	16.50	29.32	6.42	63.53	33,946	1.25	2.42	8.88	20.83	4.16	37.54
	Caribou	9,791	5.00	3.79	16.50	14.01	4.27	43.57	11,468	1.25	1.56	8.88	9.66	2.59	23.94
	Salmon	21,582	5.00	3.84	16.50	24.86	5.79	55.99	24,069	1.25	1.43	8.88	17.10	3.63	32.29
	Targhee	38,637	5.00	2.95	16.50	13.99	4.27	42.71	33,815	1.25	1.04	8.88	9.35	2.55	23.07
	Teton	42,036	5.00	4.03	16.50	22.61	5.47	53.61	40,844	1.25	1.53	8.88	15.06	3.35	30.07
Subtotal		163,787	5.00	4.13	16.50	21.23	5.28	52.14	156,964	1.25	1.58	8.88	14.72	3.30	29.73
Green River	Ashley	9,187	5.00	1.85	16.50	15.13	4.43	42.91	7,200	1.25	0.66	8.88	10.25	2.67	23.71
	Bridger	29,535	5.00	2.92	16.50	20.82	5.22	50.46	42,586	1.25	1.18	8.88	13.34	3.11	27.76
	Cache	4,665	5.00	2.91	16.50	15.51	4.48	44.40	2,174	1.25	1.14	8.88	10.40	2.70	24.37
	Caribou	762	5.00	7.54	16.50	14.47	4.34	47.85	1,137	1.25	2.96	8.88	10.14	2.66	25.89
	Wasatch	19,922	5.00	2.81	16.50	16.60	4.63	45.54	27,854	1.25	1.11	8.88	11.24	2.81	25.29
Subtotal		64,071	5.00	2.79	16.50	18.23	4.86	47.38	80,951	1.25	1.13	8.88	12.22	2.95	26.43
Missoula	Salmon	15,924	5.00	4.29	16.50	21.25	5.29	52.33	12,007	1.25	1.66	8.88	14.27	3.24	29.30
Total		243,782	5.00	3.79	16.50	20.44	5.17	50.90	249,922	1.25	1.44	8.88	13.89	3.18	28.64

1/ T.S.I. refers to the portion of stumpage receipts the Forest Service is authorized to use for Timber Stand Improvement Work.
2/ Felling, bucking, skidding, and loading.

Table A-18. Current allowable annual sawtimber cut tributary to selected sawmill sites classified by total cost of wood procurement

Headwaters Timber Development Unit

Cost class	Sawmill Sites									
	Ashton	Mackay	Ririe	Roberts	Soda Springs	Evanston	Green River	Kemmerer	Darby	Total
	M Board Feet									
Less than $35.00	-	447	686	-	1,003	-	-	-	-	2,136
$35.00 - $40.00	23,203	3,169	7,109	2,811	6,778	7,182	-	322	2,937	53,511
$40.00 - $45.00	3,785	13,654	16,415	1,877	8,729	11,771	10,784	8,678	4,195	79,888
$45.00 - $50.00	-	19,724	21,771	2,318	241	-	1,321	13,417	7,581	66,373
$50.00 - $55.00	-	10,270	19,316	2,367	-	-	14	910	1,211	34,088
$55.00 - $60.00	-	-	3,367	4,419	-	-	-	-	-	7,786
Total	26,988	47,264	68,664	13,792	16,751	18,953	12,119	23,327	15,924	243,782

Table A-19. Minimum allowable annual cut from pole-size trees 1/ tributary to selected sawmill sites classified by the total cost of wood procurement

Headwaters Timber Development Unit

Cost class	Sawmill sites									
	Ashton	Mackay	Ririe	Roberts	Soda Springs	Evanston	Green River	Kemmerer	Darby	Total
	Cords									
Less than $20.00	12,459	859	3,437	183	3,908	-	-	-	640	21,486
$20.00 - $25.00	14,072	17,412	24,469	1,751	17,180	26,707	8,810	12,026	6,578	129,005
$25.00 - $30.00	-	26,964	25,541	5,200	-	-	3,066	17,748	4,789	83,308
$30.00 - $35.00	-	2,593	8,543	4,234	-	-	-	-	-	15,370
$35.00 - $40.00	-	-	-	753	-	-	-	-	-	753
Total	26,531	47,828	61,990	12,121	21,088	26,707	11,876	29,774	12,007	249,922

1/ Lodgepole pine trees 5 - 9 inches d.b.h. other trees 5 - 11 inches d.b.h.

Table A-20. Minimum allowable annual cut available [1] for pulp by tree-size class tributary to selected chemical pulpmill sites and the average wood procurement cost to each

Headwaters Timber Development Unit

Mill site	Sawtimber	Poletimber	All timber
	- - - - - - Volume of allowable cut - cords	- - - - - -	- - - - - -
Roberts	76,526	75,655	152,181
Green River	32,013	46,937	78,950
Missoula	6,700	4,888	11,588
Total	115,239	127,480	242,719
	- - - - - - - - Cost per cord - dollars	- - - - - -	- - - - - -
Roberts	$22.06	$29.73	$25.87
Green River	20.04	26.43	23.84
Missoula	22.13	29.30	25.15
Total	$21.50	$28.50	$25.18

1/ For the purpose of making cost calculations we have assumed 47 percent of the wood to chemical pulpmills would come from sawtimber trees and 53 percent from pole trees. This amounts to 20 percent of the cubic volume of sawtimber going to pulp.

Table 21. Current allowable annual cut from sawtimber and pole trees tributary to selected pulpmill sites classified by total cost of wood procurement

Headwaters Timber Development Unit

Cost class	Cord wood from pole trees			Sawtimber		
	Mill sites			Mill sites		
	Roberts	Green River	Total	Roberts	Green River	Total
	- - - - - Cords	- - - - - - -		- - - Thousand board feet	- - - - - -	
Less than $20.00	1,035		1,035	-	-	
$20.00-$25.00	44,816	15,768	60,584	-	-	
$25.00-$30.00	52,555	58,411	110,966	-	-	
$30.00-$35.00	52,726	6,772	59,498	-	-	
$35.00-$40.00	5,832	-	5,832	9,390	-	9,390
$40.00-$45.00	-	-	-	34,957	18,115	53,072
$45.00-$50.00	-	-	-	31,754	29,813	61,567
$50.00-$55.00	-	-	-	39,761	13,060	52,821
$55.00-$60.00	-	-	-	36,009	3,083	39,092
$60.00-$65.00	-	-	-	11,916	-	11,916
Total	156,964	80,951	237,915	163,787	64,071	227,858

ALLOWABLE CUT CALCULATIONS

Allowable cut has been defined as the desirable annual cut for a particular period considering the nature of the present stand, the degree of anticipated utilization, and the management being undertaken. Any estimate at this time contains a big element of judgment. For that reason, it is to be expected that present allowable cut estimates will have to be revised as trends in utilization and management become more clearly established. Furthermore, these calculations are based on rather extensive data. More detailed information in the future might justify revising the allowable cut estimates. For the purposes of this analysis, three allowable cut estimates were calculated:

1. A minimum average allowable cut for the first rotation.
2. A maximum average allowable cut for the first rotation.
3. A reasonable average allowable cut for the following rotation.

Minimum allowable cut for the first rotation

This estimate was derived for each type by the formula:

$$C = \frac{AV}{R}$$

C = Allowable cut for the type
A = Area in the type
V = Average volume per acre of sawtimber stands
R = Rotation

The following rotations were used:

Lodgepole pine	100 years	Spruce	140 years
Douglas-fir	160 "	Alpine fir	100 "
Ponderosa pine	160 "	Hardwoods	60 "

Maximum allowable cut for the first rotation

Since the majority of the stands to be logged in the first rotation have already reached maturity, the best opportunity for increasing the allowable cut above the minimum is in capturing the heavy mortality losses. Annual mortality is estimated to be:

36 board feet per acre per year in sawtimber stands
0.12 cord per acre per year in pole stands.

If all this mortality could be captured, the cut from this source could be 110 million board feet and 147 thousand cords.

	Sawtimber	Poletimber
	MM board feet	M cords
Minimum allowable cut	244	250
Current mortality	110	147
Maximum allowable cut	354	397

Actually, as present older stands are cut over the volume available from mortality sawlogs will decline. However, it is anticipated that this decline will be offset by higher yields in future sawtimber stands plus intermediate yields. In any case, 354 million board feet and 397 thousand cords probably represent the maximum cut that can be obtained as long as we are primarily dependent upon stands we now have.

A reasonable allowable cut for the next rotation

Timber stands cut in the next rotation will not have suffered the effects of old-age that have reduced yields from present stands. Also, the effects of management should be reflected in better growth rates. We estimate the cut for the Headwaters Unit could be 514 million board feet of sawtimber plus 267 thousand cords from pole trees during the next rotation. To get this cut we will need yields by types shown below. We emphasize that this high level of cut is based on getting 10 to 15 percent of the volume from intermediate cuttings.

ESTIMATED YIELDS PER ACRE SECOND ROTATION

	Harvest cut		Intermediate cut		Total cut	
	Sawtimber	Pole-timber	Sawtimber	Pole-timber	Sawtimber	Pole-timber
	M bd. ft.	cords	M bd. ft.	cords	M bd. ft.	cords
Lodgepole pine	10	5.0	-	3.0	10	8.0
Douglas-fir	16	3.0	2	1.0	18	4.0
Ponderosa pine	18	1.0	4	0.6	22	1.6
Spruce	17	3.0	3	0.6	20	3.6
Alpine fir	10	3.0	-	1.0	10	4.0
Hardwoods	-	7.0	-	-	-	7.0

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LODGEPOLE PINE--A LUMBER SPECIES

by John H. Wikstrom

Division of Forest Economics

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
United States Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

FOREWORD

Not so long ago, lodgepole pine was, in the eyes of many, a weed tree with limited industrial use. However, during the last few years it has come into greater use for poles, pulp, and lumber. It is apparent now that the species has considerable industrial potential, and that there is reason for optimism about its future. The purpose of this report is to appraise the suitability of lodgepole pine for lumber--to consider its attributes and deficiencies for this purpose.

The Knapp Lumber Sales Company of Portland, Oregon and the South Fork Lumber Company of Belgrade, Montana, furnished some of the information which follows. Both concerns have pioneered in the production of lodgepole pine lumber for national markets. We are especially indebted to Joel L. Frykman for his help in gathering the information and making the analysis on which this report is based. Other Forest Service men in both Regions 1 and 4 also helped in collecting the information. The interpretations in the report are ours.

HARRY W. CAMP, Chief
Division of Forest Economics

Figure 1.--A lodgepole pine stand. The trees in this stand have little taper and are generally free of limbs. They will make good lumber.

THE RESOURCE

LODGEPOLE PINE IS AN IMPORTANT WESTERN TIMBER SPECIES......

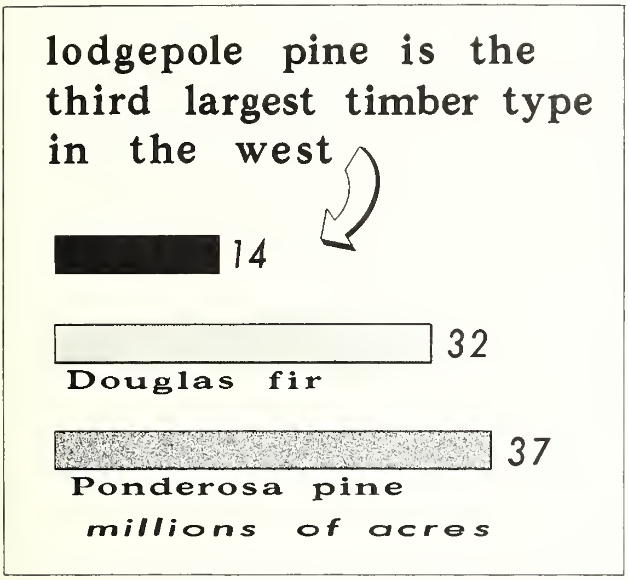

Figure 2

There are 14.5 million acres of lodgepole pine type in the United States. From the standpoint of area, it ranks third behind the Douglas-fir and ponderosa pine types in the West.

...AND IT GROWS MAINLY IN THE ROCKY MOUNTAINS.

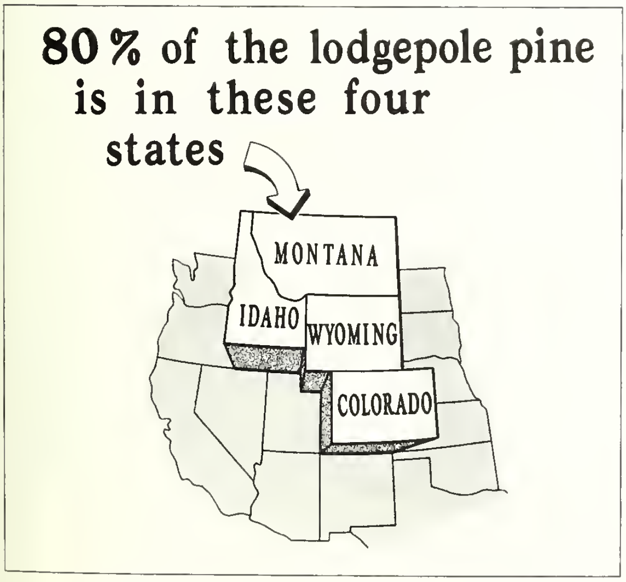

Figure 3

11.6 million acres of the type are in four Rocky Mountain States.

Montana	4.7
Idaho	3.1
Wyoming	1.9
Colorado	1.9
Total	11.6

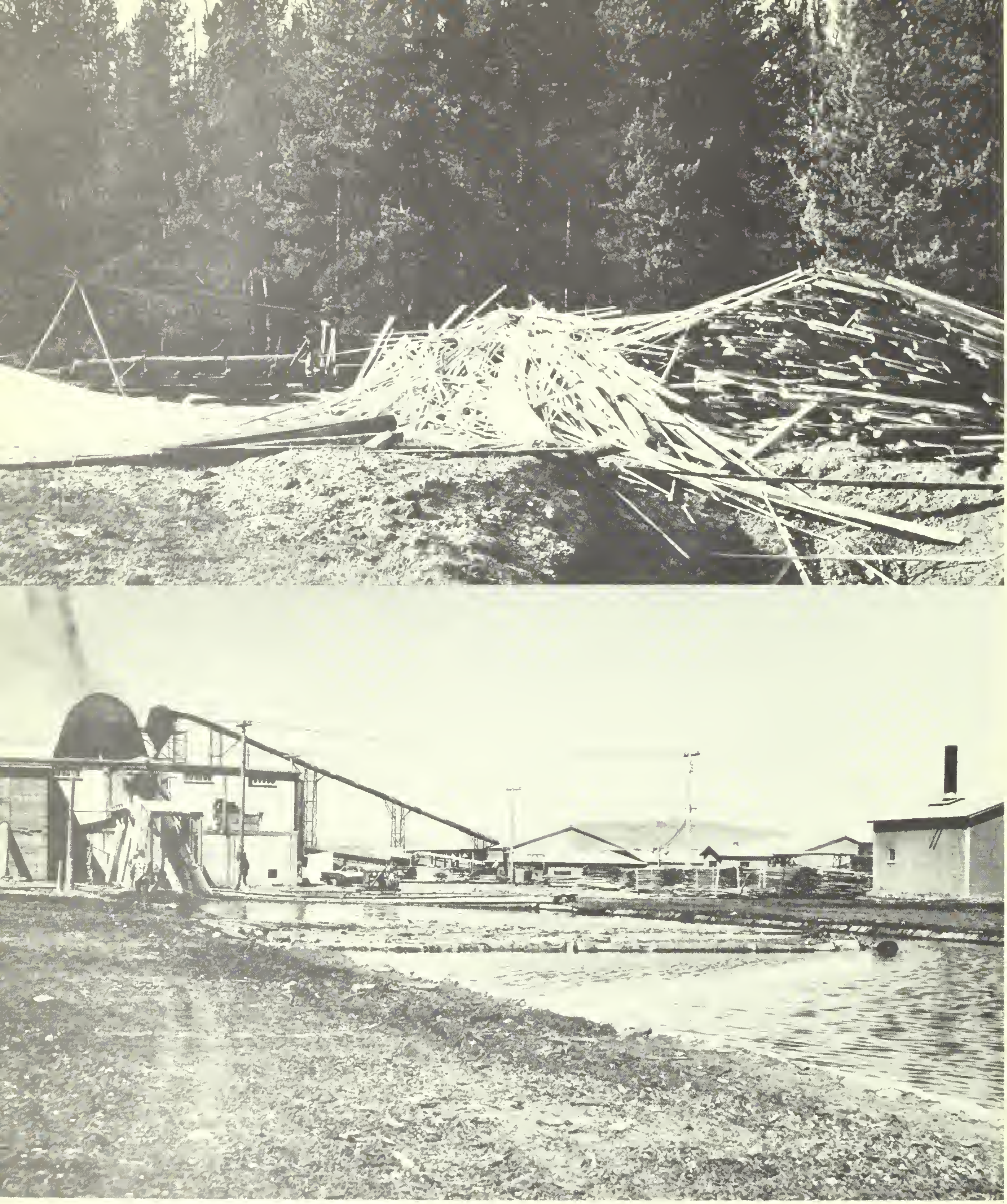

Figure 4.--Until recently, most of the lodgepole pine lumber produced was sawed by small mills (above). Now larger mills are being built to utilize this timber (below).

THE OPPORTUNITY

LODGEPOLE PINE HAS BEEN GAINING IN THE LUMBER MARKET......

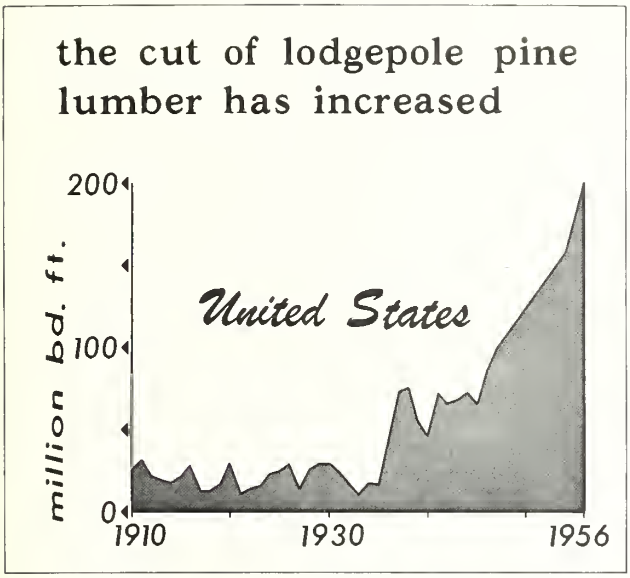

Figure 5

Lodgepole pine lumber production declined between 1910 and 1933. The species could not compete effectively with lumber from larger trees. The reverse trend and rapid rise in production in recent years reflects a shortage of the more sought-after species, and the new opportunity for lodgepole pine.

...IT OFFERS AN OPPORTUNITY FOR FURTHER INDUSTRY DEVELOPMENT.

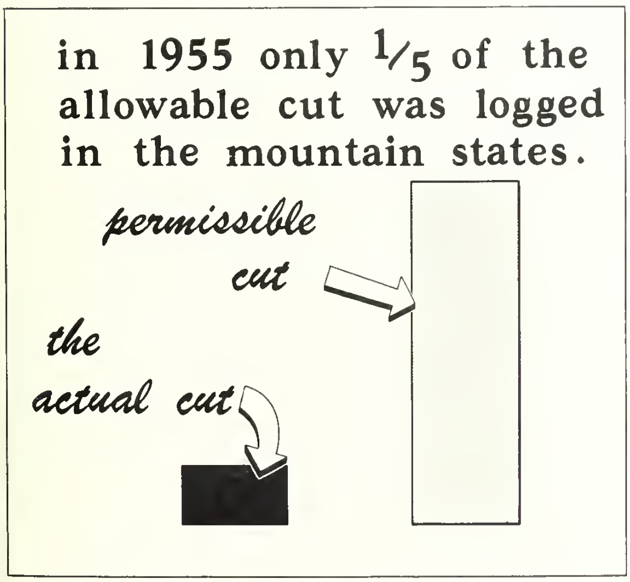

Figure 6

Lodgepole pine timber in the Rocky Mountains could support a much larger cut than it has. Two hundred million board feet were logged in 1955. The cut could be sustained at about 1,000 million board feet per year.

LODGEPOLE PINE AS A LUMBER SPECIES

IT HAS THE PHYSICAL PROPERTIES TO MAKE GOOD LUMBER

Lodgepole pine is one of our better softwoods. Table 1 compares it with ponderosa pine on the basis of some important physical properties. The results of this comparison can be summarized briefly. Lodgepole pine is slightly heavier, a little stronger, has about the same shrinkage rate, and is slightly harder than ponderosa pine. It works nearly as well as ponderosa pine and it takes paint just as well. Consequently, boards of the same size and grade of either species could be used interchangeably for most uses and should be worth about the same.

Table 1.--Lodgepole pine compares favorably with ponderosa pine in important physical properties

	Ponderosa pine	Lodgepole pine
Weight--pounds per cubic feet (8 percent moisture)	27.5	28.2
Strength--static bending, fiber stress at proportional limit, P.S.I. (12 percent moisture content)	6,300	6,700
Shrinkage based on dimensions when green; dried to 6 percent moisture content.		
Tangential (percent)	5.0	5.4
Radial (percent)	3.1	3.6
Hardness--load required to imbed 0.444-inch ball to ½ its diameter, pounds (12 percent moisture content)	450	480
Painting class[1/]	3	3

1/ Painting classification used by Forest Products Laboratories Wood Handbook, U.S.D.A. Handbook 72.

small lodgepole pine trees yield a little more lumber than ponderosa pines of the same size.

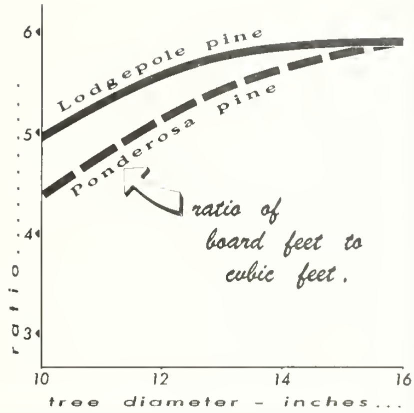

Figure 7

lumber grade recovery tends to be better from small lodgepole pine trees than from larger ones..

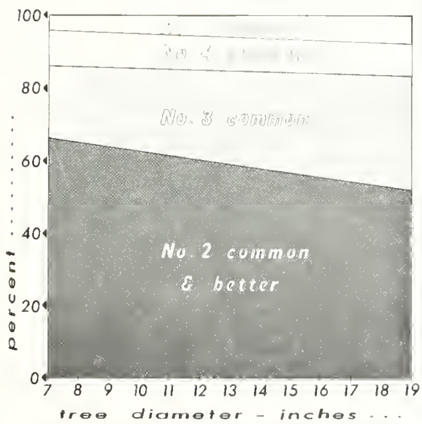

Figure 8

LUMBER VOLUME RECOVERY IS GOOD

Among small trees, lodgepole pine has good form. It is a smooth, uniform tree with little taper. As a result, in the smaller diameters, it produces more lumber per cubic foot of log than does ponderosa pine. For example, International board-foot volume tables show lodgepole pine trees in the 10- and 12-inch class will yield 10 to 15 percent more lumber per cubic foot than ponderosa pine in the same classes, (fig. 7). This advantage however, exists only in trees less than about 16 inches in diameter. On the average, lodgepole pine trees larger than 16 inches in natural stands do not have as good form as smaller trees.

THE SPECIES PRODUCES HIGH GRADE LUMBER

The T-bone steaks of the lumber business are its clear, select boards. Its hamburger is the lower common grades. Since lodgepole pine is not a big tree, it does not produce much T-bone quality lumber and neither does it produce a large proportion of hamburger. Most of the volume is in the tree sizes which produce the highest proportions of the better common grades (fig. 8). More detailed data on the relation of tree size to grade recovery are presented in table 3 in the back of this report.

Table 2 on the following page, compares lodgepole pine lumber recovery with the average grade recovery of ponderosa pine in the Inland Empire in 1955. Lodgepole pine produced 85 percent 1, 2, and 3 common lumber compared to 34 percent for ponderosa pine.

Table 2.-- Comparisons of grade recovery	Ponderosa pine	Lodgepole pine[1]
	Percent	Percent
Selects	14	½
#1 and #2 common	11	48
#3 common	23	37
#4 common	18	12
#5 common	6	½
Shop	15	-
Box, molding, and shorts	13	2
	100	100

1/ Average grade recovery determined from a 20-percent sample of a year's production of a modern medium-size mill.

MUCH OF THE LUMBER IS NARROW BOARDS

Boards are not sold by grade alone; they are sold by grade and size. Because lodgepole trees are small, a large part of the lumber cut is in narrow widths. Moving these narrow boards in the proportions in which they occur is the major merchandising problem of the lodgepole pine lumber industry. Six-tenths of the lumber recovered at one modern mill was in boards 6 inches wide and narrower (table 4).

Figure 9 shows the effect of tree size on width recovery. Over 90 percent of the lumber recovered from trees 11 inches in diameter and smaller is in 2-, 4-, and 6-inch boards. It is not uncommon in lodgepole pine stands to find half or more of the volume in trees of these sizes. Additional information on the effect of tree size on lumber width recovery is presented in table 5.

We hope markets (such as pulpwood) will develop to utilize the smaller trees. However, until such markets as pulpwood are available, sawmill operators will have to utilize as many of the smaller trees as possible. Unless many of the small trees are taken, the lodgepole pine stands cannot be cut heavily enough to get a new crop of trees started.

almost all of the lumber from 11 inch and smaller lodgepole pine trees is 6 inches & less in width.

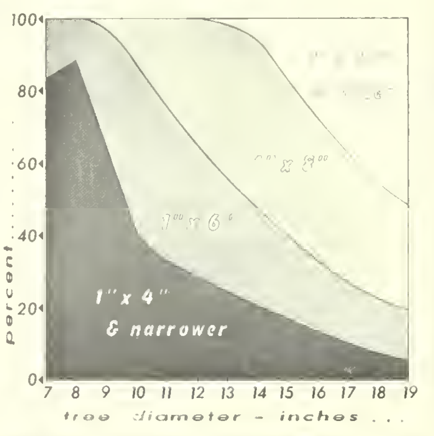

Figure 9

As figure 10 shows, the narrow boards produced in such abundance from small trees are narrow widths of lodgepole pine lumber sell for substantially less per board foot than wider widths.

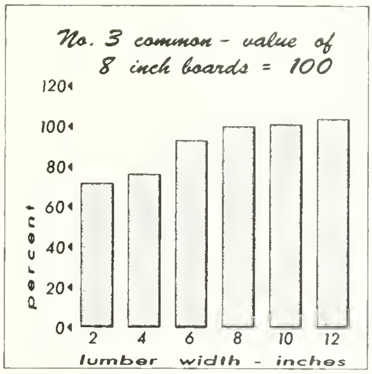

Figure 10

narrow boards hold down the lumber value of small trees.

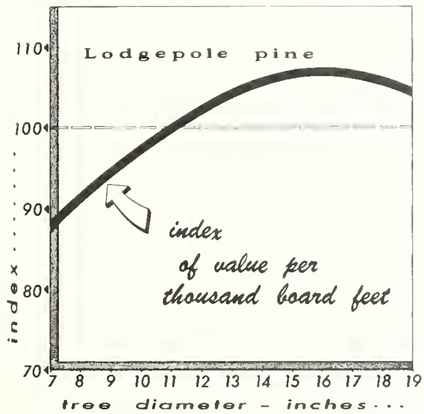

Figure 11

worth less than wide ones. in 1955, number 3 common 1 x 4's brought 20 percent less than 1 x 8's.

Value recovery from small trees is less than from larger ones. For example, the average board foot of lumber cut from 7-inch trees is worth only 87 percent as much as the average board foot cut from 11-inch trees, (fig. 11). Since lumber grade recovery is better in the smaller trees, the lower value per board foot must be blamed on the high percentage of narrow boards which the smaller trees produce.

CAPACITY OF THE LODGEPOLE PINE LUMBER INDUSTRY TO COMPETE

THE SPECIES IS BECOMING ESTABLISHED IN THE LUMBER MARKET

The price data presented in figure 12 tell an interesting story. From 1915 to 1919, lodgepole pine lumber f.o.b. sold at about the same price as ponderosa pine. Since 1919, the average price of lodgepole pine lumber has been substantially less than ponderosa pine average prices. However, by 1955, the average price of well manufactured lodgepole pine lumber from one mill was about 91 percent of the average price received for ponderosa pine lumber by Inland Empire mills. The prices reported by one mill can hardly be regarded as proof by themselves, but they are an encouraging sign of strength.

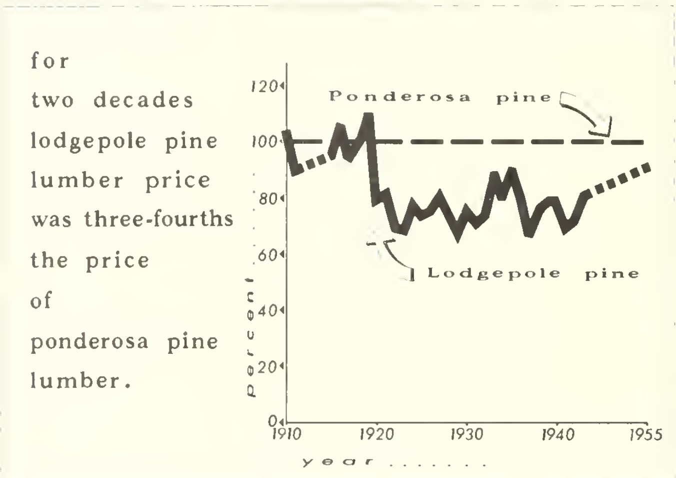

Figure 12

The currently higher average selling value of ponderosa pine only means that the species produces more select grade lumber and fewer narrow boards than lodgepole pine. Grade for grade, prices received should be about the same. One first-class sales organization has been able to get approximately as much for lodgepole pine 1 x 8 boards in the high common grades as it has for ponderosa pine of the same width and grades.

Lodgepole pine appears to have some advantages for paneling stock. As mentioned, it is slightly harder than ponderosa pine; in addition, it has smaller knots, the wood is lighter in color and will not darken as much with age. Forty-nine percent of the lodgepole pine lumber produced at one modern mill in 1955 was made into knotty pine paneling, and in the long run, this may be one of the more promising outlets for the species.

Paneling stock brings higher prices than plain boards. Selling prices in most sizes and grades were $10.00 or more above what the material would have brought as boards. Additional information on selling prices is presented in tables 6 and 7.

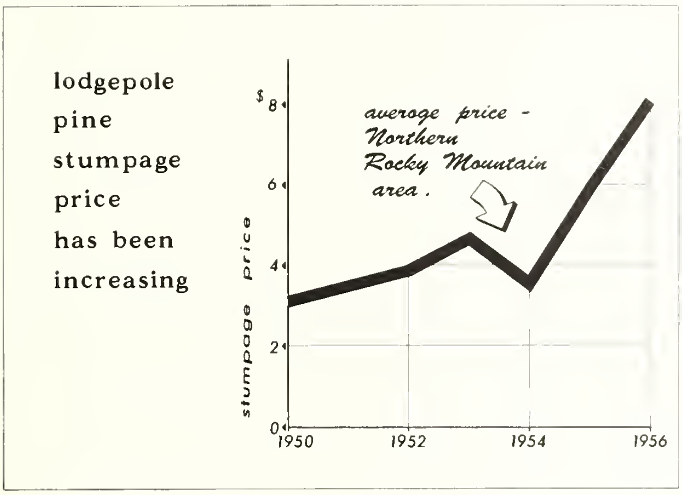

Figure 13

THE DEMAND FOR LODGEPOLE PINE LUMBER IS INCREASING

The trend in lodgepole stumpage prices is upward. This indicates a growing demand for the species for lumber. In 1950, for example, lodgepole pine on the national forests of North Idaho and Montana sold for $3.10 a thousand board feet. By 1956, the price had risen to over $8.00, (fig. 13). On a recent national forest sale in western Wyoming, lodgepole pine brought $9.75 a thousand board feet.

THE COMPETITIVE POSITION OF LODGEPOLE PINE CAN BE IMPROVED

The timber supply situation in the United States has changed to the advantage of lodgepole pine and now we can begin to emphasize its attributes for lumber. While lodgepole pine does not yield enough select boards to share in the market for the highest quality material, the grade recovery is certainly satisfactory and the lumber should be in demand for many uses.

The experience of a few sawmills pioneering in the production of lodgepole pine lumber for the national market is encouraging. Their experience lends weight to the opinion that much of our lodgepole pine could well go into lumber. However, this same experience also points to the desirability of overcoming the handicap of tree size which we have described. Right now, there are three ways the competitive position of lodgepole pine can be further improved.

1. Reduce manufacturing costs. Considerable progress has been made in reducing the sawing time for small trees. Studies made in conventional band mills a decade or two ago show tree size in the 10- to 20-inch diameter range had a marked effect on sawing time. Our study in a modern mill designed

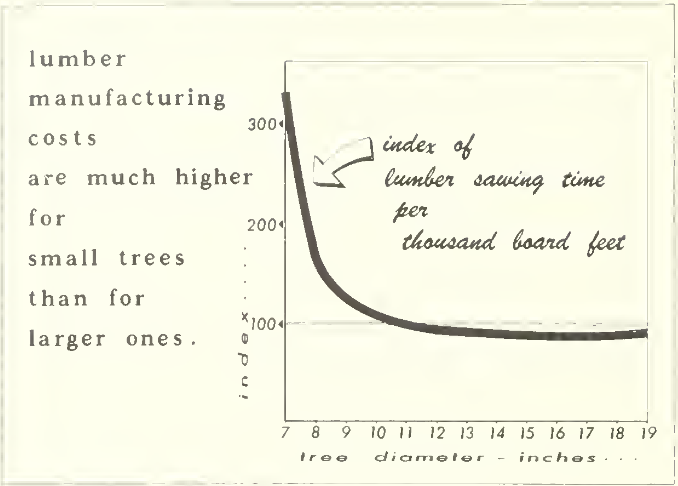

Figure 14

for small timber showed tree size has very little effect on sawing time for trees larger than 10 inches in diameter (fig. 14). However, while progress has been made, a large part of the volume in many of our lodgepole pine stands is in trees smaller than 10 inches in diameter and sawmill operators would gain if sawing time for these trees could be reduced.

2. Increase lumber recovery. As figure 7 shows, the poorest lumber recovery ratio per cubic foot of wood is in small trees. An idea that has been tried to increase the lumber yield from small trees is to cut boards as narrow as 2 inches and also to produce 1- x 3- and 1- x 5-inch boards which are not now standard sizes. Data are not available to show how much additional lumber has been recovered by this practice but estimates run over 10 percent. While this is good utilization, it poses marketing problems.

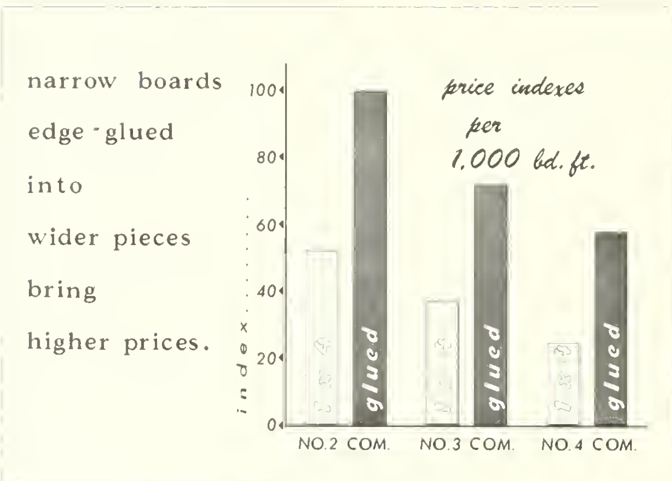

Figure 15

3. Overcome the handicap of narrow boards. The key to successful operation of a lodgepole pine mill is in marketing narrow boards. Some narrow width lodgepole pine lumber has been edge-glued into wider stock. Costs of the gluing operation are not available and the volume of glued-up material sold has been small so the comparisons shown in figure 15 may be premature. However, the comparative prices shown do suggest this might be one solution to the problem of narrow boards.

The idea of edge-gluing needs to be explored further. If this operation does prove successful, it will not only solve the width problem, it will also solve the marketing problem of odd sizes. For example, two boards 3 inches wide would glue up to a 1 x 6; a 5-inch board and a 3-inch board would make a 1 x 8. Perhaps through remanufacture to produce table tops, prefabricated cabinets, etc., marketing opportunities could be expanded and improved for glued-up stock, thus further strengthening the competitive position of this fine softwood.

Table 3.--Effect of lodgepole pine tree size on grade recovery at the Green Chain, Western Pine Association grades. (From curved data)

Tree diameter	No. 2 common and better	No. 3 common	No. 4 common	No. 5 common	Total
Inches	Percent	Percent	Percent	Percent	Percent
7	66	20	10	4	100
8	65	21	10	4	100
9	64	21	10	5	100
10	63	22	10	5	100
11	62	23	10	5	100
12	60	25	10	5	100
13	59	25	10	6	100
14	58	26	10	6	100
15	57	27	10	6	100
16	56	27	10	7	100
17	55	28	10	7	100
18	53	30	10	7	100
19	52	31	10	7	100

Table 4.--Lodgepole pine lumber recovery by width classes for a typical mill--1955

Width class	Percent of total
4-inch[1/]	16.05
6-inch	42.22
8-inch	32.35
10-inch and over	9.38
Totals	100.00

1/ Does not include a small amount of 4-inch lumber that was edge-glued into wider stock.

Table 5.--Effect of lodgepole pine tree size on lumber width recovery (From curved data)

Tree diameter	Lumber width--inches 2-3	4-5	6	8	10	12	Total
Inches d.b.h.							
7	24.9	59.2	15.9	-	-	-	100.0
8	17.9	70.9	11.2	-	-	-	100.0
9	10.7	54.5	34.0	0.8	-	-	100.0
10	6.5	33.8	46.8	12.9	-	-	100.0
11	5.3	27.4	43.1	24.2	-	-	100.0
12	4.7	23.7	36.7	34.9	-	-	100.0
13	4.1	20.4	31.0	42.3	2.2	-	100.0
14	3.5	17.3	26.1	48.8	4.3	-	100.0
15	2.8	14.3	22.1	43.7	17.1	-	100.0
16	2.3	11.1	19.7	39.1	27.8	-	100.0
17	1.7	8.4	17.6	35.9	36.4	-	100.0
18	1.1	6.2	15.6	32.6	33.6	10.9	100.0
19	0.5	4.5	14.0	29.1	31.7	20.2	100.0

Table 6.--Index of selling value of lodgepole pine by product and grade, f.o.b. sawmill, 1955

Product and grade	Index of price[1/]
Selects D and better	187
No. 2 and better common boards	89
No. 3 common boards	67
No. 4 common boards	61
No. 5 common boards	42
No. 2 common paneling	110
No. 3 common paneling	80
No. 4 common paneling	65
Molding	121
Average	88

1/ Price of No. 2 and better 1 x 6 = 100

Table 7.--Index price in relation to lumber width for common grades of lodgepole pine boards and paneling for a typical mill--1955

Product size and grade	Price as a percent of the price for 8-inch lumber
	Percent
No. 2 and better common boards	
1 x 4	85
1 x 6	88
1 x 8	100
1 x 10	103
1 x 12	102
No. 3 common boards	
1 x 4	80
1 x 6	92
1 x 8	100
1 x 10	97
No. 4 common boards	
1 x 4	57
1 x 6	87
1 x 8	100
1 x 10	90
No. 2 and better common paneling	
1 x 6	100
1 x 8	100
1 x 10	100
No. 3 common paneling	
1 x 6	98
1 x 8	100
1 x 10	100

Table 8.--Effect of lodgepole pine tree size on sawing time.[1/] (From curved data)

Tree diameter	Index of sawing time per M board feet lumber tally
Inches	Percent[2/]
7	331
8	166
9	123
10	108
11	100
12	94
13	92
14	90
15	89
16	88
17	87
18	89
19	92

1/ From time log enters head saw until last board clears resaw.

2/ 11-inch trees = 100

EFFECTS OF PLOWING AND SEEDING ON SOME FORAGE PRODUCTION AND HYDROLOGIC CHARACTERISTICS OF A SUBALPINE RANGE IN CENTRAL UTAH

By
Howard K. Orr
Division of Watershed Management Research

Many studies and demonstrations have shown that plowing and artificial seeding can increase forage production on depleted subalpine-herbaceous range in central Utah (2, 6), but the effects of this treatment on the hydrologic characteristics of that type of range are not so well understood. An opportunity to study these effects as well as changes in forage productivity was provided by a range improvement program that was undertaken by the Manti-LaSal National Forest on a portion of the Manti Canyon watershed in 1952. This report describes the project area and presents information about the soil, plant cover, surface runoff, infiltration, and erosion characteristics which was obtained on treated and untreated parts of the area in 1955, 3 years after the range improvement program was initiated.

THE STUDY AREA

The project area embraces 1,000 acres of fenced range in the extreme headwaters of the Manti Canyon watershed, at an elevation of about 10,000 feet. The topography is characterized by some very steep rim slopes, moderately sloping to low gradient benches and terraces, and gently sloping valley bottoms. Precipitation averages 32 inches per year, about 6 inches of which occur during a 3-month summer growing season. Most of the remaining 26 inches falls as snow during the winter months. The soil is mostly residual, derived from limestones and clays of the Wasatch Formation and is of variable depth and texture. Plant cover is predominantly herbaceous, with scattered clumps of Engelmann spruce in the basin proper and alpine fir and limber pine on the boundary ridges. As a result of many years of grazing by cattle and sheep, the natural and highly palatable grasses and forbs reverted to low value forbs which are less productive and less palatable.[1/]

The improvement project was undertaken primarily to increase the production of grass and to gain better control of summer storm runoff and erosion. To accomplish this, livestock grazing was temporarily excluded from the area beginning in 1952. At that time, also, about 435 acres of the most accessible lands with low to moderate slopes were treated by plowing and ripping, and seeding to a mixture of adapted plants. The species and pounds of seed per acre used were as follows:

1/ See species list, page 23.

Seeded species	Pounds per acre
Smooth brome	10.3
Tall oatgrass	1.0
Meadow foxtail	1.4
Reed canarygrass	0.5
Timothy	2.3
Orchardgrass	4.3
Mountain brome	0.5
Alsike clover	3.7
Total	24.0

STUDY PROCEDURES

A pair of 1/2-acre plots was established on each of 10 representative sites prior to plowing and seeding in 1952 as a basis for studying the effects of treatment. Two pairs of plots were located on bottom land sites, four pairs on bench or terrace sites, and four pairs on adjoining slopes. One plot in each pair was randomly selected for plowing and seeding, the other being left untreated.

In the fall of 1955, four of the 10 pairs of 1/2-acre plots were selected for an initial study of the effects of treatment. Two pairs of plots were on the bottom land sites (Nos. 5 and 6), one pair was on a slope site (No. 8), and the fourth pair was on a bench site (No. 9).

Four test plots 30.5 x 12 inches in size were located on representative portions of each of the four treated and untreated sites. The following information about the soil and plant cover was obtained on each of the 32 test plots:

1. Average slope was obtained with an Abney level.

2. Depth of soil to fractured limestone was determined by an auger.

3. Mechanical analyses were made of soil samples taken at depths of 1 to 2½ inches and 4½ to 6 inches.

4. Bulk density or volume weight of the soil at depths of 1 to 2½ inches and 4½ to 6 inches was determined from 71 cc soil cores taken with a modified San Dimas type core sampler.

5. The kind and density of plant cover as well as the amount of litter and bare soil were estimated from observations at 6 equally spaced points on each of 15 equally spaced rows across each plot, or a total of 90 observations per plot.

6. Weight of forage production was obtained by clipping the vegetation and weighing it green and air dried.

Each plot was also subjected to an application of approximately 3.0 inches of artificial rainfall in 50 minutes by means of a Type FA infiltrometer to determine its surface runoff, infiltration, and erosion characteristics. The plots were prewet 24 hours in advance of each test to create uniform moisture conditions in the surface soil.

Measurements were made at 5-minute intervals of the amount of artificial rainfall applied and of the resulting runoff from each plot. Runoff percentages were calculated for the first 1 inch of rain and for the total of about 3 inches.

Infiltration rates were calculated from differences between 5-minute amounts of rainfall and runoff. These calculations provided from 8 to 10 values for developing an infiltration curve for each plot.

All soil washed from each plot was collected and filtered. The filtered sediment was oven-dried, weighed, and the amounts were converted to pounds per acre.

SOIL AND SLOPE CHARACTERISTICS

Slopes averaged about 5 percent on the two bottom land sites and on the bench site, and about 17 percent on the slope site. Within each of the four study sites there was no significant difference in slope between the treated and untreated plots (table 1).

Soil depth was greatest on the two bottom sites. On five of the study plots within these sites, soil depth exceeded 60 inches. On the other 10 plots within these sites on which measurements were obtained, soil depth ranged from 18 to 44 inches. Soil depth on the slope site plots averaged about 29 inches. On the bench site plots, soil depth ranged from 2 to 13 inches. Within each of the four study sites there was no significant difference in the depth of soil between the treated and untreated plots.

Mechanical analyses showed the soil at a depth of 1 to 2½ inches to be a silty clay loam on 14 study plots, silty loam on 13 plots, clay loam on 2 plots, and silty clay, loam, and clay on 1 plot each. Soil on the two bottom land sites tended to be more sandy than on the slope and bench sites. Soil texture was essentially similar on the treated and untreated plots within each of the four study sites (table 2).

The soil at a depth of 4½ to 6 inches contained slightly less sand and more clay than at 1- to 2½-inch depth. Though actual differences were relatively small, there was enough less sand and more clay at the 4½- to 6-inch depth than at the 1- to 2½-inch depth on the bottom land site (No. 5) to change the average texture class from silty clay loam to silty clay, and to change it from silty loam to silty clay loam on the other bottom land site (No. 6). Differences in the sand and clay fractions between the 1- to 2½-inch and the 4½- to 6-inch depths on the slope

Table 1.--Ground slope and soil depth of treated and untreated test plots

Plot number	Plowed and seeded: Slope	Plowed and seeded: Soil depth	Untreated: Slope	Untreated: Soil depth
	Percent	Inches	Percent	Inches
		Bottom Site (5)		
1	3	41	1	60
2	6	37	7	44
3	6	22	8	No record
4	4	60	5	18
Av.	5	40	5	41
		Bottom Site (6)		
1	10	21	3	27
2	2	60	2	60
3	4	40	2	60
4	5	16	7	23
Av.	5	34	4	42
		Slope Site (8)		
1	12	32	22	23
2	16	28	10	29
3	14	30	24	33
4	18	28	14	26
Av.	15	30	18	28
		Bench Site (9)		
1	6	8	2	3
2	7	12	4	6
3	4	9	6	7
4	4	13	4	12
Av.	5	10	4	7

Table 2.--Soil texture classes at 1- to 2½-inch depth on treated and untreated plots

Plot number	Plowed and seeded				Untreated			
	Sand	Silt	Clay	Texture class 1/	Sand	Silt	Clay	Texture class 1/
	Percent				Percent			
				Bottom (5)				
1	9	56	35	SiCL	13	36	51	C
2	17	56	27	SiCL	22	49	29	CL
3	17	53	30	SiCL	18	53	29	SiCL
4	25	47	28	CL	26	49	25	L
Av.	17	53	30	SiCL	20	47	33	SiCL
				Bottom (6)				
1	20	58	22	SiL	13	64	23	SiCL
2	14	60	26	SiL	10	68	22	SiL
3	13	65	22	SiL	12	69	19	SiL
4	10	67	23	SiL	9	64	27	SiL
Av.	14	63	23	SiL	11	66	23	SiL
				Slope (8)				
1	7	66	27	SiCL	12	63	25	SiL
2	1	59	40	SiC	8	63	29	SiCL
3	8	63	29	SiCL	6	56	38	SiCL
4	8	63	29	SiCL	9	65	26	SiL
Av.	6	63	31	SiCL	9	62	29	SiCL
				Bench (9)				
1	8	67	25	SiL	17	65	18	SiL
2	7	63	30	SiCL	22	56	22	SiL
3	13	64	23	SiCL	6	69	25	SiL
4	3	59	38	SiCL	8	58	34	SiCL
Av.	8	63	29	SiCL	13	62	25	SiL

1/ Si = silt; C = clay; L = loam

and bench site were not sufficiently great to change their average texture class (table 3).

Soil bulk densities on the average were about 10 percent greater on the bottom land sites than on the slope and bench sites. They also tended to average about 10 percent greater at the $4\frac{1}{2}$- to 6-inch depth than at the 1- to $2\frac{1}{2}$-inch depth. Though they tended to average slightly greater on the untreated than on the treated areas, the differences were not statistically significant (table 4).

It was anticipated that bulk density of the soil on the treated areas would be significantly less than on the untreated sites. It has been well established that plowing usually loosens the soil and increases its volume. Moreover, during the field tests the soil on the treated areas was much softer under foot than on untreated areas. It was also noticed that pegs and infiltrometer plot frames were driven into the ground more easily on the treated than on the untreated areas.

The nonsignificance of differences in the bulk density of the soil on treated and untreated areas could be due to several factors. A resettling of the soil since it was plowed in 1952 would seem to be the most logical reason. This seems reasonable when it is considered that the study area had been subjected to the melting of three snowpacks, three spring seasons of alternate freezing and thawing, and three seasons of summer rainfall.

The reason for the softer feel of the soil on the treated areas is difficult to explain in view of the similarity of the bulk density values obtained on the treated and untreated plots. It could perhaps have been due to some difference in soil structure that was not measured.

GROUND COVER AND FORAGE PRODUCTION

Total ground cover, including live plants and litter, averaged 65 percent on the treated plots and 70 percent on the untreated plots, a difference that is not statistically significant (table 5). These amounts of ground cover are at least twice as great as those found on more depleted areas of this type of range in that vicinity. However, they still fall short of an 80- or 90-percent ground cover which is possible for such areas.

Treated plots had slightly more live plant cover and about half as much litter as untreated plots. The lesser amount of litter on the treated plots no doubt is due in part to plowing under of original litter and in part to the relatively short time for litter to develop following soil disturbance. The rate of litter accumulation on the treated plots was actually relatively rapid when it is considered that the seeded grasses were seedlings during the first year and that many had not yet reached full development by the third growing season.

Table 3.--Soil texture classes at 4½- to 6-inch depth on treated and untreated plots

Plot number	Plowed and seeded				Untreated			
	Sand	Silt	Clay	Texture class 1/	Sand	Silt	Clay	Texture class 1/
	Percent				Percent			
Bottom (5)								
1	5	44	51	SiCL	9	36	55	C
2	5	57	38	SiCL	4	52	44	SiC
3	8	50	42	SiC	13	58	29	SiCL
4	16	52	32	SiCL	12	50	38	SiCL
Av.	8	51	41	SiC	10	49	41	SiC
Bottom (6)								
1	14	60	26	SiCL	2	66	32	SiCL
2	10	56	34	SiCL	5	57	38	SiCL
3	10	56	34	SiCL	6	67	27	SiL
4	4	64	32	SiCL	11	59	30	SiCL
Av.	10	59	31	SiCL	6	62	32	SiCL
Slope (8)								
1	6	64	30	SiCL	4	58	38	SiCL
2	2	56	42	SiC	1	59	40	SiCL
3	4	66	30	SiCL	2	57	41	SiC
4	7	63	30	SiCL	0	62	38	SiCL
Av.	5	62	33	SiCL	2	59	39	SiCL
Bench (9)								
1	6	67	27	SiL	Rock	Rock	Rock	--
2	3	57	40	SiC	Rock	Rock	Rock	--
3	4	61	35	SiCL	0	60	40	SiC
4	0	51	49	SiC	6	56	38	SiCL
Av.	3	59	38	SiCL	3	58	39	SiCL

1/ Si = silt; C = clay; L = loam

Table 4.--Bulk density of soil on treated and untreated plots (grams per cc)

Plot number	Plowed and seeded		Untreated	
	1- to 2½-inch depth	4½- to 6-inch depth	1- to 2½-inch depth	4½- to 6-inch depth
		Bottom (5)		
1	1.07	1.28	1.19	1.35
2	1.13	1.26	1.04	1.19
3	1.10	1.26	1.23	1.22
4	1.21	1.24	1.06	1.19
Av.	1.13	1.26	1.13	1.24
		Bottom (6)		
1	1.10	1.16	1.14	1.34
2	1.36	1.40	1.32	1.39
3	1.29	1.37	1.34	1.36
4	1.18	1.27	1.24	1.18
Av.	1.23	1.30	1.26	1.32
		Slope (8)		
1	0.89	1.08	0.90	1.09
2	0.97	1.08	1.12	1.13
3	1.01	1.14	0.96	1.06
4	1.03	1.04	1.06	1.15
Av.	0.98	1.09	1.01	1.11
		Bench (9)		
1	1.08	1.01	0.96	Rock
2	1.12	1.14	1.08	Rock
3	1.09	1.10	1.17	1.16
4	1.10	1.22	1.12	1.29
Av.	1.10	1.12	1.08	1.23

Table 5.--Ground cover conditions on treated and untreated test sites

Plot number	Plowed and seeded					Untreated				
	Live plant	Plant litter	Total ground cover	Rock pave-ment	Bare soil	Live plant	Plant litter	Total ground cover	Rock pave-ment	Bare soil
	Percent					Percent				
					Bottom Site (5)					
1	32	12	44	0	56	29	13	42	2	56
2	47	19	66	0	34	55	18	73	0	27
3	67	6	73	0	27	47	12	59	0	41
4	75	13	88	0	12	67	12	79	0	21
Av.	55	13	68	0	32	49	14	63	0	36
					Bottom Site (6)					
1	75	11	86	0	14	38	44	82	1	17
2	51	6	57	0	43	31	12	43	0	57
3	52	9	61	0	39	43	18	61	0	39
4	72	7	79	0	21	74	24	98	0	2
Av.	63	8	71	0	29	47	24	71	0	29
					Slope Site (8)					
1	80	12	92	0	8	87	11	98	0	2
2	68	6	74	1	25	63	7	70	1	29
3	67	12	79	1	20	73	26	99	0	1
4	37	9	46	0	54	63	11	74	0	26
Av.	63	10	73	0	27	71	14	85	0	15
					Bench Site (9)					
1	29	7	36	0	64	48	14	62	2	36
2	55	8	63	0	37	50	26	76	0	24
3	39	11	50	0	50	33	3	36	0	64
4	41	3	44	0	56	49	14	63	1	36
Av.	41	7	48	0	52	45	14	59	1	40
Av. all	56	9	65	0	35	53	17	70	0	30

There was considerable variation in total ground cover between sites which appeared to be associated with differences in the depth and texture of the soil. Slope site (No. 8) had the greatest total ground cover, averaging 85 percent on the untreated plots and 73 percent on the treated plots. Here the soil is apparently deep enough to support a fairly complete ground cover and the light, porous structure is favorable to plant growth. On bottom land sites where soil is deeper but also heavier and more compact, total ground cover density averaged 63 percent on the site five untreated plots, 68 percent on the site 5 treated plots, and 71 percent on the site six plots, both treated and untreated. On bench site (No. 9) where soil is relatively light and porous but quite shallow, total ground cover density averaged 59 percent on the untreated plots and 48 percent on the treated plots.

Treatment drastically altered the composition of the plant cover. On treated plots there was five times more grass cover and only 40 percent as much forb cover as on untreated plots (table 6). The most notable change in the grass cover on treated plots was reduction of Letterman needlegrass and Kentucky bluegrass, and dominance of the seeded grasses. Orchardgrass was the most conspicuous of the seeded species. This grass made up almost 50 percent of the total live plant cover on the treated plots.

Treatment also caused a reduction in both the occurrence and density of the larger perennial forbs, such as penstemon, geranium, cinquefoil, and sweetsage. Common dandelion did not occur as frequently on the treated as the untreated plots but it was sufficiently abundant on several plots to be classified as one of the dominant forbs on the treated sites. Douglas knotweed was considerably more abundant and more vigorous on the treated plots than on the untreated plots. However, this annual is expected to decrease in abundance with further development of the seeded vegetation. Slenderleaf gilia, another annual forb, which was very plentiful during the first growing season following treatment, has already largely disappeared under the competition from the more vigorous forbs and grasses.

A further increase in the number and size of seeded grass plants is expected on the treated plots. It is also likely that there will be a change in the order of dominance among the seeded species. The currently dominant orchardgrass and timothy are relatively short-lived and will probably decline in favor of slower developing but more adaptable species Experience on this type of range has shown that as these plants decline, smooth brome with its strong, sod-forming growth habit will probably become dominant. It is also likely that meadow foxtail will become more prominent because of its ability to spread by natural seeding.

Table 6.--Live plant cover composition on 16 treated and 16 untreated test plots

Plant species	Plowed and seeded		Untreated	
	Plots occurred	Average density	Plots occurred	Average density
	Number	Percent	Number	Percent
Grasses				
Kentucky bluegrass	0	0	7	3.2
Letterman needlegrass	2	0.1	11	3.1
Meadow foxtail*	4	1.3	0	0
Mountain brome*	2	0.5	0	0
Nodding brome	0	0	1	0.1
Orchardgrass*	15	25.7	0	0
Slender wheatgrass	4	0.4	4	0.9
Smooth brome	3	2.8	0	0
Timothy*	7	5.8	0	0
Unidentified	1	0.1	2	0.2
Total		36.7		7.5
Forbs				
Alsike clover	2	0.8	0	0
American vetch	0	0	4	0.4
Bladderpod	0	0	2	0.1
Cinquefoil	1	0.1	7	1.2
Common dandelion	6	5.8	12	6.2
Douglas knotweed	15	5.9	7	1.2
Evening primrose	2	0.1	1	0.1
False carrot	0	0	2	0.1
Fleabane	0	0	8	7.2
Geranium	6	3.1	8	9.5
Groundsel	1	0.1	4	2.8
Ligusticum	0	0	1	0.2
Low agoseris	0	0	3	0.2
Meadowrue	1	0.2	0	0
Peavine	1	0.1	1	0.1
Rockjasmine	1	0.1	1	0.1
Rydberg penstemon	2	0.1	12	8.1
Showy goldeneye	1	0.8	2	0.9
Slenderleaf gilia	0	0	1	0.1
Sulphur paintedcup	0	0	2	0.1
Sweetsagebrush	1	0.8	7	2.4
Western yarrow	0	0	7	1.1
Unidentified	4	0.5	7	2.1
Total		18.5		44.2
Grand Total		55.2		51.7

* Seeded species

Treatment substantially increased both green and air-dry weights of forage production (tables 7 and 8). Green weights averaged 4,321 pounds per acre on the treated plots and 2,491 pounds per acre on the untreated plots. Corresponding dry weights averaged 1,551 and 848 pounds per acre. Grasses made up about 78 percent of the total forage production on the treated plots and about 14 percent on the untreated plots.

Forage production tended to vary with plant cover density on both treated and untreated plots. However, treated plots generally produced more forage per unit of live plant cover density than untreated plots because of the taller growth and larger volume of the seeded grass plants.

RUNOFF RELATIONS

There was no significant difference in runoff from the treated and untreated plots during either the 1 inch or 3 inches of applied rainfall (table 9). However, between individual plots, runoff varied from 1 to 79 percent during the 1 inch of rain, and from 1 to 90 percent during the 3 inches of rain.

When the data from the treated and untreated plots were grouped together, analysis showed that runoff varied inversely with the amount of total ground cover. Similar inverse relationships have been found in virtually all studies on comparable rangelands (3, 4).

Further analysis showed that the runoff-ground cover relationship was also affected by the bulk density of the soil. Throughout the range of plant cover densities, runoff increased uniformly with increased bulk density (fig. 1). On sites having soil with a bulk density of 0.89, a ground cover of 43 percent was effective in controlling runoff to 50 percent of applied rainfall. A virtually complete ground cover would be required to achieve the same degree of runoff control on sites having soils with a bulk density of 1.34.

INFILTRATION

Infiltration rates at the end of about 1 inch of applied rainfall varied from 0.27 inch to 3.60 inches per hour, or about the full rate of rainfall application. Rates near the end of 3 inches of rainfall varied from 0.22 to 3.57 inches per hour (table 10). There were no over-all significant differences in infiltration between the treated and untreated plots for either 1 or 3 inches of rainfall. However, analysis of individual plot data showed infiltration rates to vary directly with amounts of ground cover.

To further study the latter relationship, average infiltration curves were developed with data from seven treated plots and nine untreated plots having above average amounts of ground cover. Similar

Table 7.--Green weight forage production on treated and untreated test plots

Plot number	Plowed and seeded			Untreated		
	Grass	Forbs	Total	Grass	Forbs	Total
	Pounds per acre					
	Bottom Site (5)					
1	680	378	1,058	302	1,058	1,360
2	3,476	378	3,854	378	2,645	3,023
3	4,307	1,813	6,120	227	2,267	2,494
4	4,231	831	5,062	491	2,267	2,758
Av.	3,173	850	4,023	350	2,059	2,409
	Bottom Site (6)					
1	8,236	1,587	9,823	453	1,587	2,040
2	2,040	302	2,342	151	453	604
3	831	1,209	2,040	76	1,209	1,285
4	7,103	907	8,010	2,305	2,267	4,572
Av.	4,552	1,001	5,553	746	1,379	2,126
	Slope Site (8)					
1	4,080	1,133	5,213	453	3,174	3,627
2	3,929	1,209	5,138	76	1,360	1,436
3	3,854	302	4,156	756	3,249	4,005
4	2,418	378	2,796	76	2,720	2,796
Av.	3,570	756	4,326	340	2,626	2,966
	Bench Site (9)					
1	1,889	756	2,645	189	3,022	3,211
2	4,534	1,285	5,819	Trace	3,174	3,174
3	1,965	1,285	3,250	151	756	907
4	Trace	1,813	1,813	Trace	2,569	2,569
Av.	2,097	1,285	3,382	85	2,380	2,465
Av. all	3,348	973	4,321	380	2,111	2,491

Table 8.--Air-dry weight forage production on treated and untreated test plots

Plot number	Plowed and seeded: Grass	Plowed and seeded: Forbs	Plowed and seeded: Total	Untreated: Grass	Untreated: Forbs	Untreated: Total
	Pounds per acre					
	Bottom Site (5)					
1	151	38	189	38	302	340
2	1,360	76	1,436	76	831	907
3	1,511	529	2,040	38	756	794
4	1,662	227	1,889	76	604	680
Av.	1,171	218	1,389	57	623	680
	Bottom Site (6)					
1	2,871	680	3,551	227	529	756
2	756	76	832	76	189	265
3	227	227	454	38	453	491
4	2,947	151	3,098	831	907	1,738
Av.	1,700	284	1,984	293	520	813
	Slope Site (8)					
1	1,662	453	2,115	189	1,360	1,549
2	1,511	453	1,964	Trace	491	491
3	1,587	76	1,663	151	1,285	1,436
4	831	38	869	Trace	982	982
Av.	1,398	255	1,653	85	1,030	1,115
	Bench Site (9)					
1	529	189	718	38	831	869
2	1,738	378	2,116	Trace	1,209	1,209
3	756	453	1,209	38	189	227
4	Trace	680	680	Trace	831	831
Av.	756	425	1,181	19	765	784
Av. all	1,256	295	1,551	114	734	848

Table 9.--Runoff in percent of applied rainfall on treated and untreated test plots

Plot number	Plowed and seeded		Untreated	
	1-inch rainfall	3-inch rainfall	1-inch rainfall	3-inch rainfall
	Percent		Percent	
		Bottom Site (5)		
1	62	79	68	86
2	59	74	47	66
3	41	60	58	71
4	6	16	36	51
Av.	42	57	52	68
		Bottom Site (6)		
1	44	56	51	62
2	71	87	79	91
3	69	80	73	87
4	38	61	13	17
Av.	56	71	54	64
		Slope Site (8)		
1	<1	1	3	3
2	20	23	55	68
3	12	19	2	2
4	43	54	50	65
Av.	19	24	28	34
		Bench Site (9)		
1	35	60	20	35
2	11	30	5	10
3	33	58	57	78
4	67	80	39	51
Av.	36	57	30	44
Av. all	38	52	41	53

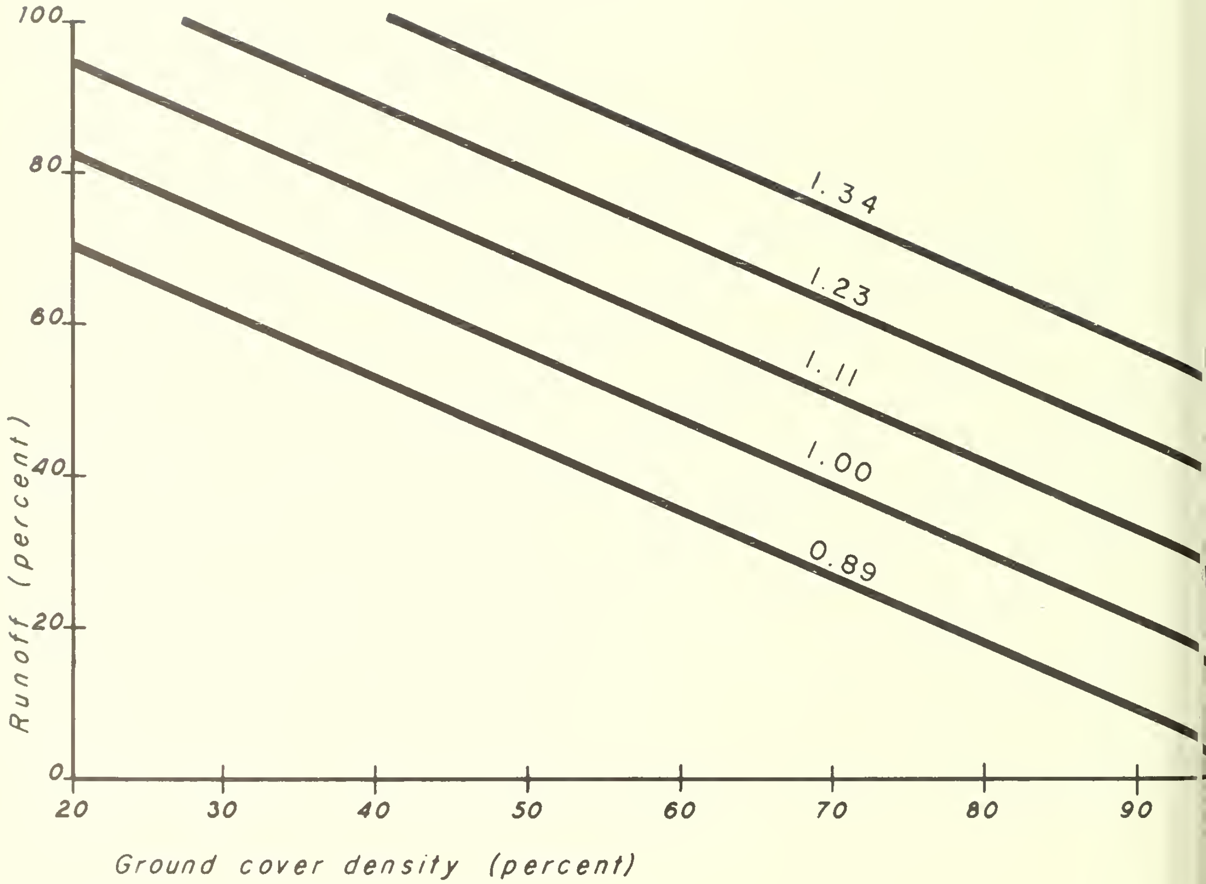

FIG. 1. Runoff from 3 inches of rainfall in relation to ground cover as influen[c]
by bulk density of the surface soil. Numbers on each curve are
bulk density values.

Table 10.--Infiltration rates after constant rate application of 1 and 3 inches of rainfall on treated and untreated test plots

Site and plot number	Plowed and seeded		Untreated	
	1-inch rainfall	3-inch rainfall	1-inch rainfall	3-inch rainfall
	Inches per hour		Inches per hour	
5-1	0.59	0.54	0.39	0.30
5-2	.79	.77	1.14	1.00
5-3	1.21	1.25	.93	.79
5-4	3.09	2.90	1.71	1.64
Av.	1.42	1.36	1.04	.93
6-1	1.45	1.37	1.27	1.20
6-2	.41	.22	.27	.27
6-3	.67	.62	.42	.41
6-4	1.45	.98	3.00	2.90
Av.	1.00	.80	1.24	1.20
8-1	3.60	3.57	3.48	3.52
8-2	2.86	2.72	1.05	.92
8-3	2.89	2.73	3.59	3.54
8-4	1.67	1.38	1.21	1.04
Av.	2.76	2.60	2.33	2.26
9-1	1.51	1.06	2.35	1.99
9-2	2.65	1.98	3.38	3.25
9-3	1.44	1.07	.67	.48
9-4	.54	.58	1.84	1.58
Av.	1.54	1.17	2.06	1.82
Av. all	1.68	1.48	1.67	1.55

curves were developed for nine treated and seven untreated plots having below average amounts of ground cover. These showed the final infiltration rates of the plots with above average ground cover to be more than double those of plots having below average ground cover (fig. 2).

The average infiltration curves also showed that whereas initial water intake rates were high and essentially similar on all plots, there was a strong tendency for rates to decrease more rapidly on the untreated than on the treated plots, after which the rates were again essentially similar. Thus, appreciably more water would sink into the soil during the first 15 minutes of rainfall on the treated than on the untreated plots. This is an important difference because summer rains in that locality are of short duration and the most rapid rainfall tends to occur during the first 10 to 20 minutes, even during the most torrential storms.

SEDIMENT ERODED

Sediment production varied from 162 to 6,550 pounds per acre among the treated plots and from 10 to 7,852 pounds per acre among the untreated plots. Sediment production from treated plots averaged about 600 pounds per acre more than from untreated plots but this difference was not significant at the 5-percent level of probability (table 11).

There were no significant differences in the texture of the sediment eroded from the treated and untreated plots, probably because there were no real differences in the texture of the surface soil, as was previously brought out. However, it was observed during the filtering process that much of the sediment from the treated plots appeared to be in the form of small soil aggregates whereas the material from the untreated plots appeared to be mostly of single grain structure. This difference conceivably could be due to the ridging and loosening effect of plowing which left soil aggregates more susceptible to detachment by rain action than those on the undisturbed areas.

Sediment production from individual plots, like runoff, was found to be inversely related to the total density of ground cover, the coefficient of correlation being -.755. This inverse relationship reflects the greater extent to which a dense plant and litter cover protects the soil from the direct impact of raindrops than a sparse ground cover.

The degree to which plant and litter cover is dispersed over the soil surface has been recognized as an important factor affecting erosion in addition to the effect of the average density of the ground cover. In a study of erosion on rangelands in Idaho, Packer developed a "bare soil opening" index that was based upon the width of bare soil areas along the lower portion of a 6- x 6-foot infiltrometer plot (5). Though the values derived were found to be highly correlated with erosion and storm runoff, the index did not integrate the effects of bare soil areas on the plot as a whole.

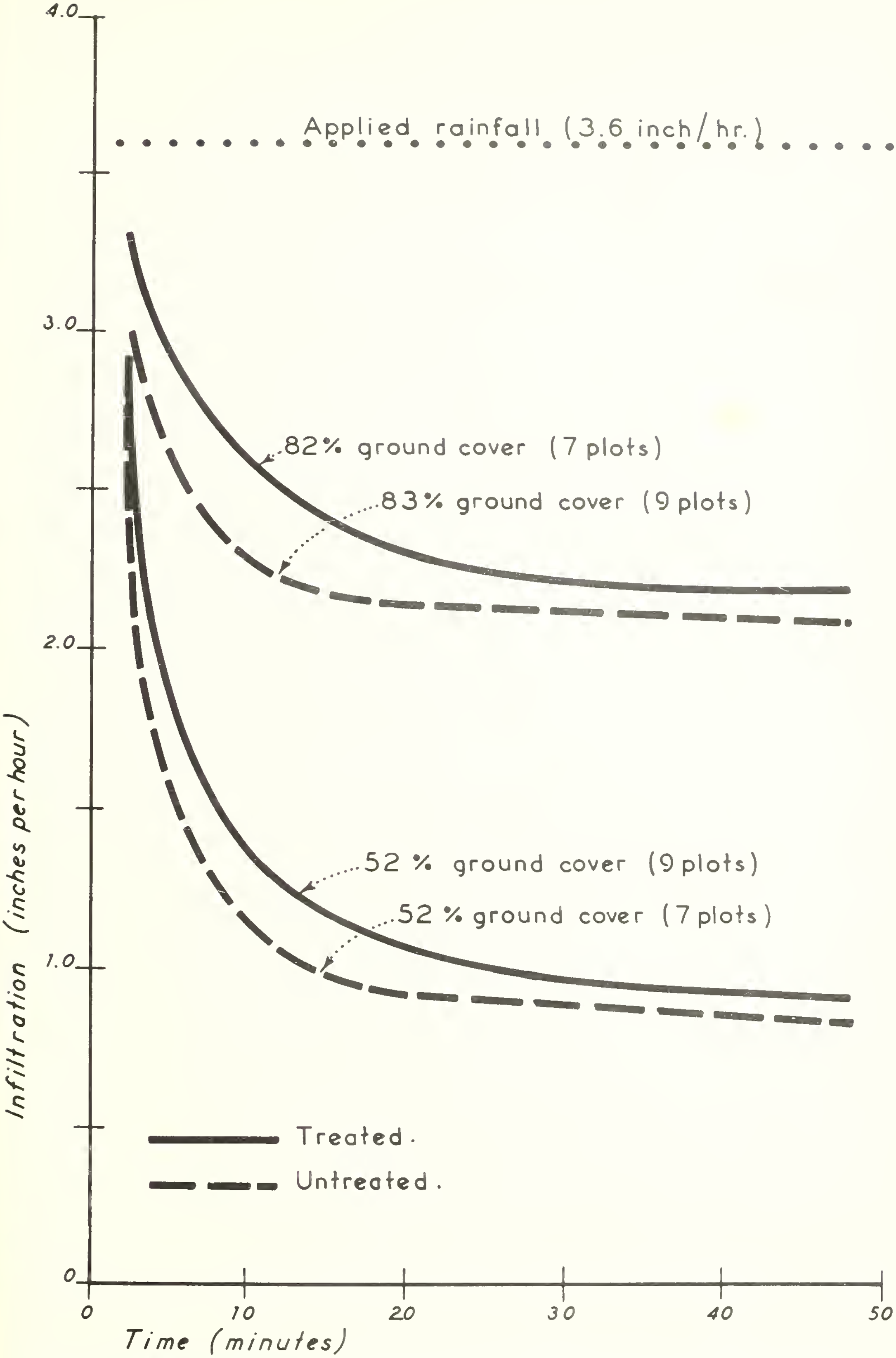

FIG.2. Average infiltration curves for treated and untreated plots with ground cover densities above and below average.

Table 11.--Sediment eroded by total applied rainfall (3 inches) on treated and untreated test plots

Site and plot number	Plowed and seeded				Untreated			
	Sediment eroded	Texture			Sediment eroded	Texture		
		Sand	Silt	Clay		Sand	Silt	Clay
	Pounds/acre	Percent			Pounds/acre	Percent		
5-1	3,411	4	59	37	5,463	4	59	37
5-2	3,351	5	59	36	847	-	-	-
5-3	5,927	19	49	32	4,477	7	54	39
5-4	162	-	-	-	2,085	13	58	29
Av.	3,213	-	-	-	3,218	-	-	-
6-1	2,090	11	61	28	1,817	8	68	24
6-2	5,392	6	70	24	2,962	6	71	23
6-3	2,403	7	65	28	4,236	8	63	29
6-4	1,881	8	64	28	170	-	-	-
Av.	2,942	-	-	-	2,296	-	-	-
8-1	234	-	-	-	10	-	-	-
8-2	2,822	2	62	36	816	-	-	-
8-3	416	-	-	-	27	-	-	-
8-4	6,551	2	67	31	3,431	7	64	29
Av.	2,506	-	-	-	1,071	-	-	-
9-1	3,170	3	66	31	1,382	4	74	22
9-2	1,031	0	64	36	434	-	-	-
9-3	4,549	6	65	29	7,852	4	66	30
9-4	5,607	0	65	35	2,935	7	63	30
Av.	3,589	-	-	-	3,151	-	-	-
Av. all	3,062	-	-	-	2,434	-	-	-

For the present study, a more comprehensive "bare soil dispersion" index was developed. This index is based on the theory that a given bare soil area will result in a greater sediment production if it is located near the bottom of a plot where detached soil particles can be splashed or carried in suspension directly into a measuring device than if it is located farther up the plot slope where there is a chance for the detached material to be trapped by vegetation or in depressions down slope. To obtain a numerical expression of this effect, the 15 horizontal point observation rows on each plot were numbered from 1 to 15 from top to bottom and each row number was then squared. These values were multiplied by the number of bare soil strikes per row and the products were then summed for each plot.

The "bare soil dispersion" indexes thus obtained were found to be more highly correlated with sediment production (r = -.826) than was average ground cover (r = -.755). This bears out the theory that a uniformly dispersed ground cover will, in general, more effectively minimize erosion than one of the same density which is in the form of more distinct bunches or patches. It also suggests that with uniform slope and soil conditions the sediment production potential will be greater on bared areas adjacent to channels than comparable areas upslope which have densely covered areas between them and established channels.

CONCLUSIONS

Reseeding and protection from grazing for 3 years brought about a substantial improvement in the quality and quantity of subalpine-herbaceous forage on parts of the Manti Canyon range rehabilitation project area. By the third year of the improvement program, the tested portion of the treated area also provided control of surface runoff, infiltration, and erosion approximately equal to that of untreated, paired areas. Further improvement in both forage production and control of storm runoff and erosion should occur in the next few years providing the treated area is so managed as to allow for the full development of the newly established young plants, for the establishment and growth of new seedlings, and for the accumulation of litter. Additional measurements will be required in the years ahead to determine the potential effects of the treatment program.

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COMMON AND BOTANICAL NAMES OF SPECIES MENTIONED

Common Name	Botanical Name
Alfalfa	Medicago sativa
Agoseris	Agoseris spp.
Aster	Aster spp.
Bladderpod	Lesquerella spp.
Bluegrass, Kentucky	Poa pratensis
Bluegrass	Poa spp.
Brome, nodding	Bromus anomalus
Brome, mountain	Bromus carinatus
Brome, smooth	Bromus intermis
Canarygrass, reed	Phalaris arundinacea
Cinquefoil	Potentilla spp.
Clover, alsike	Trifolium hybridum
Dandelion, common	Taraxacum officinale
Evening primrose	Oenothera spp.
Fir, alpine	Abies lasiocarpa
Fleabane	Erigeron spp.
Foxtail, meadow	Alopecurus pratensis
Geranium	Geranium spp.
Gilia, slenderleaf	Gilia linearis
Goldeneye, showy	Viguiera multiflora
Groundsel	Senecio spp.
Knotweed, Douglas	Polygonum douglasii
Ligusticum, Porter	Ligusticum porteri
Meadowrue	Thalictrum spp.
Needlegrass, Letterman	Stipa lettermani
Needlegrass, subalpine	Stipa columbiana
Oatgrass, tall	Arrhenatherum elatius
Orchardgrass	Dactylis glomerata
Paintedcup, sulphur	Castilleja sulphurea
Peavine	Lathyrus spp.
Penstemon, Rydberg	Penstemon rydbergi
Pine, limber	Pinus flexilis
Pseudocymopterus	Pseudocymopterus spp.
Rockjasmine	Androsace diffusa
Sagebrush, sweet	Artemisia discolor
Spruce, Engelmann	Picea engelmanni
Timothy	Phleum pratense
Vetch, American	Vicia americana
Wheatgrass, slender	Agropyron trachycaulum
Yarrow, western	Achillea lanulosa

Research Paper 48 1957

THE PROJECT SKYFIRE CLOUD-SEEDING GENERATOR

By
Donald M. Fuquay, Research Meteorologist
The Munitalp Foundation, Inc.
and
H. J. Wells, AGC, USN
President's Advisory Committee on
Weather Control

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

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THE PROJECT SKYFIRE CLOUD-SEEDING GENERATOR

INTRODUCTION

One of the aims of Project Skyfire is to determine the possibility of preventing lightning fires or reducing their severity by cloud-seeding. Research completed to date indicates that cloud modification for purposes of lightning suppression requires the production of enormous quantities of silver iodide nuclei. These nuclei may be dispersed either from ground-based equipment or from similar equipment mounted in aircraft. In addition to being able to produce a relatively high output of silver iodide nuclei, cloud-seeding generators for experiments in lightning suppression should be economical and simple to operate; easy to transport and service in rough, mountainous country; and be safe for use in highly flammable forests. This publication presents the reasons for development of the generator, summarizes calibration procedures and results, and describes the equipment. The generator calibration and development program will be covered fully in a later report.

The Project Skyfire cloud-seeding generator is designed to produce silver iodide nuclei for experiments performed in devising techniques for lightning suppression. This generator produces freezing nuclei by volatilizing a silver iodide-acetone solution in a propane flame.

The Project Skyfire cloud-seeding generator described in this publication is the result of equipment research by the writers during the spring and summer of 1957 aimed at meeting the broad objectives described above. Although preliminary tests indicate success in meeting the general objectives, the generator must be considered as still being in a developmental stage. Final evaluation of its performance awaits full-scale field tests.

SILVER IODIDE SMOKE GENERATORS

Several different types of silver iodide smoke generators were used during exploratory field programs. During 1956 an airborne string-type generator, designed for Skyfire operations and mounted in a Cessna 180 aircraft, was operated for about 60 hours. In addition, three ground-based string-type generators were employed several times near Flagstaff, Arizona and Missoula, Montana. Late in the 1956 field season a network of 10 acetone-burning generators was used at the Montana test site.

The two general types of generators tested, string- and acetone-burning, differ mainly in the manner in which the silver iodide is injected into the flame to form a smoke of silver iodide crystals. In the acetone-burning type, silver iodide is first dissolved in a solution of acetone and sodium iodide. The resulting solution is then sprayed into a flame by propane gas pressure through an internal-mixing paint spray nozzle (fig. 1). The mixture of propane gas and acetone solution burns in a flame holder.

Figure 1.--Acetone-burning silver iodide generator.

The string technique involves saturating cotton cord, such as window sash cord, in a concentrated silver iodide-sodium iodide-acetone solution. When the cord dries, it remains impregnated with silver iodide. In the various string-burning generators, the cord impregnated with silver iodide is fed into a propane or oxy-propane flame through a feed gear driven by a light battery-powered motor (fig. 2). As many as 100 operating hours can be obtained from a single spool of impregnated cord.

GENERATOR DEVELOPMENT

All previously developed generators tested during and after the 1956 season had serious disadvantages for Skyfire use. The acetone type produced a relatively high output of effective nuclei but had high consumption rates for both the silver iodide solution and propane gas; furthermore, it operated irregularly because of clogging in the spray nozzle. This type presented problems in logistics and maintenance and was a serious fire hazard. The string type was virtually trouble-free in operation, and had simple supply requirements. However, it had the serious disadvantages of relatively low output per unit and high initial cost. After all known facts about existing silver iodide smoke generators had been considered, it was obvious that none of these generators was entirely suitable for Skyfire operations. In addition, not enough was known about the generation of silver iodide nuclei and the general characteristics of generators to make recommendations for a generator suitable for Skyfire use.

Figure 2.--String-burning silver iodide generator.

Experience with generators used during the 1956 season indicated what features were necessary for silver iodide generators designed to operate in mountainous country and in forested areas.

First, the generator must be absolutely safe; particularly, it should create no fire hazard and present no danger to operating personnel. Second, the generator must operate reliably for extended periods (up to 8 hours) without maintenance. Third, it must produce the highest possible output of nuclei from a minimum of materials to reduce the logistics problems in mountainous terrain. Fourth, the generator must be simple to operate since any sizable operation would require several generators to be operated and maintained by relatively inexperienced personnel. The goal set for a generator was 8 hours' unattended operation each day with procurement and operating costs within a limited budget.

Accordingly, in the fall of 1956 a program for the calibration of all available silver iodide smoke generators used, or considered for use, in Project Skyfire was started. The calibration program had three objectives: (1) to determine the effective output of nuclei from smoke generators used during the 1956 operation; (2) to investigate the effects of changes in design on the output and efficiency of smoke generators; (3) to supply data necessary for planning future cloud-seeding operations. The complete calibration program will be reviewed in a later report.

The following method was used to calibrate the output of effective freezing nuclei of the generators at various activating temperatures. The smoke from a generator being calibrated was mixed with a large volume of air forced at a known rate through a vertical wind tunnel placed over the generator. A measured sample was taken from the mixed air stream, diluted by a known amount, and introduced into a cold box. Each effective silver iodide crystal present in the sample would cause an ice crystal to grow to visible size in a supercooled fog already present in the cold box. The number of crystals found within a known volume in the cold box was visually counted with the aid of a 10-power microscope as the crystals scintillated in a bright beam of light. Subsequent samples were introduced as the cold box temperature was changed from -22° to -6° C. Calibration values for various generators tested are shown in table 1. A 4-percent silver iodide-acetone solution was used in the calibration studies.1/

The calibration tests, construction details, and generator designs indicated need for more information about the effects of such factors as flame temperature, quench rate, shape of flame chamber, and solution injection rate on the number of effective nuclei produced by a generator. A series of tests was performed to gather the necessary data. Since a large quantity of silver iodide solution was already available to the project, and since comparative studies of other generators showed the acetone-burning type most likely to fit our needs, study was concentrated on this type of generator.

The first problem was to develop a satisfactory nozzle for injecting the acetone solution into a flame. No internally mixing nozzle was found that was free from clogging. After several tests, a nebulizer using a propane stove orifice and a hypodermic needle was devised. This nozzle proved to be very reliable, was inexpensive to build, and easy to adjust.

A great many flame chambers of various sizes and shapes were tested. Cylindrical chambers of steel pipe, perforated tubing, and various ceramic materials were tried. A cylindrical chamber capped by a quench plate yielded the highest output. A series of ports near the bottom of the chamber regulated the amount of air drawn into this chamber. The ceramic material alundum was found to be best for the flame chamber. However, no material that was immediately available at a reasonable price withstood the periodic, nonuniform heating and cooling without cracking or crumbling. Steel tubing proved almost as effective as the ceramic material and was cheaper and more rugged.

Temperature in the flame chamber was varied by changing the amount of propane gas introduced into it. The output of nuclei increased linearly as

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1/ Sixteen pounds of commercial grade silver iodide dissolved in a solution of 4 pounds of sodium iodide and 55 gallons of acetone. Sediment was removed by filtering through glass-wool filters.

Table 1.--Output of effective silver iodide nuclei at various activating temperatures

Temp. of cold box (°C.)	Standard MRI[1/]	High output MRI[2/]	ACWC[3/]	Skyfire[4/]
-8	4×10^{6}	1.5×10^{8}	3×10^{8}	9×10^{10}
-9	3×10^{7}	7×10^{8}	2×10^{9}	3×10^{11}
-10	2×10^{8}	3×10^{9}	2×10^{10}	8×10^{11}
-11	2×10^{9}	1.5×10^{10}	2×10^{11}	1×10^{12}
-12	1×10^{10}	7×10^{10}	6×10^{11}	3×10^{12}
-13	1×10^{11}	3×10^{11}	1×10^{12}	4×10^{12}
-14	4×10^{11}	1×10^{12}	2×10^{12}	6×10^{12}
-15	6×10^{11}	2×10^{12}	3×10^{12}	9×10^{12}
-16	9×10^{11}	3×10^{12}	4×10^{12}	1×10^{13}
-17	1×10^{12}	4×10^{12}	7×10^{12}	1.5×10^{13}
-18	----	5×10^{12}	1×10^{13}	2×10^{13}
-19	----	6×10^{12}	2×10^{13}	2.5×10^{13}
-20	2×10^{12}	8×10^{12}	2×10^{13}	3×10^{13}
-21	----	1×10^{13}	3×10^{13}	4×10^{13}

1/ A standard string-burning generator manufactured by Meteorology Research, Inc. String feed is 2.5 centimeters per minute into a propane torch burner; silver iodide consumption is 0.9 gm. per hour.

2/ Similar in principle to Standard MRI except that it has an oxy-propane flame; string feed 10 cm. per minute; silver iodide consumption, 14.4 gm. per hour.

3/ An acetone-burning type used on Project Overseed, in which propane pressure forces a silver iodide-acetone solution through an internal mixing spray nozzle; silver iodide consumption, 33 gm. per hour.

4/ Silver iodide consumption about 16 gm. per hour.

the temperature was increased from about 400° F. to about 2,000° F.; the rate of increased output decreased as temperature rose above 2,000° F. About 2,000° F. appeared to be the most efficient operating temperature fo all flame chambers tested.

Attempts were made to increase the generator output by injecting chem icals into the flame. In some tests, output was increased from two- to threefold by injecting iodine vapor. However, when the problems of injection and personnel safety were considered, such injections did not appear feasible. Ammonia vapor kept the generator free of deposits in the flame chamber but did not change the generator output.

PROJECT SKYFIRE CLOUD-SEEDING GENERATOR

Since the acetone-burning type of silver iodide smoke generator had performed most satisfactorily in preliminary tests, a generator of this ty was designed for Project Skyfire (fig. 3). In use, silver iodide dissolve in a solution of acetone and sodium iodide is drawn from a reservoir throu a modified hypodermic needle and nebulized by a jet of propane gas. This mixture of atomized acetone solution, propane, and air is directed into a flame chamber and ignited. The volatilized silver iodide condenses into crystals as the smoke passes from the flame around a quench plate mounted

Figure 3.--Skyfire generator showing from left to right the solution reservoir, framework, flame holder, windshield, and propane supply tank.

above the flame chamber. The quench plate serves the dual function of containing the mixture in the flame chamber and also disperses the smoke immediately above the flame. This quenching action yields a larger crystal output than an open chimney. This rapid quenching also seems to give a more nearly uniform size to the nuclei produced, as indicated by the action of the nuclei in forming ice crystals.

The Skyfire generator is constructed in four parts: a support frame, an externally mixing spray nozzle, a flame chamber, and a windshield. The support frame serves as a mount for the flame chamber, windshield, and reservoir for the silver iodide solution. All the major components can be removed easily as separate units for servicing or for replacing defective parts.

At sea level the generator consumes about 600 milliliters per hour of 4-percent silver iodide-acetone solution when 6 p.s.i. propane gas pressure is applied to the mixing nozzle. Propane gas consumption at this gas

Table 2.--Approximate consumption rate of silver iodide-acetone solution by the Skyfire generator (milliliters per hour)

Elevation (MSL)	Propane gas pressure at orifice (p.s.i.) 5	10	15
Sea level	600	750	900
3,000 feet	500	600	700
6,000 feet	400	500	600

pressure with a 0.029-inch orifice, is about 1 pound per hour. The output of nuclei under these conditions was 3×10^{13} nuclei per second effective at -20° C. (fig. 4).

Since the rate of flow of the acetone solution depends upon the difference between the nozzle gas pressure and the ambient air pressure, the gas pressure must be increased in order to maintain a constant flow of 600 milliliters per hour at higher elevations. At 3,200 feet MSL the solution flow at 6 pounds gas pressure was about 500 milliliters per hour. At 6,500 feet MSL, 12 pounds of propane pressure was necessary to yield the calibrated output. The average propane consumption was about 2 pounds per hour at 6,500 feet elevation.

Soon after the Skyfire generators were installed in the field, it was found that high ambient temperature, or operation at higher elevations (5,000-7,000 feet MSL) at even moderate temperatures, would develop vapor lock in the vacuum line that fed the silver iodide solution to the nozzle. The vapor lock occurred at the highest point where the solution line left the reservoir and passed down under the windshield to the nozzle. The vapor lock developed because under these operating conditions the entire unit was near the boiling point of the acetone solution. Further reduction in pressure, coupled with radiational heating from the flame chamber, caused a bubble to form in the line; this bubble blocked the flow of silver iodide solution.

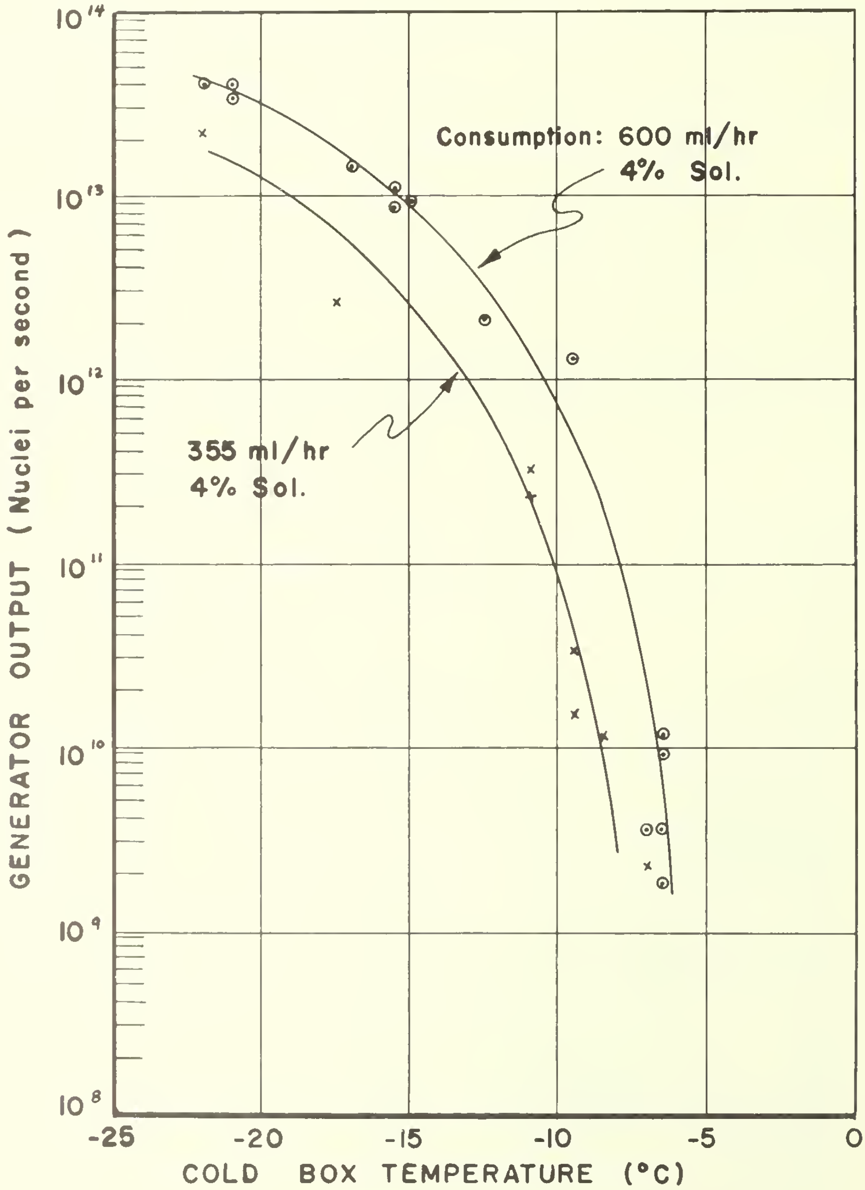
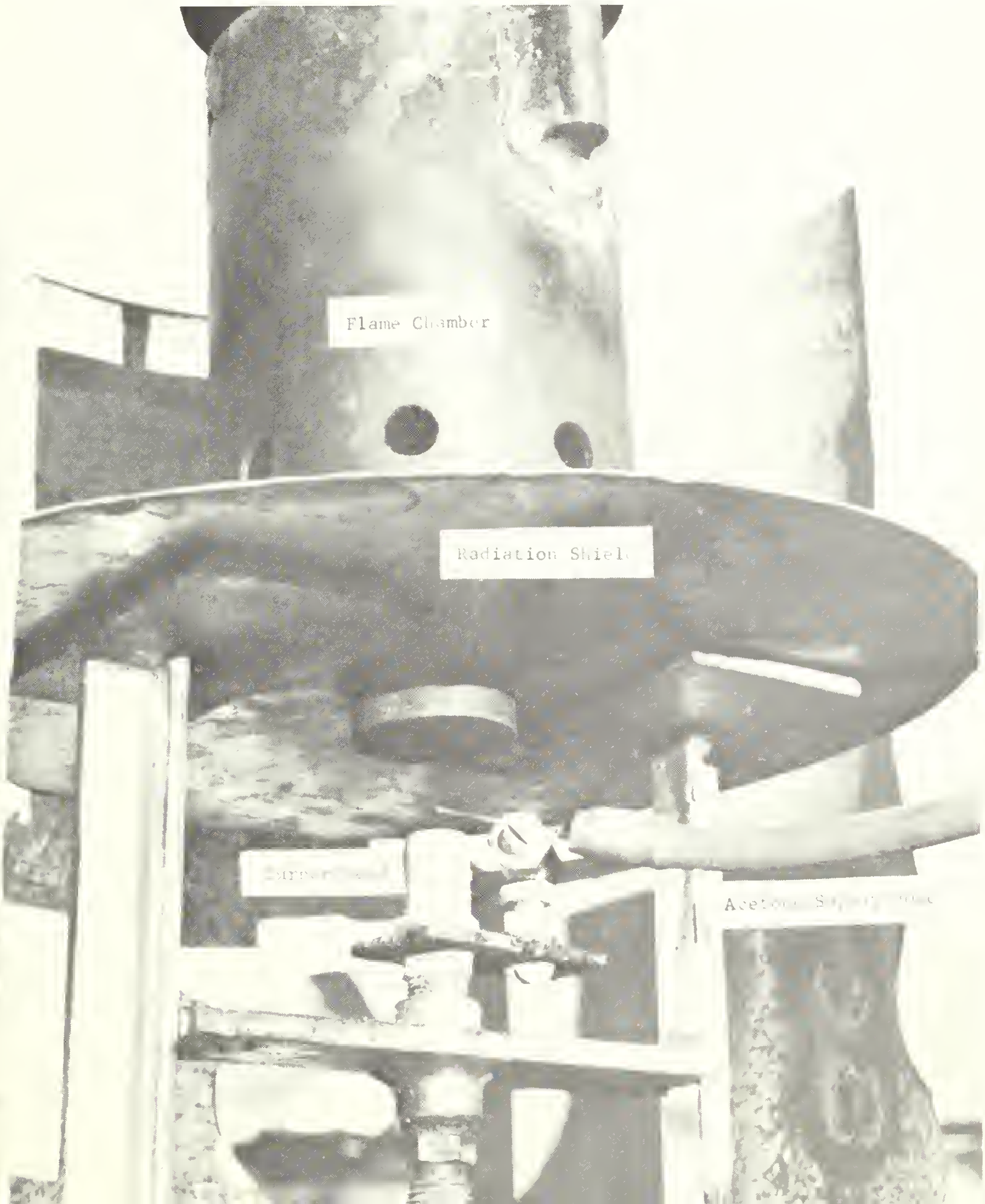


Figure 4.--Calibration diagram for Skyfire generator showing effective silver iodide crystal output at various temperatures.

The vapor-lock problem was eliminated by two slight modifications in design of the generator. The loop in the solution line was eliminated by running the line directly from the top of the solution reservoir to the nozzle through a hole in the windshield. Thus, if bubbles formed in the line, they would be drawn up the line and expelled through the nozzle.

It was still possible on hot days for radiation from the flame chamber to heat the hypodermic needle to the point where a vapor lock could occur at the base of the needle. To eliminate this, a circular aluminum shield was added below the flame chamber (fig. 5). Annular rings of asbestos fiberboard placed under the flame chamber further isolated the nozzle from the hot chamber.

Figure 5.--Modifications of Skyfire generator to prevent vapor lock.



Thirty Skyfire generators were operated in various combinations for a total of 2,560 hours during the 1957 Skyfire season. These generators were operated at elevations from 5,000 feet to 6,500 feet MSL. Average consumption for the season was 380 milliliters per hour of 4-percent silver iodide-acetone solution and about 2 pounds per hour of propane. Virtually no operating time was lost because of equipment failure after the minor modifications were made. In general, this generator met all the requirements specified for such equipment to be used in remote and forested areas.

Steel tubing was used in the flame chamber and steel plate in the quench plates in the 30 test generators as an economy measure. As expected, the usable life of these steel components was about 200 hours of operation. Stainless steel is recommended for all components subject to high temperatures, such as the flame chamber and quench plate, in any generator designed to operate longer than one season.

APPENDIX

Installation and Operating Instructions for the Skyfire Generator

The generator should be mounted on level ground in an area approximately 10 feet in diameter clear of all overhanging branches and brush. All surface litter and flammable material should be removed down to mineral soil.

After the generator is assembled, connect the gas line from the propane tank to the spray nozzle. Check the alignment of the hypodermic needle. The tip of the needle should be centered over the gas orifice and about three-sixteenths of an inch above the top of the gas nozzle. After the needle has been properly adjusted, it should not need to be adjusted for subsequent operations.

The steps listed below should be followed in lighting the generator:

1. Insert the latex tubing fastened to the hypodermic needle into the reservoir of solution.

2. Open the large valve on top of the propane tank at least 6 turns.

3. Adjust the control on the gas pressure reducer to the desired gas pressure (table 2). A light mist of atomized solution should emerge from the top of the burner.

4. Carefully insert a lighted match into the top of the flame chamber.

5. With the generator operating, visually check all parts for leaks of gas or solution.

The following steps should be taken in shutting off the generator:

1. Remove the tubing from the solution reservoir and wait until all solution has been purged from the line. This is very important. If any solution is allowed to remain in the tubing after the generator is shut off, clogging of the needle is likely to result.

2. After step 1 is completed, close the main valve on the propane tank.

The generator requires virtually no maintenance. After every third or fourth operation, remove the flame chamber and cap and clean both with a wire brush. At times a small deposit may form on top of the hypodermic needle. This can be removed by gently brushing the needle tip with the finger or a small stick. Take care not to alter the position of the needle.

WORKING DRAWINGS OF SKYFIRE GENERATOR

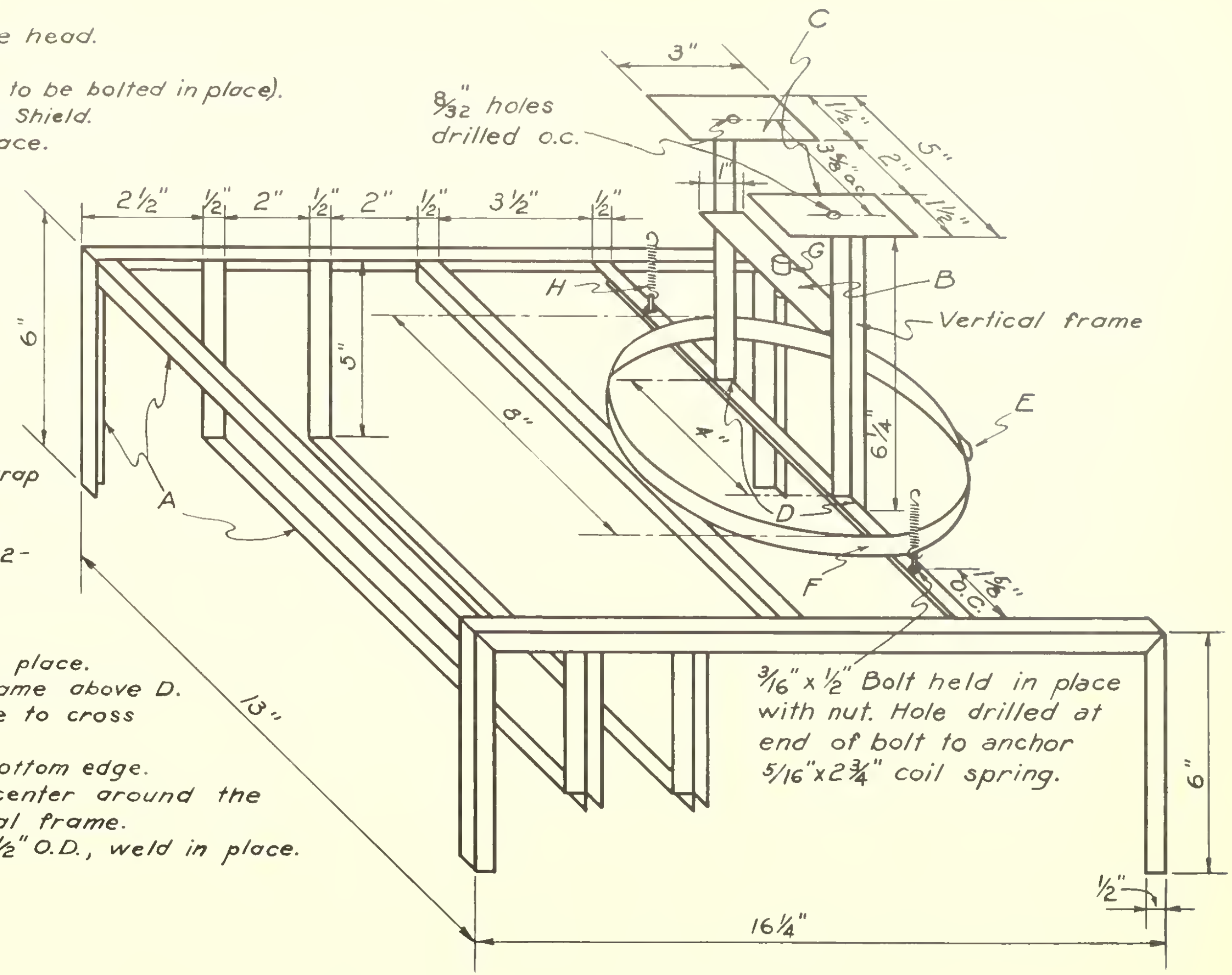
A. Frame.
B. Cross member to hold nozzle head.
C. Base for flame holder.
D. Base of vertical frame, (legs to be bolted in place).
E. Lip to support base of Wind Shield.
F. Ring to hold Wind Shield in place.
G. Standard pipe union mount for nozzle head.
H. Spring anchored to bolt, to hold wind shield in place.

MATERIAL

A. 1/2" angle iron 1/8" thick.
B. 1"x4" strap iron 3/16" thick.
C. 1 1/2"x3" strap iron 1/8" thick.
D. 3/16" bolt & nut to hold legs to frame.
E. 1/2"x 2 1/2" strap iron thick.
F. 8" diam. ring made from 1/2" strap iron 1/8" thick.
G. 1/2" O.D. standard pipe union.
H. 2 - 3/16"x 1/2" bolts with nuts & 2 - 5/16" x 2 3/4" coil springs.

CONSTRUCTION

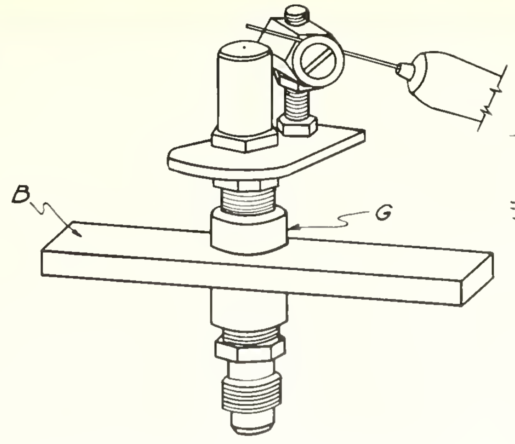
A. All weld except at points D.
B. Drill 1/2" O.D. at center, weld in place.
C. Weld to legs of vertical frame above D.
D. Bolt legs of vertical frame to cross member of frame A.
E. Weld lip to ring at outside bottom edge.
F. Weld ring so that it will center around the base of the of the vertical frame.
G. Insert standard pipe union 1/2" O.D., weld in place.



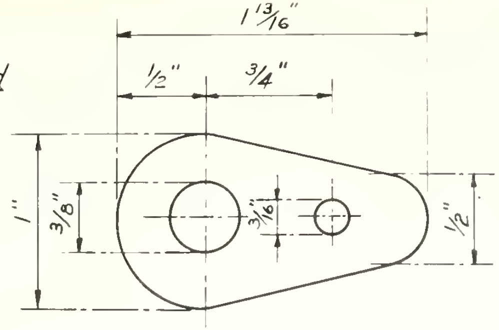
Scale: 3" = 1'-0"

Frame of Ag I Smoke Generator

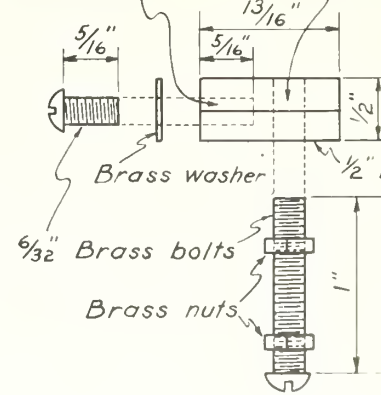
G.H.T. 57



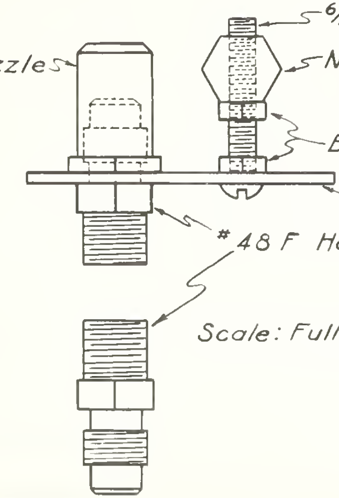
Burner Head Mounted



Brass Mounting Plate
Scale: Full size



Needle Mount Details
Scale: Full size



Scale: Full size

Burner Head Details

NOTE:
Seal all threaded joints with Harbinsons insoluble sealant or equivalent.

Burner Head Assembly

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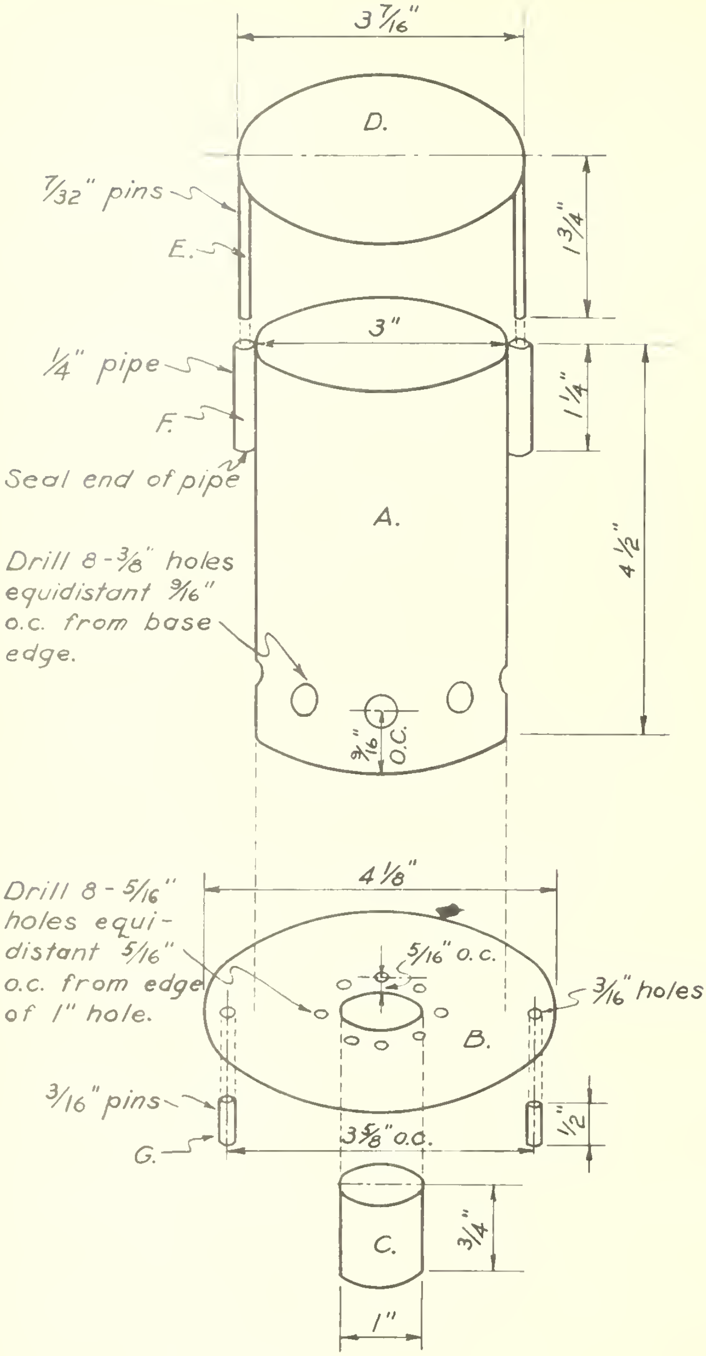


Scale: 6" = 1'-0"

MATERIAL

A. 4 1/2" x 3" x 1/16" steel tube.
B. 4 1/8" x 1/16" steel plate. 1" hole cut out of center.
C. 1" x 3/4" x 1/16" steel tube.
D. 3 7/16" x 1/16" steel plate.
E. 2 - 1 3/4" x 7/32 steel pins.
F. 2 - 1/4" x 1 1/4" steel pipe.
G. 2 - 3/16" x 1/2" steel pins.

CONSTRUCTION

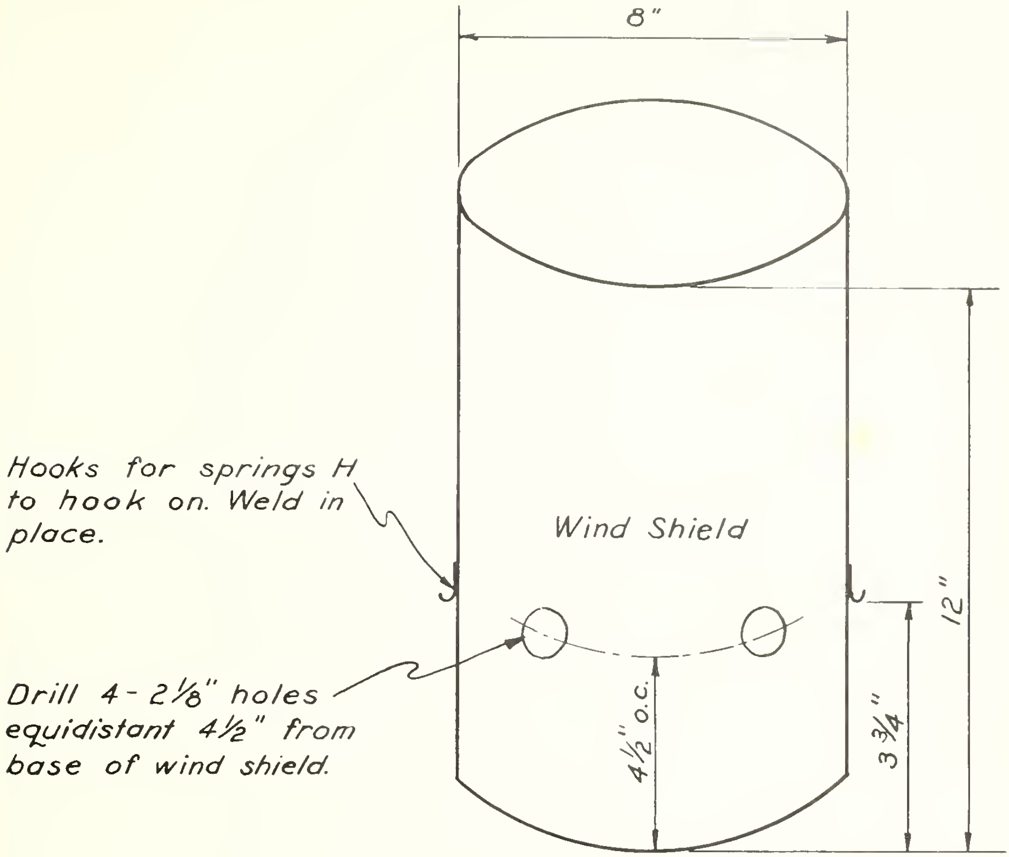
Drill 8 - 3/8" holes 7/8" from base edge of A. Cut base plate B, cut 1" diameter from center and drill 8 - 5/16" holes 5/16" o.c. from edge of 1" hole. Cut D and weld pins E and pin holders F in place. Weld pins G in holes of plate B.

ASSEMBLY

Insert C in center hole of B and weld. Place A on B with center over center of C and weld (spot 4 places). Place pins E into pin holders F.

Flame Holder

G.H.T. 57



Scale: 3" = 1'-0"

MATERIAL

2 Steel hooks, weld in place.
Wind shield to be made of 16 gauge galv. steel.

Wind Shield

G.H.T. 57

Research Paper No. 49 1957

THUNDERSTORM ANALYSIS IN THE NORTHERN ROCKY MOUNTAINS

By

DeVer Colson
Meteorologist

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U.S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

THUNDERSTORM ANALYSIS IN THE NORTHERN ROCKY MOUNTAINS

DeVer Colson[1]
U.S. Weather Bureau
Washington, D.C.

INTRODUCTION

Lightning-caused fires are a continuing serious threat to forests in the northern Rocky Mountain area. More than 70 percent of all forest fires in this area are caused by lightning. In one 10-day period in July 1940 the all-time record of 1,488 lightning fires started on the national forests in Region 1 of the U.S. Forest Service.[2]

Project Skyfire was planned and organized to study the causes and characteristics of lightning storms and to see what steps could be taken to decrease the great losses caused by lightning fires. One important phase of Project Skyfire is the study and analysis of the weather phenomena associated with the formation and growth of lightning storms. A better understanding of these factors is valuable to both the forester and the meteorologist. In the Project Skyfire research program, analyses are being made of the specific characteristics of individual lightning storms and the general characteristics of storms during an entire fire season. This paper presents an analysis of thunderstorm development and characteristics in the northern Rocky Mountains for the 1955 fire season (July and August).

OPERATIONS

The area being studied by Project Skyfire is closely identified with Region 1 of the U.S. Forest Service and includes 16 of its national forests. Certain strategically located lookouts in this region were chosen to be the 15 Skyfire stations, and two additional outlying stations were established at the Russell Mountain Lookout in Wallowa-Whitman National Forest in eastern Oregon and at Mt. Washburn Lookout in Yellowstone National Park. These last two stations were chosen to observe the storms moving into the area from the southwest and southeast quadrants. All Skyfire lookout stations were manned during the main fire season, July and August.

In addition to their training for regular duties in fire detection and control, the Skyfire observers were instructed to measure and record the dry and wet bulb temperatures, wind speed and direction, and cloud types and movement at three observation times daily: 0800, 1200, and 1630 MST. From weather measurements they computed the burning index (a numerical measure of

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1/ Research meteorologist, U.S. Weather Bureau, Washington, D.C. He has collaborated in Intermountain Station's fire research program since 1954.

2/ Includes Montana, Idaho north of the Salmon River, northeastern Washington, Yellowstone National Park, and northwestern South Dakota.

fire danger) daily for their station, and recorded the time of beginning and ending, location and movement, and the number of cloud-to-ground lightning strikes in each thunderstorm during each 24-hour period within a 20-mile radius of their tower.

In addition to the 17 Skyfire stations, more than 80 weather stations were operated in this area during the fire weather season. Some of these stations were in Glacier National Park and on Indian reservations, and most of them were operated by Forest Service personnel. At these stations the dr and wet bulb temperatures, wind speed and direction, and fuel moisture were measured. The burning index was computed and the data recorded for the 1630 MST observation time together with the maximum cumulus activity for the afte noon and the time of beginning and ending of lightning for the 24-hour perio in their district. The network of weather stations and the Skyfire stations were connected by radio to a central radio station in Missoula, Montana, where weather reports were received daily at 1700 MST. Regular teletype weather data and facsimile maps were available at the Weather Bureau Airport Station in Missoula.

ANALYSIS OF DATA

Distribution of storms over the entire area during the 1955 season (fig. 2) shows greater frequency of storms on the east side of the Continental Divide. Yellowstone National Park and Gallatin National Forest had the greatest frequency; fairly even distribution occurred over the other nationa forests east of the divide. West of the divide, the Nezperce, Bitterroot, and Lolo Forests, or the southern section, had more lightning storms than other areas. This concentration in the southern sections is in agreement with the general topography and the windflow.

Distribution of the reported initial times of lightning storms is shown in figure 3. The largest number of storms began during the late afternoon and evening (1400-2200 MST); the second largest number began about midnight; and the least number began in the early morning hours.

Distribution of the number of lightning strikes reported by the 17 Skyfire stations is shown in figure 4. The greatest total number of lightning strikes was recorded at the Sliderock and Double Arrow Lookouts in the Lolo National Forest, Mt. Washburn Lookout in Yellowstone, Gisborne Lookout near the Priest River Experimental Forest, and Cold Springs Lookout in the Nezperce National Forest. The number of strikes per storm is rather evenly distributed over the entire area. The seasonal average of lightning strikes per storm for the entire area was 35.

A calendar of the lightning storm activity is shown for the months of July and August 1955 (tables 1 and 2). These tables record the lightning activity and the precipitation both east and west of the Continental Divide. Comments in the "Remarks" column indicate the type of storm and list the mor significant meteorological features. Some of the more interesting storms ar treated in detail later in this paper, but a few general comments on the whole season follow here.

Table 1.--Lightning activity, July 1955

DATE	WEST OF DIVIDE		EAST OF DIVIDE		REMARKS
	ϟ	PRECIP.	ϟ	PRECIP.	
1					
2					
3					COLD LOW ALOFT EXCEPT FOR BREAKS ON
4					JULY 2 AND 7-8
5	+	M	+	L	
6	⊕	H	⊕	M	UPPER LEVEL TROUGH MOVED ACROSS AREA
7	O	H	O	M	
8	–	L	+	L	
9	⊕	M	+	L	
10	+	M	+	M	
11	+	M	+	M	
12	O	L	–	M	SCATTERED AIRMASS OR TOPOGRAPHICAL
13	–	L	+	L	" " " "
14	O	O	+	L	" " " "
15	+	L	+	L	DEEPENING SURFACE LOW - FRONTAL ZONE
16	⊕	L	+	L	" " " " "
17	+	M	+	L	COLD FRONTAL PASSAGE
18	+	L	+	M	" " "
19	O	O	+	L	SCATTERED AIRMASS OR TOPOGRAPHICAL
20	+	L	+	L	" " " "
21	+	L	+	L	" " " "
22	⊕	M	+	M	" " " "
23	⊕	M	+	M	" " " "
24	⊕	M	⊕	L	COLD LOW ALOFT
25	⊕	M	⊕	M	" " "
26	O	L	–	L	" " " } COLD FRONTAL PASSAGE
27	⊕	M	+	M	" " " } UPPER TROUGH MOVED
28	O	L	+	M	ACROSS AREA
29	O	L	–	L	
30	O	L	O	O	WEAK FRONTAL PASSAGE
31	O	L	O	O	" " "

Explanation of symbols: lightning, 0 none; - few isolated storms; + considerable activity over parts of area; ⊕ widespread activity; precipitation, 0 none; L trace - 0.10 inch; M 0.11 - 0.50 inch; H more than 0.50 inch.

July was characterized by considerable lightning activity and also by heavy precipitation, especially in the first part of the month. Total rainfall from October 1 through June in the Priest River area had been unusually low, but precipitation in early July was sufficient to reduce the fire danger greatly; it remained low until near the end of the season.

The period from July 1 to 11 was associated with a persistent deep cold low aloft and quite moist air at all levels. A frontal zone with deepening surface pressure was evident July 15 and 16, and was followed by a cold frontal passage on the 17th. Another period with a cold low aloft appeared July 24-28, but this time the moisture seemed to be confined more in the higher levels. This period was associated with a surface cold frontal passage July 26-27 and with the passage of an upper trough July 27-28. Most of the storms in the first part of the month were lower level storms accompanied by considerable precipitation. Many storms east of the divide from July 12 to 21

Table 2.--Lightning activity, August 1955

DATE	WEST OF DIVIDE		EAST OF DIVIDE		REMARKS
	ϟ	PRECIP.	ϟ	PRECIP.	
1	0	0	+	0	WEAK FRONTAL ZONE
2	-	0	-	L	COLD LOW ALOFT-LOCAL HIGH LEVEL MOISTURE
3	0	0	-	L	
4	0	0	0	0	
5	0	0	0	0	
6	0	0	-	0	
7	+	L	0	0	COLD FRONTAL PASSAGE
8	+	L	+	L	" " "
9	0	0	0	0	
10	0	0	0	0	
11	0	0	0	0	COLD FRONTAL PASSAGE
12	0	0	+	L	" " "
13	0	0	+	L	
14	+	0	⊕	M	COLD LOW ALOFT
15	+	L	⊕	L	COLD FRONTAL PASSAGE
16	0	L	0	L	" " "
17	0	0	0	0	
18	+	0	-	0	COLD LOW ALOFT - HIGH LEVEL MOISTURE
19	+	L	+	L	COLD FRONTAL PASSAGE-HIGH LEVEL MOISTURE
20	0	0	-	0	" " " " " "
21	0	0	0	0	
22	0	0	-	0	
23	0	0	0	0	
24	0	0	+	L	COLD TROUGH ALOFT - HIGH LEVEL MOISTURE
25	⊕	L	⊕	L	" " " AND INSTABILITY
26	0	0	+	L	" " "
27	0	0	0	0	
28	0	0	0	0	
29	0	0	0	0	
30	0	0	0	0	
31	0	0	0	0	COLD FRONTAL PASSAGE

Explanation of symbols: lightning, 0 none; - few isolated storms; + considerable activity over parts of area; ⊕ widespread activity; precipitation, 0 none; L trace - 0.10 inch; M 0.11 - 0.50 inch; H more than 0.50 inch.

and west of the divide after the 17th probably were airmass or orographic. The storms from July 22 through July 28 were higher level storms. A weak frontal zone was present on July 30-31, but the air was too dry and stable for any activity except some light precipitation.

There was less lightning storm activity in August than in July. The storms were of the high-level type and were usually associated with little no precipitation. The periods of August 7-9, 14-16, and 18-19 were associated with cold fronts. In the last period, a cold low aloft was also in evidence. The period of August 24-25 was associated with a well developed col low aloft with the moisture and instability concentrated in the higher leve

CHARACTERISTIC SOUNDINGS

A tabulation of the upper air data at the standard levels was made for Boise, Spokane, Medford, and Tatoosh Island. Mean soundings were computed for various periods of storm activity and corresponding periods with little or no activity. The results for Spokane are shown in figure 5. In the set of diagrams on the upper right, the solid lines refer to the temperature and dew point profile for the period July 5-11. These soundings show considerable moisture at all levels and extremely low temperatures at the 500- and 400-millibar levels. The computed bases of clouds would be quite low. The conventional Showalter Stability Index for this mean sounding is +2. While there may be some question about the interpretation of the exact numerical value of the stability index when applied to a mean sounding, the relative values of the stability indices computed for a series of mean soundings should furnish considerable information on the comparative degree of stability.

Except for a break July 7-8, this period was characterized by widespread storm activity and moderate to heavy rainfall, and the bases of the storm clouds were low. The mean sounding for the July 12-14 (B) period shows decided warming at all levels with generally lower relative humidities. While the over-all stability has not changed much, there has been pronounced drying above the 500-millibar level, which could inhibit buildup of the convective activity to sufficient heights for storms to develop. During this particular period, no storm activity occurred in the northwestern section around Spokane.

The mean sounding for the July 15-17 (C) period shows adequate moisture at all levels and a stability index of +1. This sounding shows considerable heating in the lower levels rather than the cooling aloft that occurred in the July 5-11 period. Thunderstorms and considerable precipitation appeared during this period. The mean sounding for the corresponding period July 18-21 (D) shows a very dry and stable airmass with no chance for convective activity; no storms occurred during that period.

The mean sounding for the period of July 22-25 (E) shows possible activity. However, some additional lifting by either frontal or orographical action would be necessary to produce thunderstorm activity. In any case the cloud bases would be high (above 10,000 feet). There were scattered storms in this period. The mean sounding for the period of July 26-31 (F) shows fairly high relative humidity, but increased stability due to cooling in the lower levels. The stability index was +6 in contrast to +1 in period (E).

The mean sounding for the first part of August (G) shows a very dry and stable airmass (stability index of +7) with little chance of any thunderstorm activity. The sounding for August 3 (H) shows no definite indication of activity except for the drop in temperatures at the 500- and 400-millibar levels. The moisture seems insufficient for thunderstorms, but scattered storms were observed; the moist tongue may have been quite narrow and may not have shown on the Spokane sounding. Soundings (I) and (J) (August 19 and August 7-9) do not show a sufficient amount of moisture or instability to produce thunderstorms. The stability indices were +2 and +4. In these periods, additional lifting apparently was provided by frontal lifting. The bases of any indicated storms would be rather high.

The sounding for August 25 (L) shows little indication of activity below the 500-millibar level; the conventional stability index was +6. However, the layer between the 500- and 400-millibar levels shows high relative humidity and considerable instability. This was also shown on the corresponding soundings at Boise. The mean sounding for the period of August 17-September 9 (except for the two periods of August 19 and August 25) shows a very dry and stable airmass (stability index of +7).

Similar mean soundings computed for Boise are shown in figure 6. As in the data for Spokane, a comparison of the mean soundings for the period of July 9-11 (A), which had considerable activity, and for the period of July 12-15 (B), which had little or no activity, shows the presence of very cold air in the higher levels and considerable moisture at all levels in the first period; there was a decided warming at all levels and much drier air above the 500-millibar level in the latter period. The two sets of readings show little change in the stability index.

In the mean sounding for the period of July 16-18 (C), the stability index was 0 as compared to a value of +8 in the mean sounding for the corresponding period July 18-19 (D), which had little or no activity. There was definitely drier air in the lower levels in the latter period. Similarly the mean sounding for the period of July 20-25 (E), associated with widespread lightning activity and precipitation, shows a stability index of -1, while the mean sounding for the corresponding period of July 26-31 (F) with no activity, shows decided drying and increased stability (index of +6).

The mean sounding for the period of August 7-9 (G), which was associated with scattered storm activity, shows a stability index of 0 with the moisture concentrated in the upper levels. The mean sounding for the periods of August 1-7 and 9-14 (H), with no activity, shows much drier air at all levels and increased stability (index of +4). The mean sounding for the period of August 24-26, associated with widespread lightning activity, shows the moisture concentrated above the 700-millibar level. This mean sounding suggests that additional lifting, probably orographical, will be necessary to set off the storm activity. Individual soundings will be discussed later in a case history of this period. The mean soundings for the three periods of August 17-23, August 26-31 (J), and September 1-5 (L), which had no thunderstorm activity, show extremely dry and quite stable air. The mean sounding for the period of September 5-7 (K), which had scattered high level storms, shows the moisture and instability concentrated above the 500-millibar level.

Careful analysis of upper air conditions is essential in the understanding and forecasting of thunderstorm and lightning activity. In this and similar mountainous areas, the moisture and instability at higher levels are extremely important. In any consideration of stability, not only the current soundings but the possible modifications by advection and vertical motions

ust be considered; these modifications include the advection of warmer or
older air and moist or dry air, lifting caused by surface frontal action or
he passage of upper fronts or troughs, and mixing processes. Another lifting
echanism quite important in this area is the orographical lifting when the
rflow is in the proper direction. Another factor in this upper air analysis
s the moist tongues that may be too narrow to be observed on any existing
adiosonde stations. A possible remedy for this difficulty is to watch the
urface moisture at key high elevation stations.

CASE HISTORIES OF STORMS

July 1-11.--Upper air soundings during this period showed considerable
oisture at all levels, and rather low stability. Instability was increased
y the presence of extremely cold air at the 500- and 400-millibar levels.
igure 7 shows the 500-millibar contours and isotherms for 2000 MST on July
, 2, 3, and 4, the location of the 300-millibar jet stream axis, and the
00-millibar low center. The low storm activity on July 2 is associated with
he breakup of the cold low aloft and the warming of the air over the area on
hat day. Return of the cold air aloft, as indicated by the -20°C. isotherm,
oincides with the new storm activity on July 3. These storms were accompa-
ied by low ceilings and considerable precipitation. Since there was little
hange in either the map or the activity on July 5, the map for that day is
ot shown. Figure 8 shows similar charts for 2000 MST on July 6, 7, 8, and
. The decided reduction in storm activity on July 7-8 is reflected in the
reakup of the cold low aloft on those days. Renewed storm activity, with
he return of the cold low aloft, is indicated on the map for July 9. Storm
ctivity continued with little change in the upper level patterns on July 10
nd 11, but maps for these days are not shown.

July 21-23.--This period was characterized by a low pressure trough at
he surface through Nevada and eastern Oregon and Washington, with a high
ressure area gradually moving southward east of the divide. The pattern
loft at both the 500- and 300-millibar levels (fig. 9) shows a high pressure
rea over the southwest with southwesterly flow at most levels over the Sky-
ire area. The 300-millibar sequence shows a new jet stream axis appearing
n the evening of July 21; the wind at Spokane increased to 80 knots at
5,000 feet at 0200 MST on July 22. After this maximum was reached, the axis
f the jet stream remained over the area but the speed decreased to about 60
nots by the middle of that afternoon.

Figure 10 shows an interesting sequence of storms moving across the area
rom the southwest during the night of July 21-22. This was a very narrow
and of storms. On July 22, altocumulus castellatus appeared about 0800 MST.
uring the afternoon the convective cells were seen to build up to about
0,000 feet and then to dissipate above this level. Inspection of the sound-
ngs at Spokane (fig. 11) shows high relative humidity from 12,000-18,000
eet, but dry air above 23,000 feet at the 0800 MST observation time. By the
ime of the 2000 MST sounding, the air column showed drying down to 18,000
eet. This lack of buildup during the afternoon may well have been due to this

extremely dry layer aloft. The vertical shear of the wind alone seems not to be sufficient between the 18,000- and 25,000-foot levels to be responsible for the breakdown of the convection. The thunderstorms that reappeared later during the night of July 22 probably were associated with the adiabatic layer just above the 500-millibar level.

August 2.--Local thunderstorms occurred in the Colville National Forest about 50 miles to the north of Spokane. Figure 12 shows the 500- and 300-millibar charts for 2000 MST on August 1, 2, and 3. The cold air at the 500- and 300-millibar levels can be seen on the chart for August 2. Figure 13 shows the time cross section of the wind, temperature, and dew point profiles for Spokane. The change in the wind profile shows existence of a strong jet stream axis with the isotach center passing across the area. In this situation the storms occurred as the isotach center passed over the area. The actual soundings do not reveal sufficient moisture for thunderstorm activity, but it must be remembered that the storms were quite localized, and the moist tongue may have been quite narrow and not in evidence on the Spokane sounding

August 24-25.--Figure 14 shows another interesting progression of storms from the south and west across the area during the evening of August 24 and the morning of August 25. The 500- and 300-millibar charts are shown in figure 15. The general circulation is from the southwest. The time sequence of the temperature and dew point profiles at both Spokane and Boise are shown in figure 16. The interesting feature is the moisture and instability at high levels. This is evident on the Boise sounding for 0800 MST on the 24th, with a nearly dry adiabatic lapse rate from 500 to 400 millibars and near saturation above the 540-millibar level. This condition progressed to the north and northeast and is evident at Spokane on the 0800 MST sounding of August 25. The lapse rate is dry adiabatic between 525- and 495-millibar levels and nearly dry adiabatic up to the 400-millibar level. The air is nearly saturated from the 600- to 400-millibar layer.

JET STREAM

Possible relationships between the high level jet stream and the occurrence of thunderstorms have been considered for some time. Presence of zones of high winds and strong wind shears and associated vertical currents may influence the stability of the atmosphere considerably.

The position of the main jet stream axis at the 300-millibar level was recorded daily along with the occurrence or nonoccurrence of lightning or thunderstorm activity (fig. 17). The larger area outlined in this figure represents the area used to define whether a jet stream was present. Any reports of thunderstorm or lightning activity at any of the Skyfire stations, the fire weather stations, regular Weather Bureau, or CAA reporting stations in the smaller outlined area were recorded.

A summary of results shows 27 days with no jet stream axis in the area; there was storm activity on only 8 of these days. Of the 41 days when jet stream axis was present, 30 days had storm activity.

Further analysis shows that on the 19 days when the major jet stream was ocated to the north and west, thunderstorms occurred on 12 days but not on he other 7 days. Of the 11 days when the jet stream was overhead, thunder-torms occurred on only 7 days. On all the 11 days when the jet stream had assed on across the area, thunderstorms occurred.

While there seems to be some correlation between thunderstorm occurrence nd presence of the large scale or hemispheric jet stream, as indicated on he 300-millibar chart, a more useful approach would be to consider zones of igh winds local in nature and of short duration. These local wind maxima an be detected on the upper level wind reports at the individual stations. 'ime cross sections of the local winds at Spokane for the months of July and ugust 1955 are shown in figures 18 and 19; similar time cross sections for he local winds at Great Falls for July and August are shown in figures 20 nd 21. The periods of storm activity (indicated by the + symbol at the top f the diagram) are associated with the zones of high winds and wind shear. n some days no major jet stream axis was indicated on the 300-millibar chart, ut the local wind diagram indicated zones of high winds and wind shear.

There are some instances of strong local winds and wind shear zones with o storm activity. Vertical motions induced around these local high winds nd shear zones cannot produce storm activity if insufficient moisture is resent or if the atmosphere is too stable. More research is needed to btain data about the fine structure of the wind speed around these zones of igh wind and possible induced vertical motions near these zones.

COLD LOW ALOFT

One of the most important factors in thunderstorm occurrence in this rea is the influence of the cold low aloft off the Northwest coast. The dvection of cold air at high elevations often produces the instability nec-ssary for the formation of thunderstorms to the east of this cold low. Dis-lacement of this cold low to the south and east or the eastward movements of inor waves or troughs must be watched very carefully for the development of hunderstorms. When there is a major displacement of this cold low eastward cross the area with a sufficient moisture supply in the middle and upper ayers, the thunderstorms usually move rapidly with high level bases, and ittle or no precipitation reaches the ground.

SUMMARY

This paper reports and discusses in detail the occurrence and movement f thunderstorms during the 1955 fire season in the northern Rocky Mountain rea and the meteorological conditions associated with these storms. The mportant meteorological factors are the moisture patterns in both the lower nd upper levels, the temperature and wind profiles, the instability of the irmass, and the lifting mechanisms.

Thunderstorms during this season are discussed with reference to geographical distribution, time of occurrence, number of lightning strikes, amount of associated precipitation, and storm movement.

Various types of thunderstorms and the associated meteorological conditions are pointed out in this paper. Some storms are of a local airmass type in which surface heating and orographic lift are the important factors. This type of storm prevailed in the eastern portions of the region. Other storms were associated with the passage of surface or higher level cold fronts.

The main association of the jet stream with thunderstorm activity is somewhat indirect. The strong vertical wind shear associated with the major jet axis and its displacement is definitely connected with vertical motions in the atmosphere. The best condition for storm development probably is found with the superposition of divergence aloft over a low level convergence pattern.

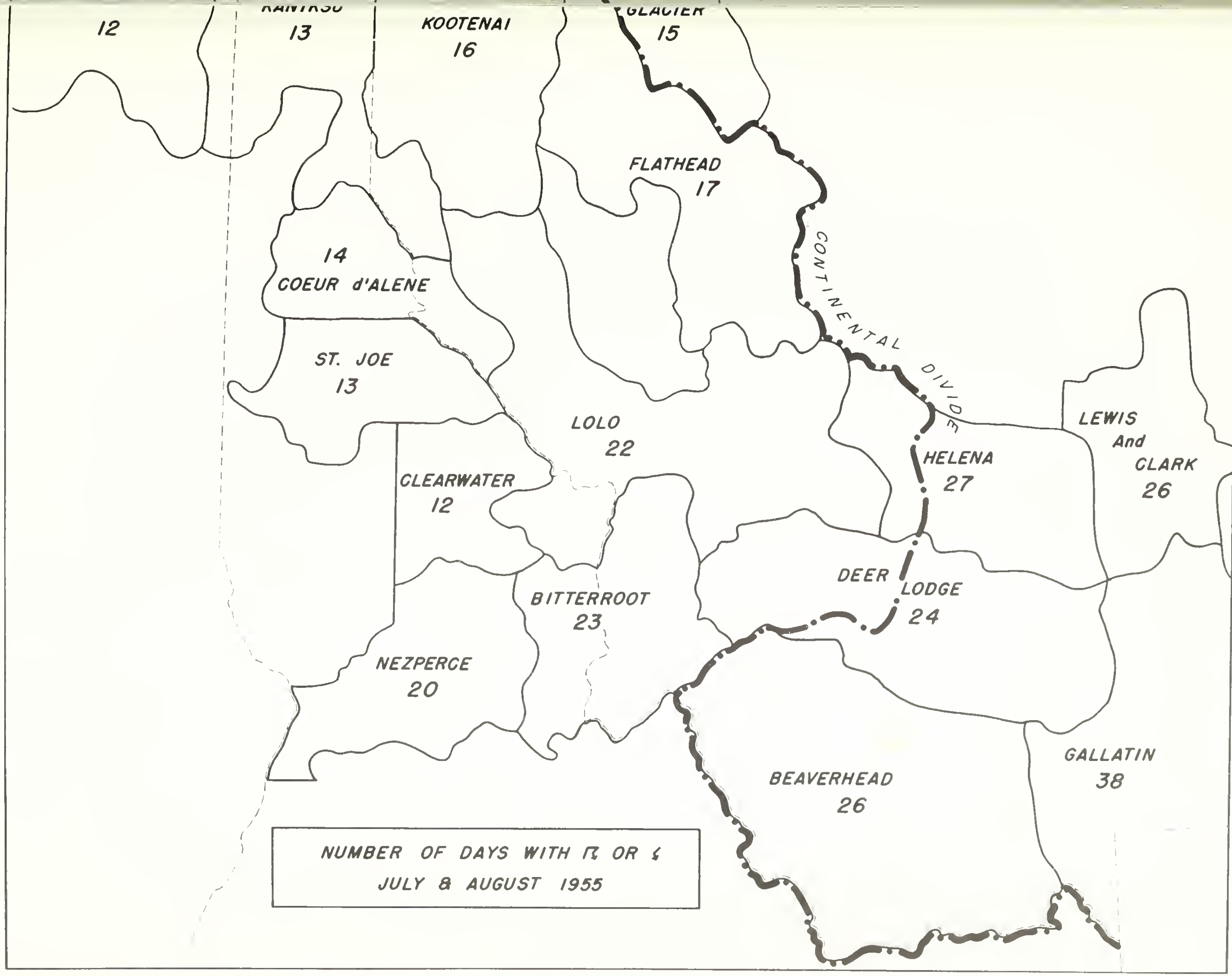


Figure 2.--Distribution of lightning storms over observation area.

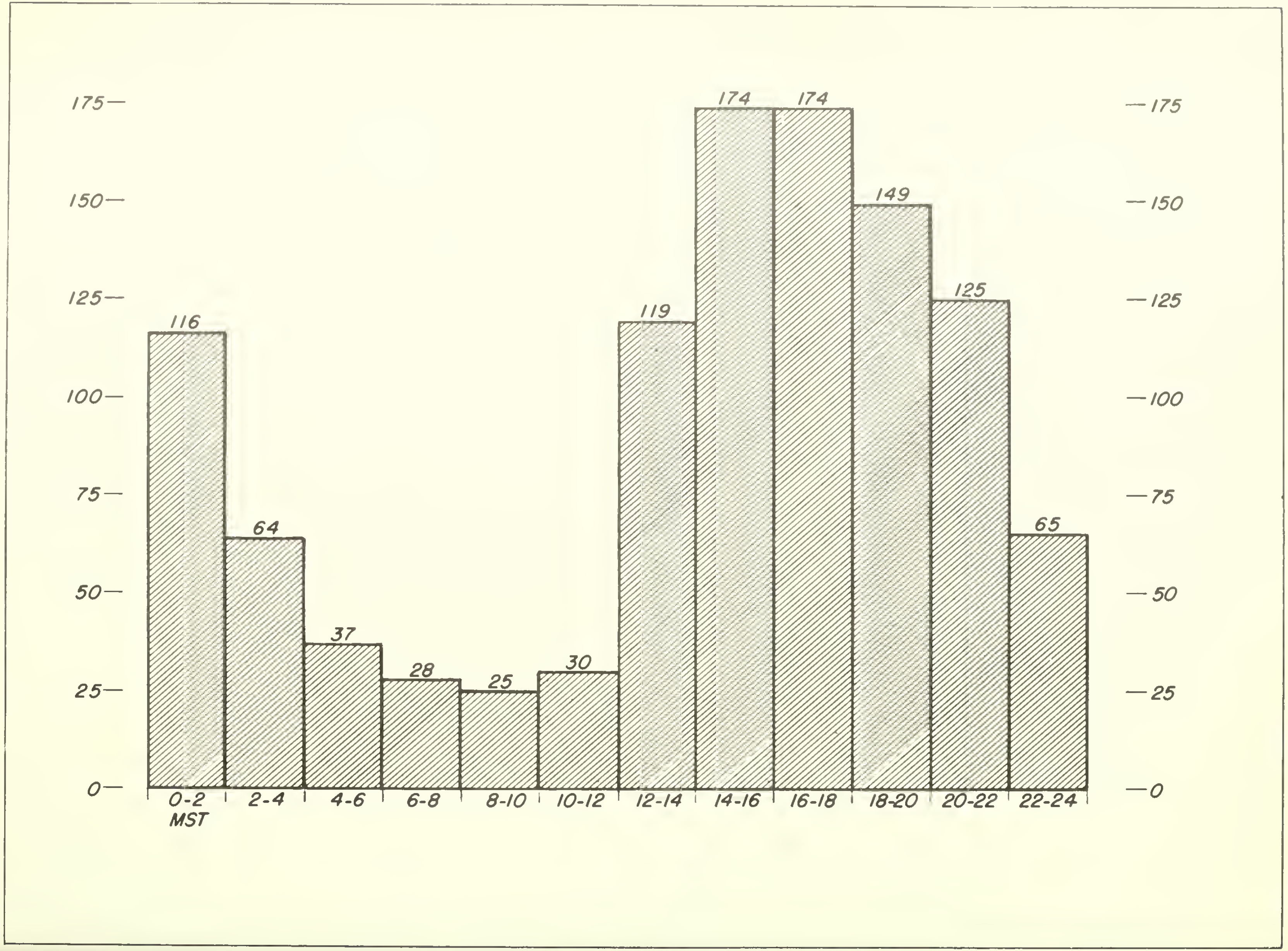


Figure 3.--Time-frequency of initial lightning over Project Skyfire area, July and August 1955

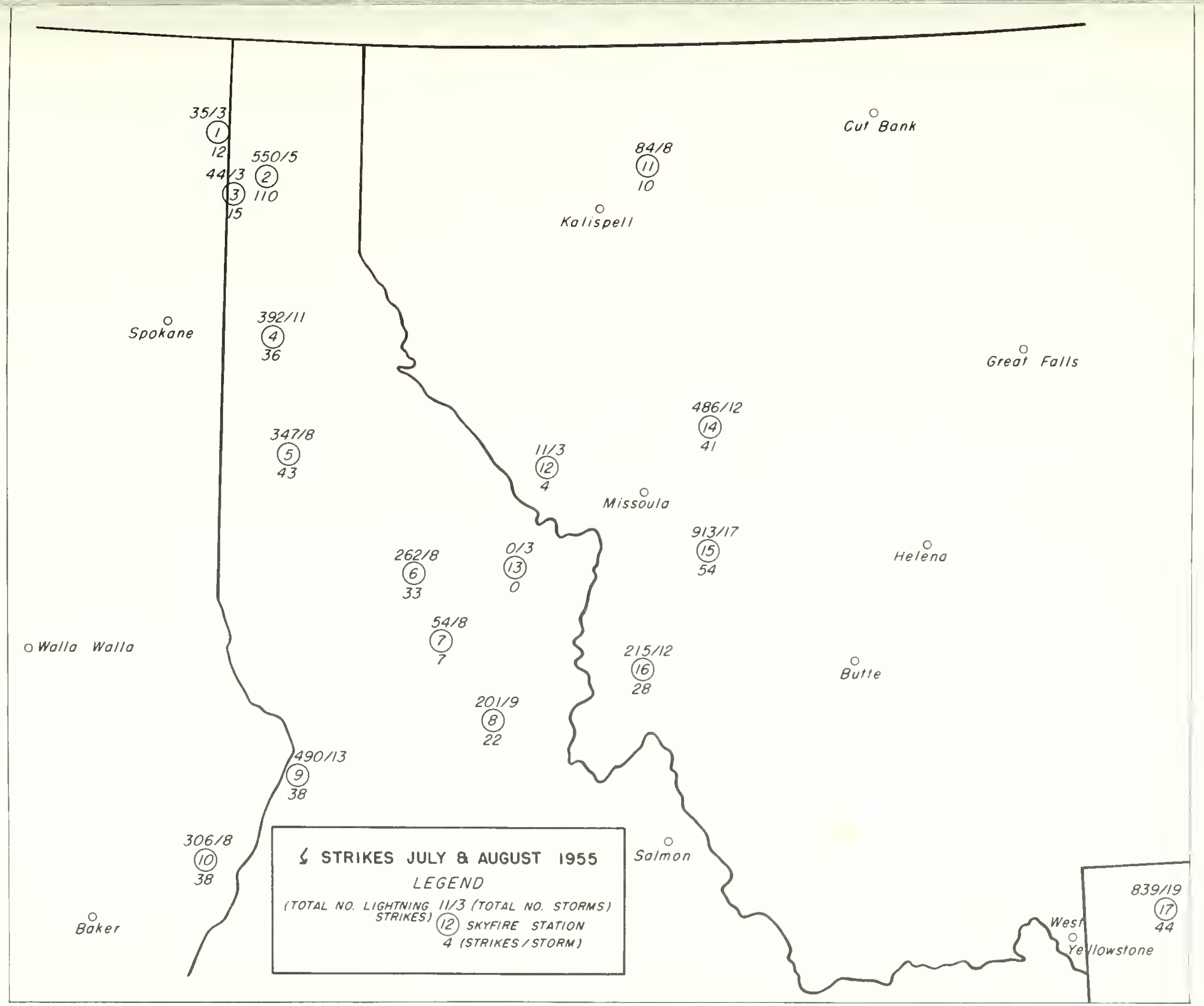
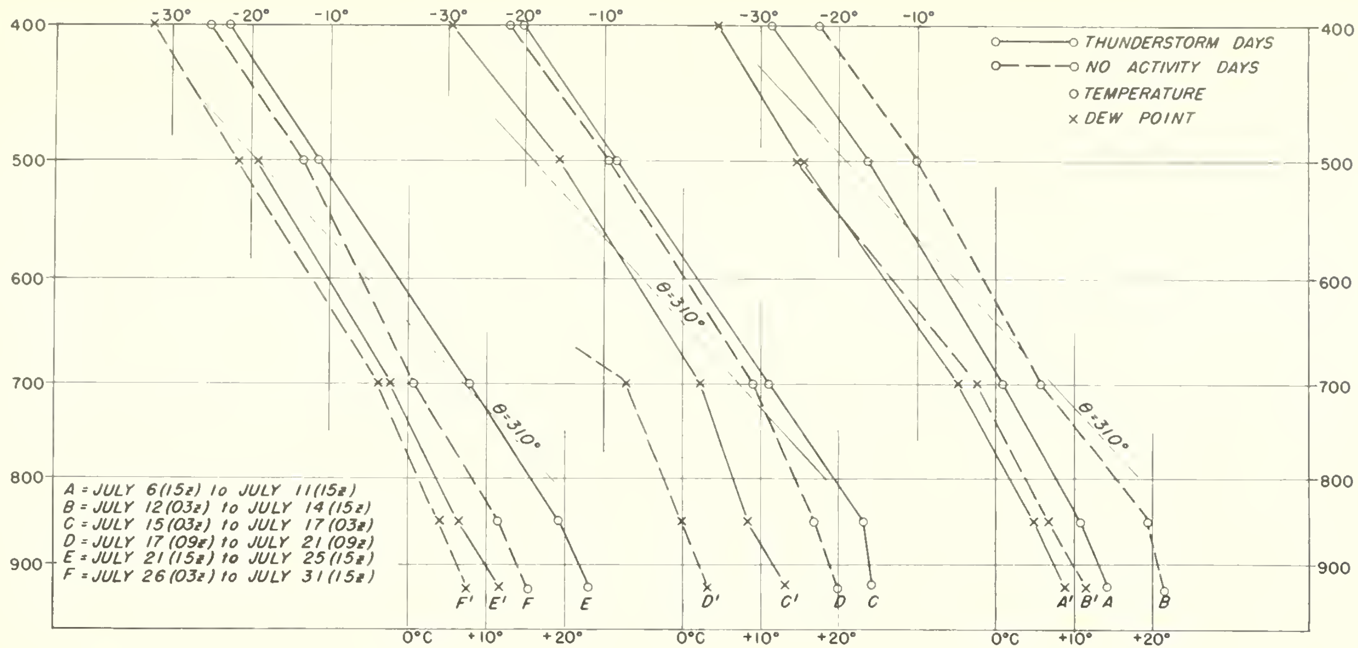
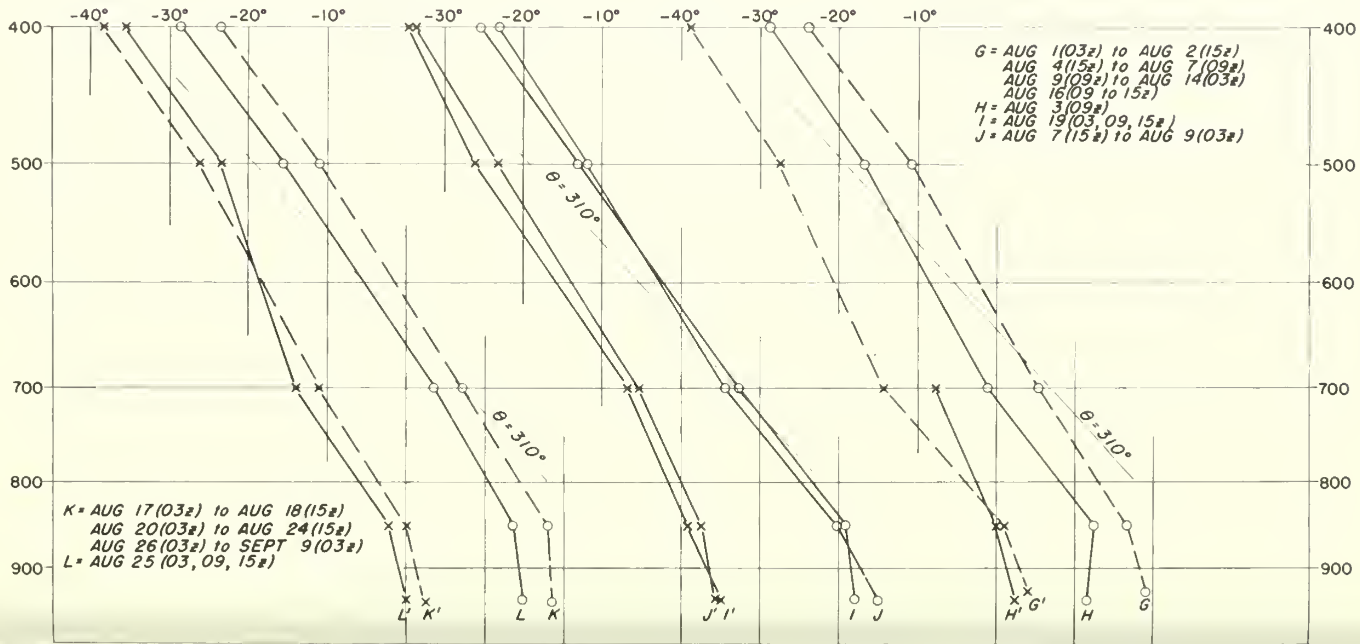


Figure 4.--Distribution of lightning strikes, July and August 1955.


THUNDERSTORM DAYS
NO ACTIVITY DAYS
TEMPERATURE
× DEW POINT
θ = 310°
A = JULY 6(15z) to JULY 11(15z)
B = JULY 12(03z) to JULY 14(15z)
C = JULY 15(03z) to JULY 17(03z)
D = JULY 17(09z) to JULY 21(09z)
E = JULY 21(15z) to JULY 25(15z)
F = JULY 26(03z) to JULY 31(15z)
0°C
+10°
+20°
400
500
600
700
800
900


G = AUG 1(03z) to AUG 2(15z)
AUG 4(15z) to AUG 7(09z)
AUG 9(09z) to AUG 14(03z)
AUG 16(09 to 15z)
H = AUG 3(09z)
I = AUG 19(03, 09, 15z)
J = AUG 7(15z) to AUG 9(03z)
K = AUG 17(03z) to AUG 18(15z)
AUG 20(03z) to AUG 24(15z)
AUG 26(03z) to SEPT 9(03z)
L = AUG 25(03, 09, 15z)
θ = 310°
400
500
600
700
800
900

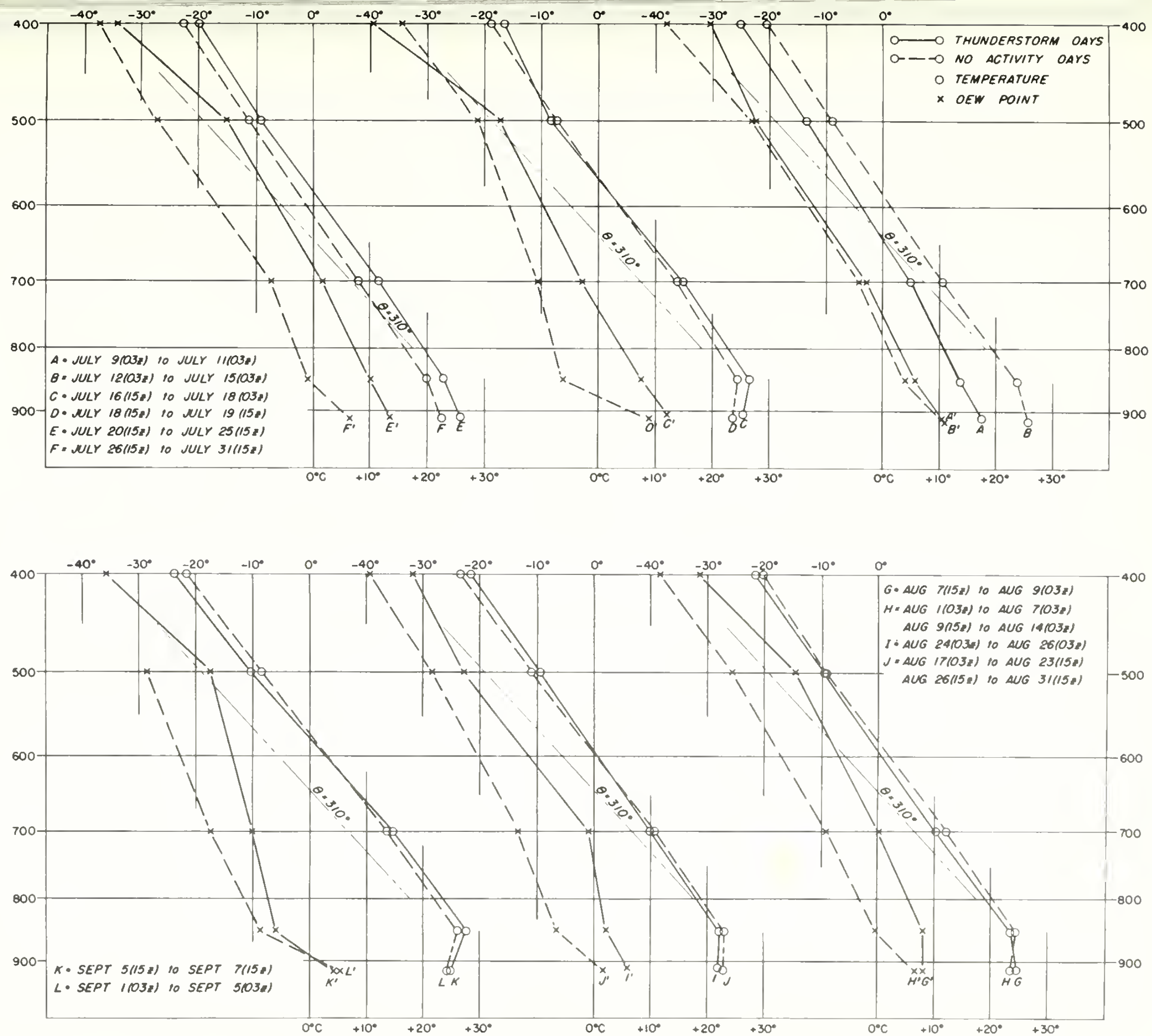


Figure 6.--Characteristic soundings at Boise for periods of thunderstorm activity and periods of no activity.

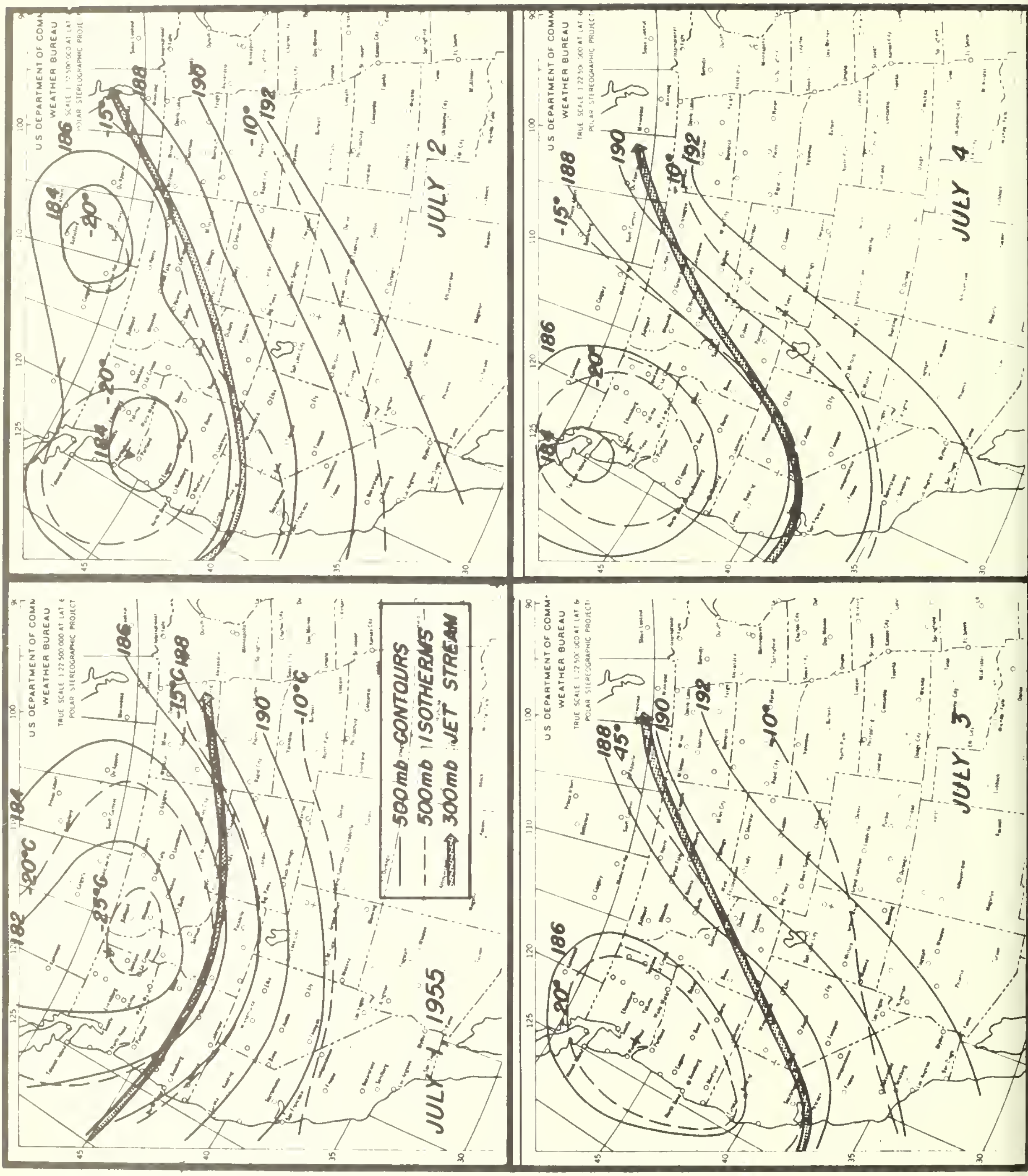


Figure 7.--500-MB charts for July 1-4, 1955.

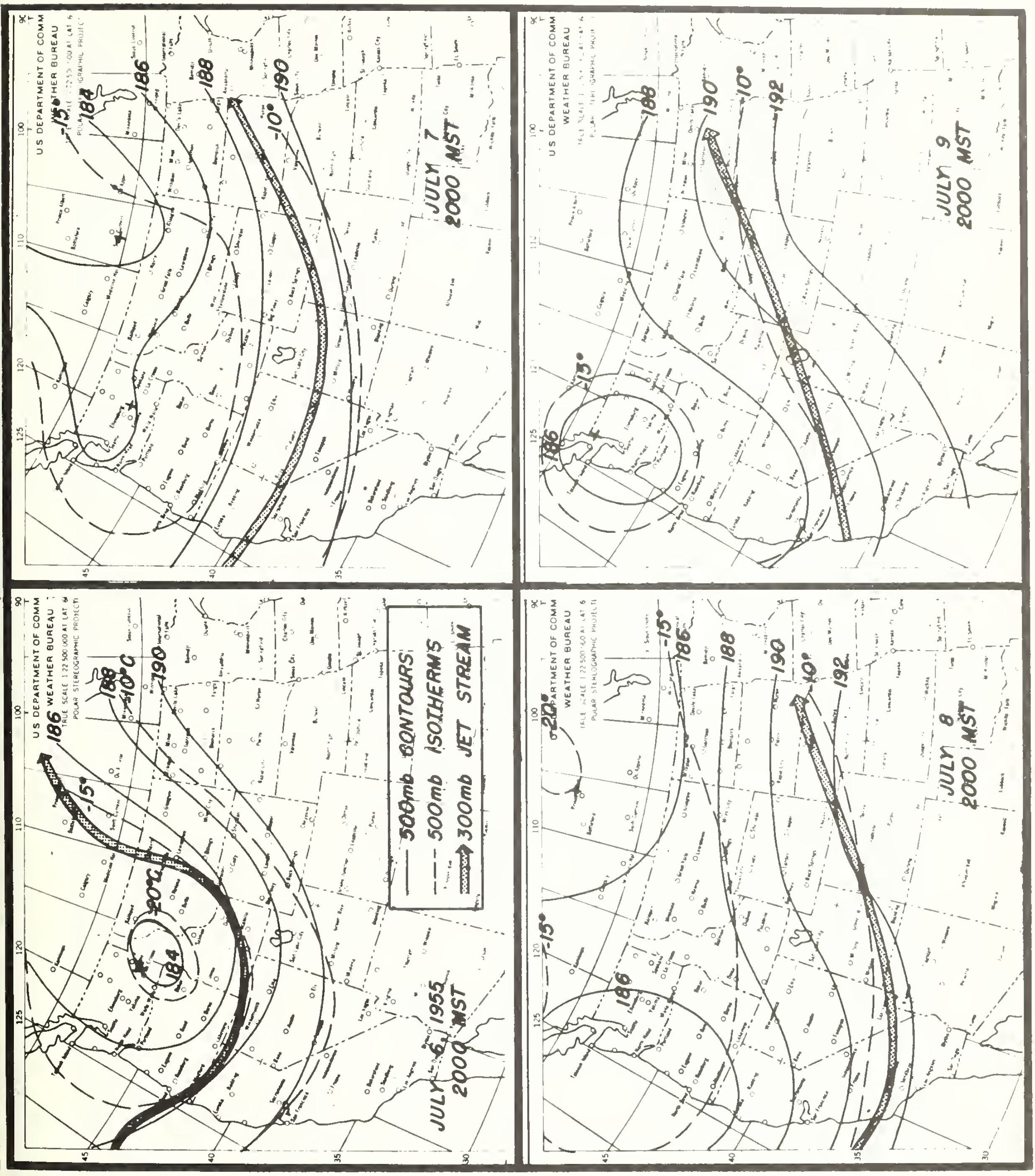


Figure 8.--500-MB charts for July 6-9, 1955.

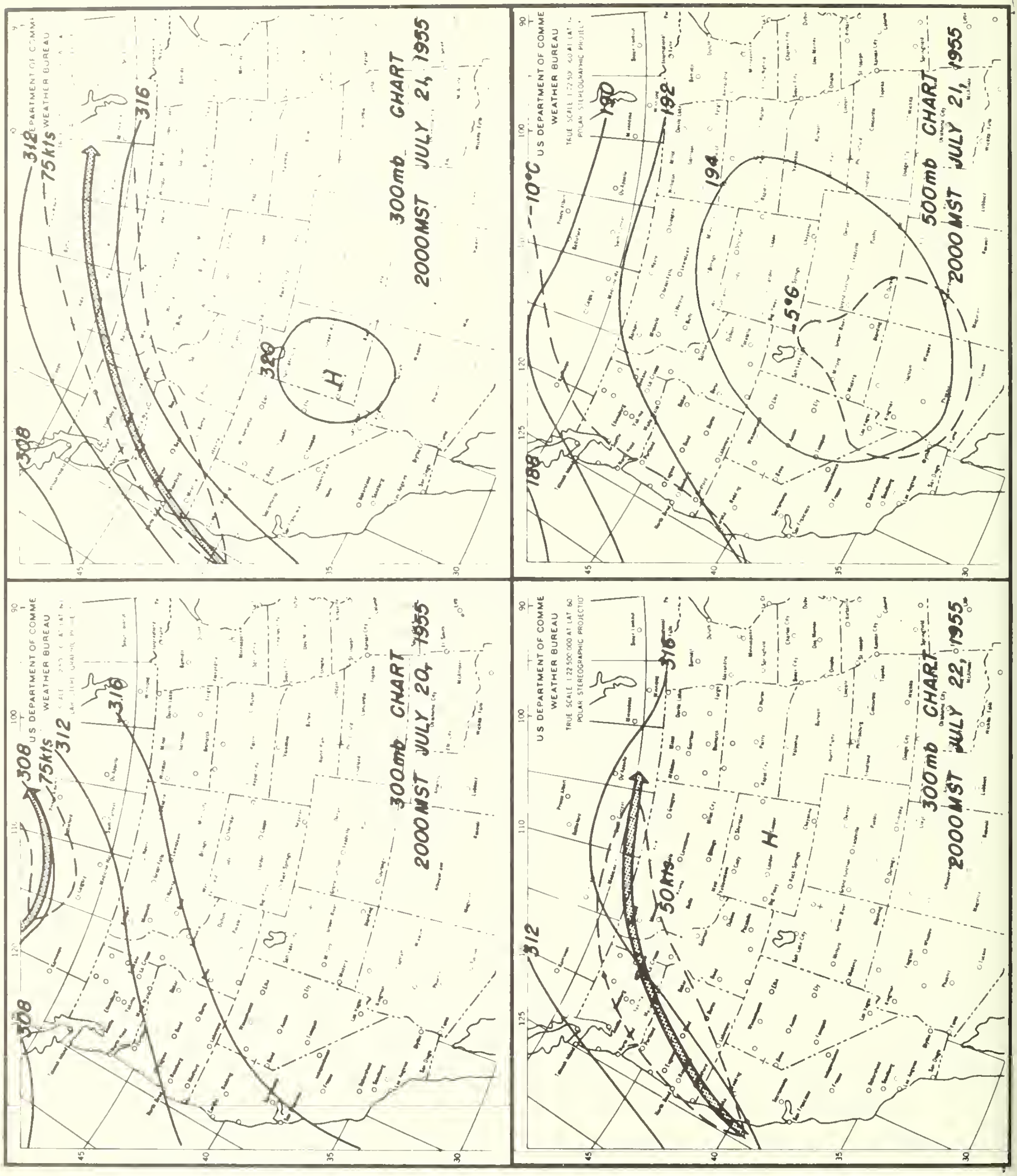


Figure 9.--500- and 300-MB charts for July 20-22, 1955.

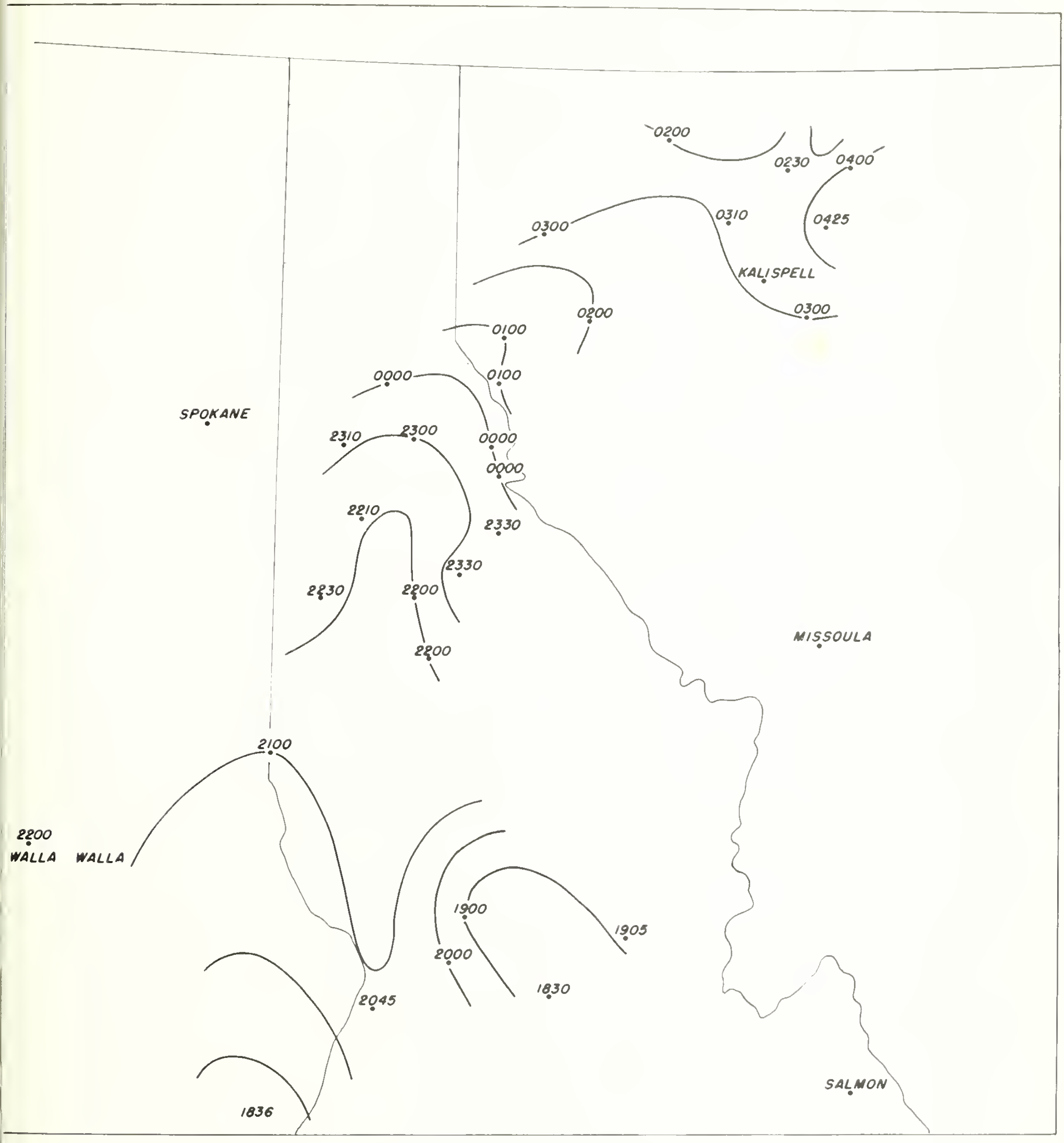


Figure 10.--Isochrones of initial lightning July 21-22, 1955.

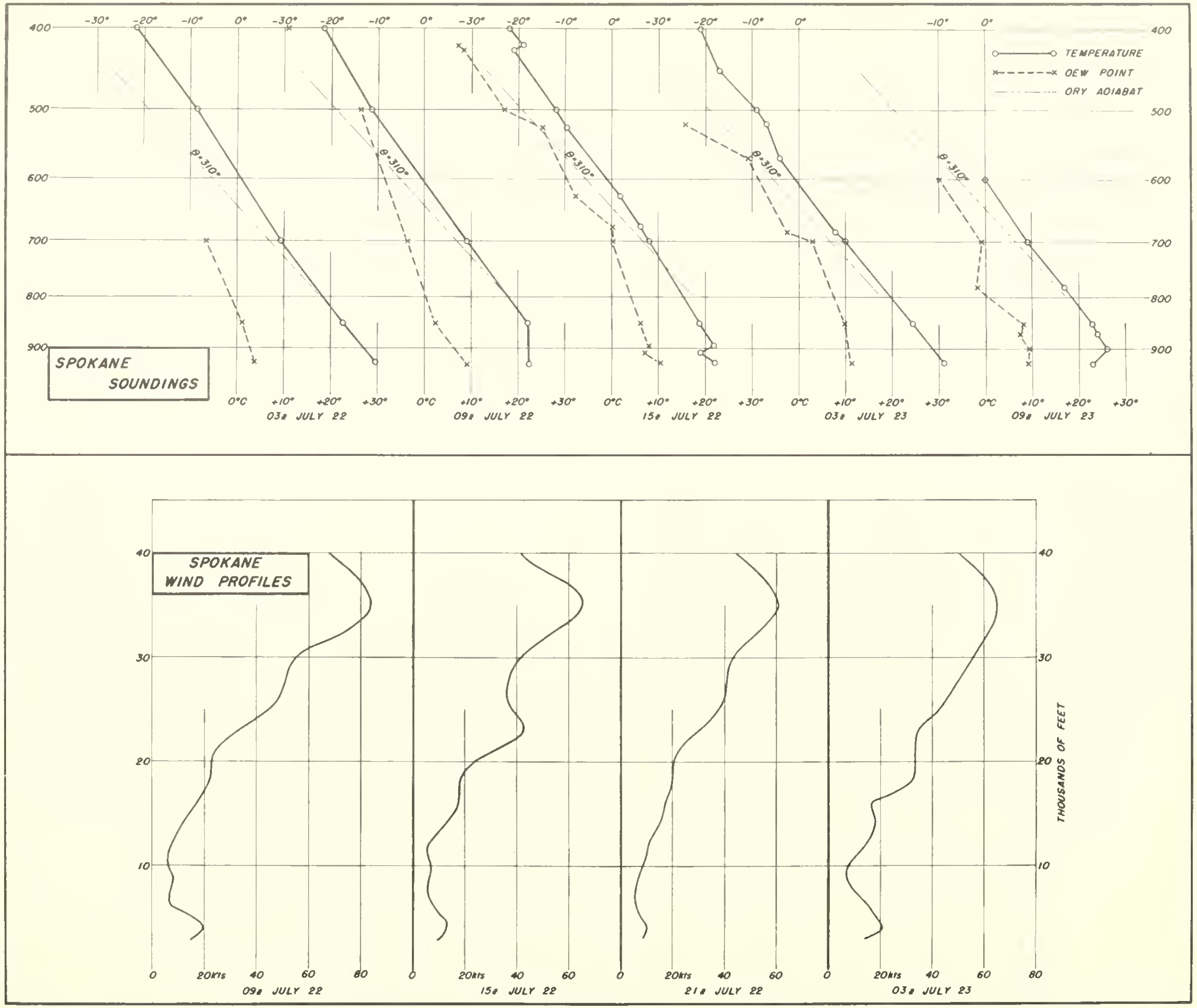


Figure 11.--Temperature, dew point, and wind profiles at Spokane, July 22-23, 1955.

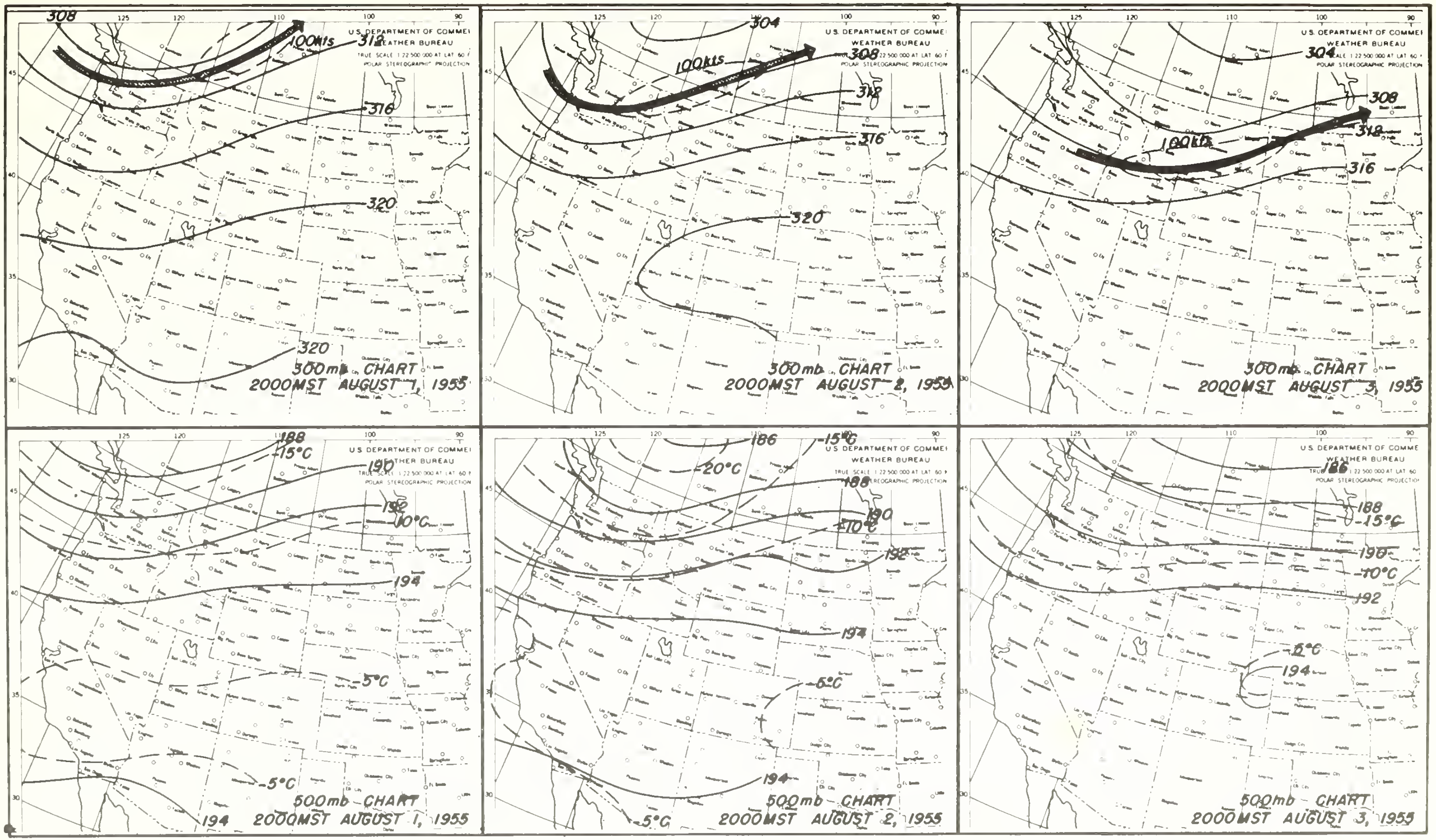
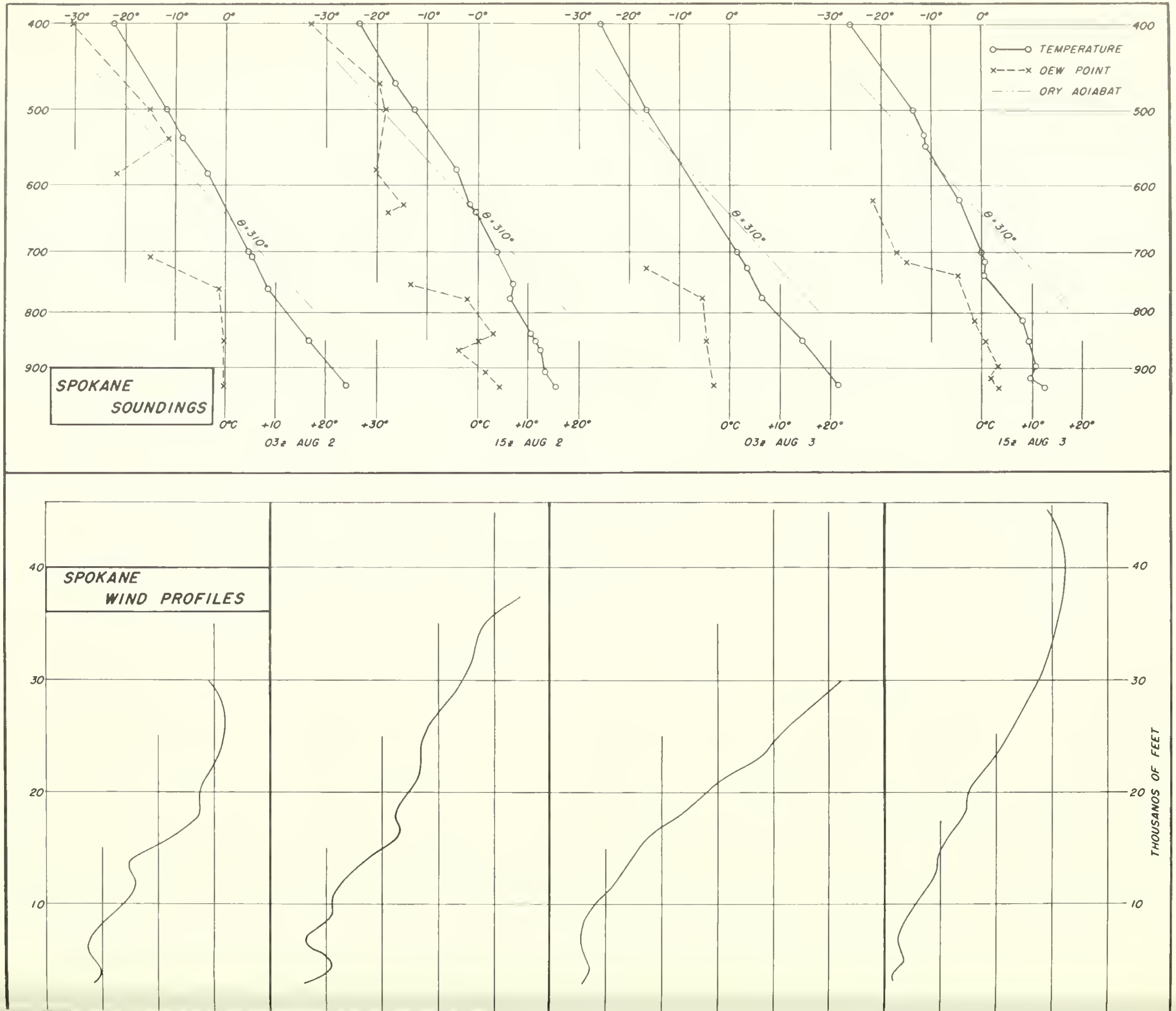


Figure 12.--500- and 300-MB charts for August 1-3, 1955.



SPOKANE SOUNDINGS
TEMPERATURE
OEW POINT
ORY AOIABAT
θ = 310°
03z AUG 2
15z AUG 2
03z AUG 3
15z AUG 3
SPOKANE WIND PROFILES
THOUSANOS OF FEET

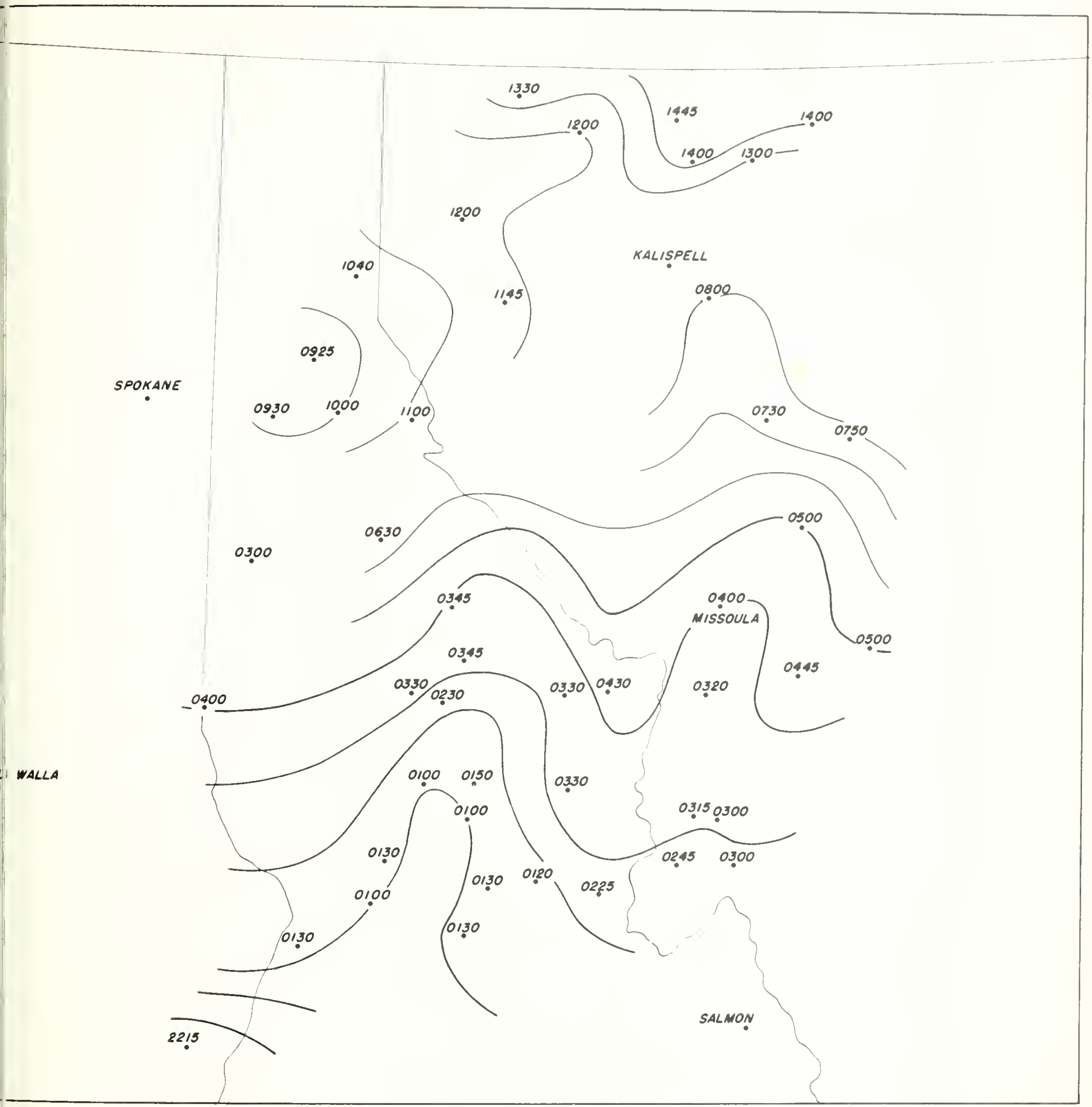


Figure 14.--Isochrones of initial lightning August 24-25, 1955.

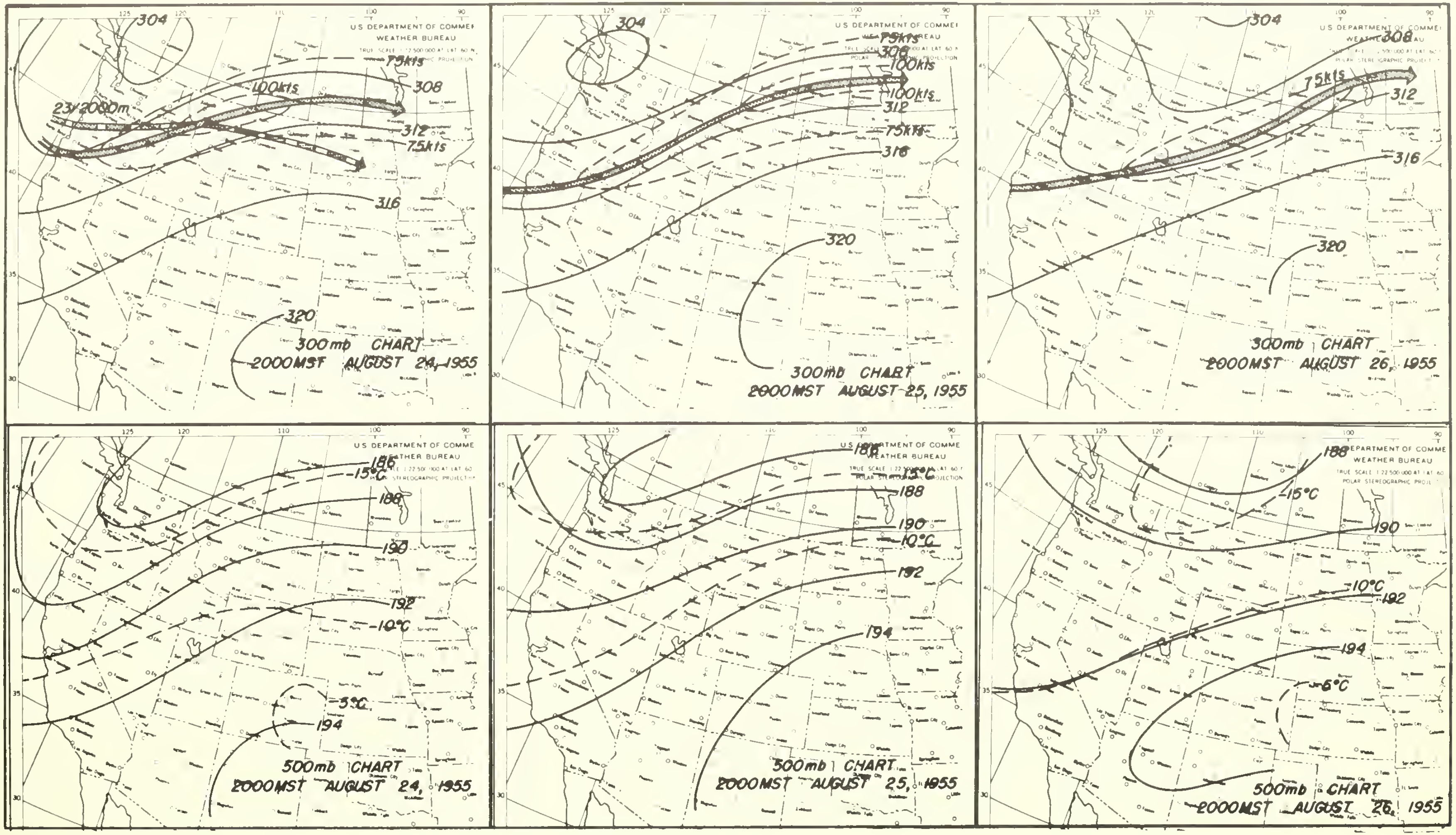


Figure 15.--500- and 300-MB charts for August 24-26, 1955.

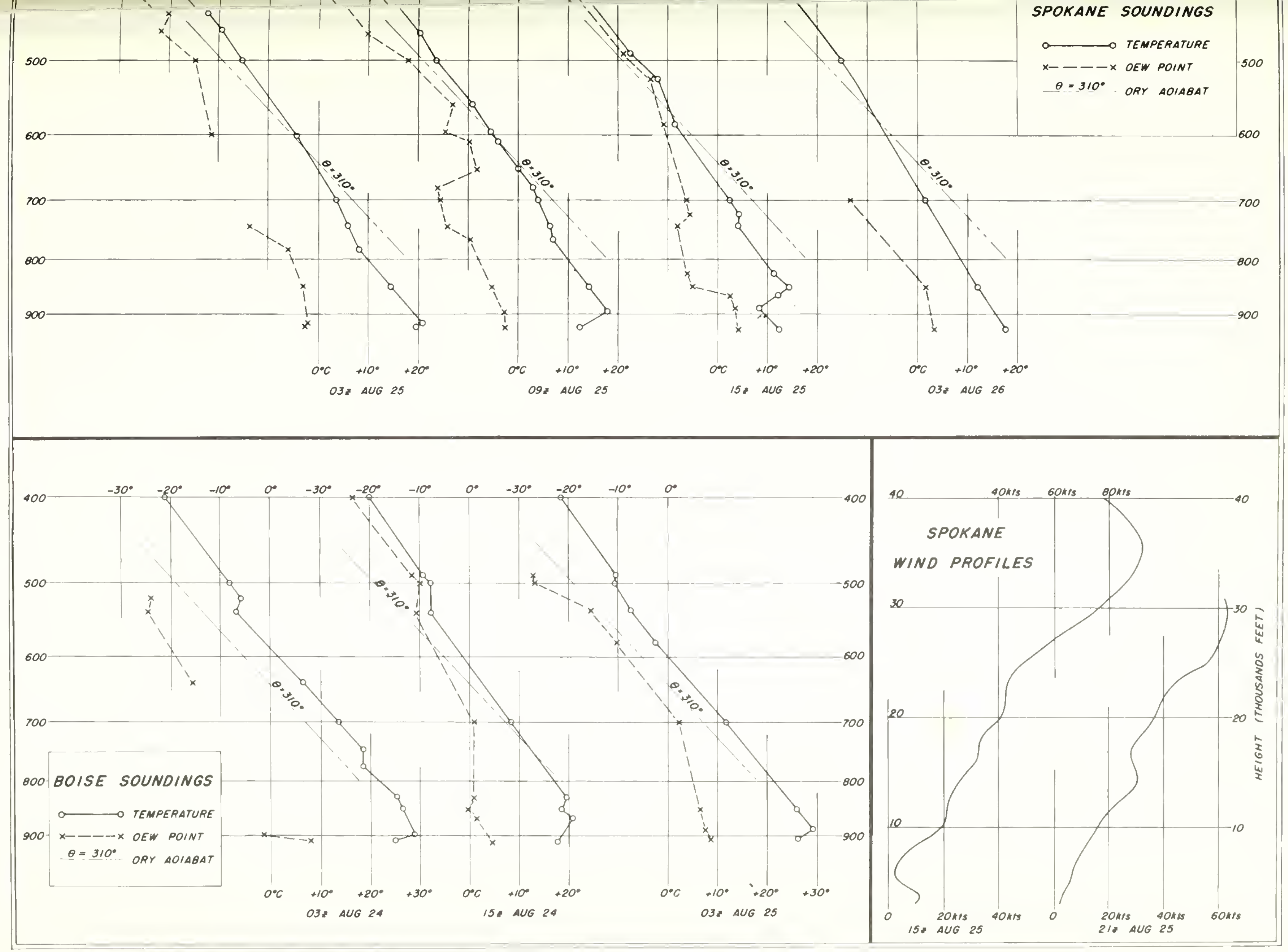
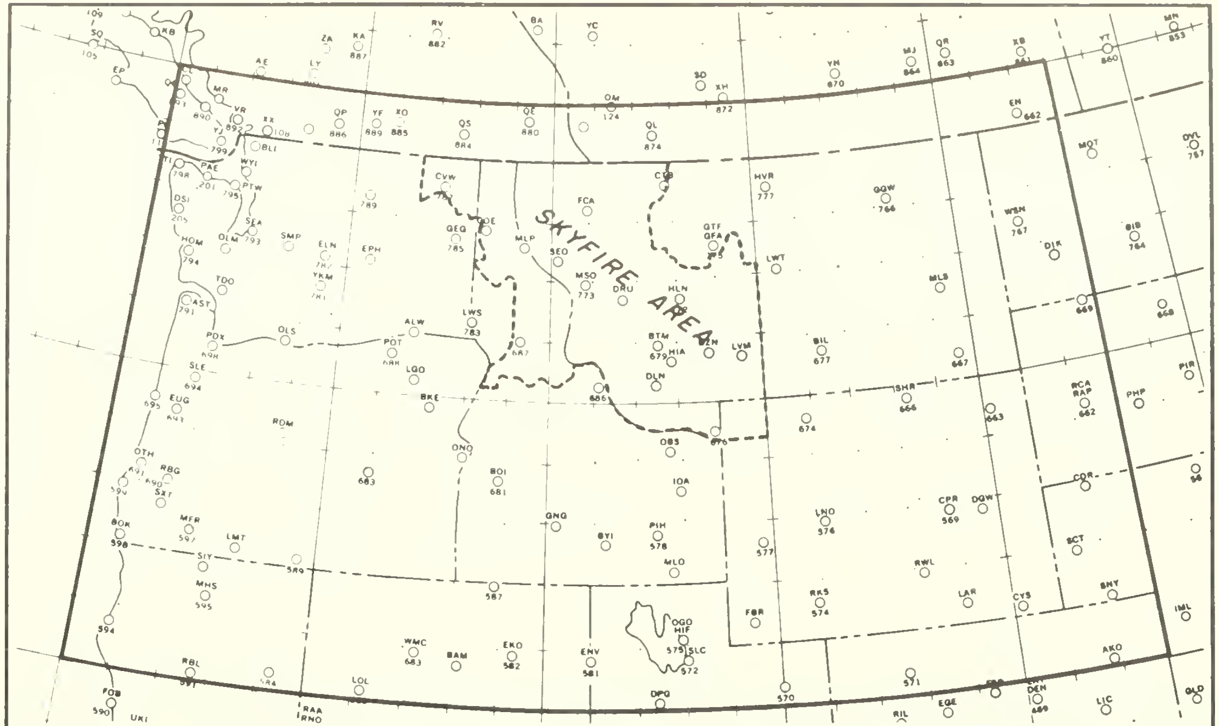


Figure 16.--Temperature, dew point, and wind profiles at Spokane and Boise for August 24-26, 1955.



	☈	NO ☈
NO JET IN AREA	8	19
JET IN AREA	30	11
JET TO N & W	12	7
JET TO S & E	11	0
JET OVERHEAD	7	4

Figure 17.--Jet stream-thunderstorm summary, July 4-September 9, 1955.

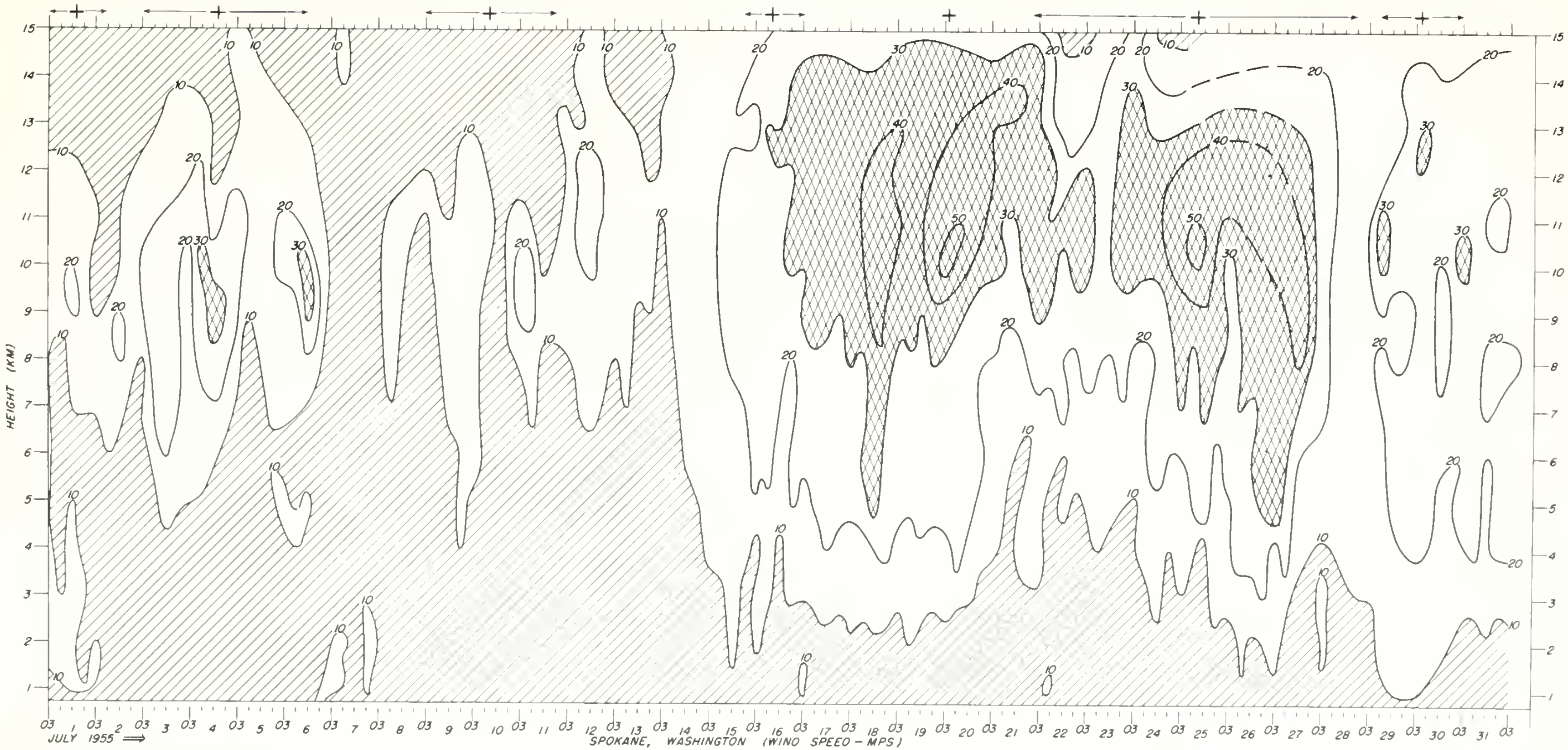


Figure 18.--Time cross section of upper-level winds at Spokane for July 1955. "+" at top indicates thunderstorm period.

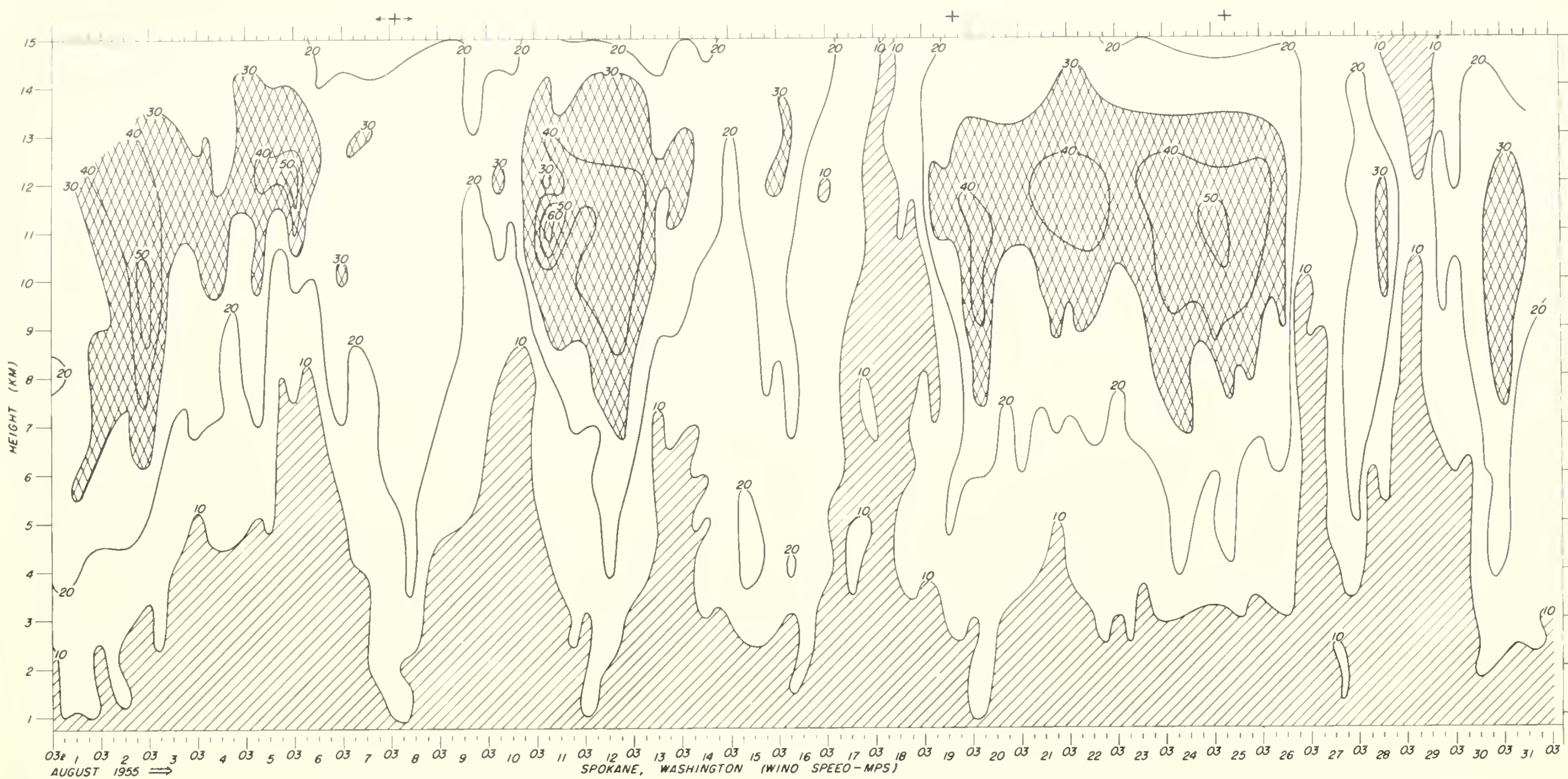


Figure 19.--Time cross section of upper-level winds at Spokane for August 1955.
"+" at top indicates thunderstorm period.

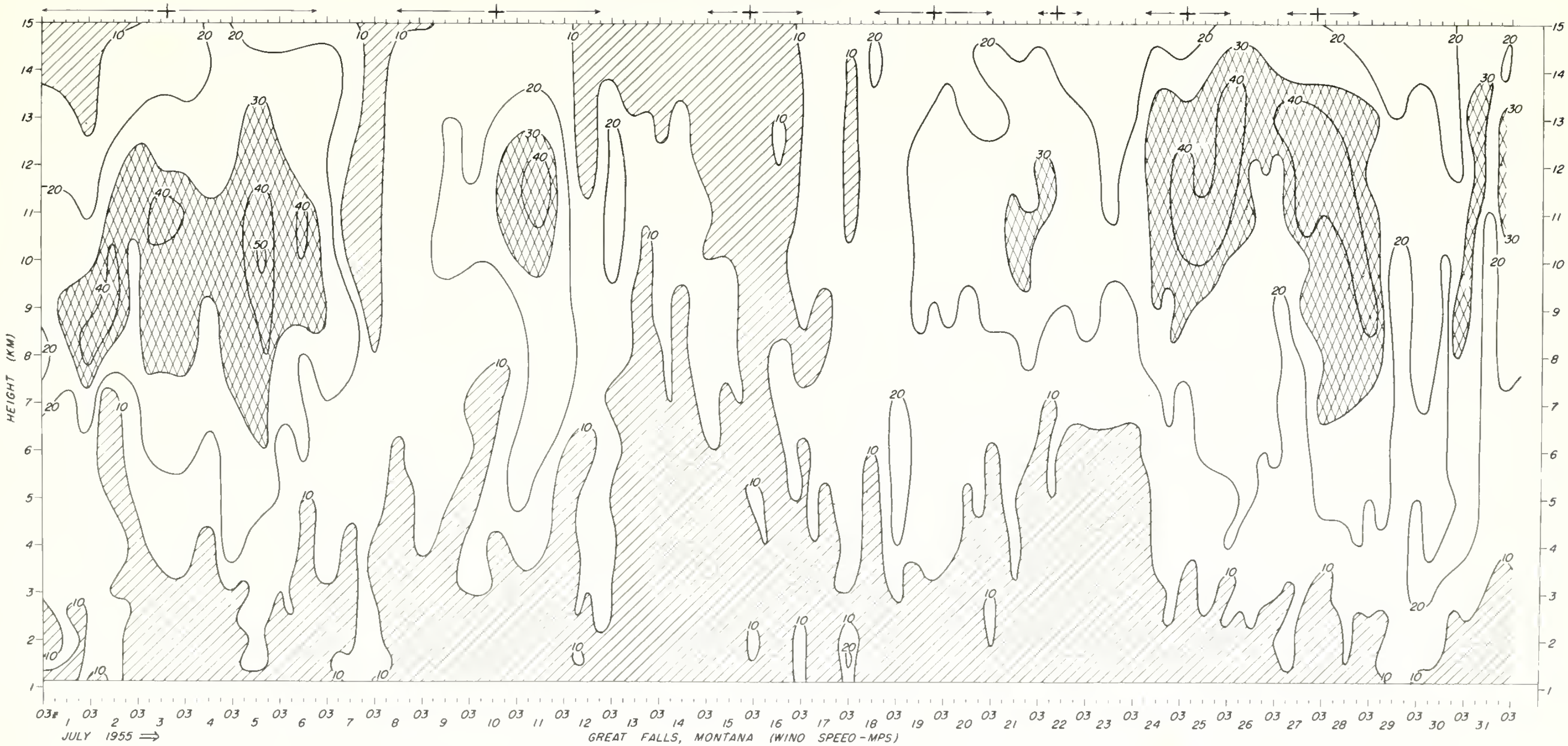


Figure 20.--Time cross section of upper-level winds at Great Falls for July 1955.
"+" at top indicates thunderstorm period.

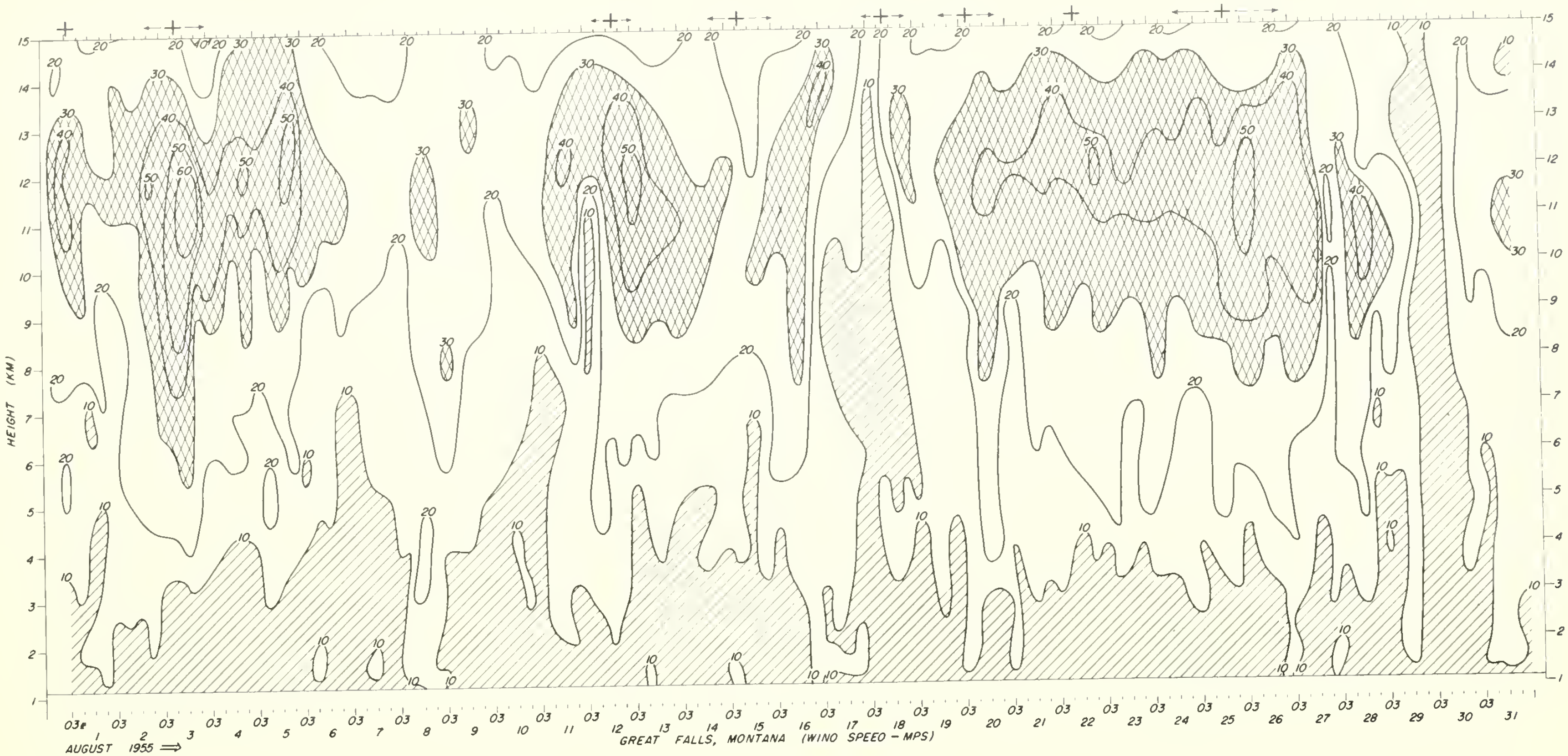


Figure 21.--Time cross section of upper-level winds at Great Falls for August 1955.
"+" at top indicates thunderstorm period.

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COSTS OF LOGGING VIRGIN PONDEROSA PINE IN CENTRAL IDAHO

Alvin K. Wilson and Gordon H. Greenway[1]

INTRODUCTION

The installation of an experiment[2] on the Boise Basin Experimental Forest[3] near Idaho City, Idaho, during 1953 and 1954 afforded an opportunity to study the costs of logging virgin ponderosa pine. Production rates and costs for several phases of logging, as influenced by initial stand per acre, intensity of cut, and sizes of skidding equipment under two timber marking methods were collected and analyzed. Provisions for the collection of data for such an analysis were written into the timber sale contract with the Boise Payette Lumber Company, which in turn delegated the task to their operator, the MacGregor Triangle Company.

While many aspects of the logging operation study will be of interest mainly to logging contractors, the analysis of data concerning skidding equipment should also be useful to forest land administrators, especially when considered in conjunction with prospective damage to reproduction and watersheds. These effects as related to skidding machinery size were incorporated in the over-all study and results will be published in later papers.

The study areas were in the virgin ponderosa pine type at elevations between 4,600 and 5,800 feet above sea level. The topography is dissected by many intermittent watercourses, and steep slopes to a maxima of 84 percent are often encountered. The soil is granitic, sandy, and very erosive.

Logging roads were located prior to the sale and were kept, with very few exceptions, to grades of 8 percent or less. They followed watercourses for the most part, with particular attention given to preserving a 10-foot strip of undisturbed vegetation between the drainage bottom and the toe of the road overspill.

1/ Foresters, Intermountain Forest and Range Experiment Station, Forest Service, and MacGregor Triangle Company, Boise, Idaho, respectively.

2/ Curtis, James D. 1955. A study of ponderosa pine production in central Idaho. Intermountain Forest and Range Expt. Sta. Misc. Pub. 4, 9 pp., illus.

3/ Maintained by the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah.

A total of 4,902 M board feet, gross saw scale,[4] was cut within study areas to produce a net log scale of 4,201 M b.f. The average cut for the whole operation amounted to 35.5 percent of the gross initial volume.

The conditions under which the logging operation on the experimental forest was carried out differ only in minor respects from those encounter- ed in current national forest sales in central Idaho. The experimental forest is more easily reached by road than most of the virgin ponderosa pine now being logged. Differences attributable to accessibility would influence only the equipment mobilization and trucking costs. The high degree of supervisory control over the operation was exceptional but nece- sary to insure successful installation of the timber management study. E- cept for these differences, the study area provided typical conditions fo a logging operation in central Idaho.

EXPERIMENTAL DESIGN

Sixteen compartments, totaling 847 acres and ranging in size from 32 to 79 acres, were used in the study. Each compartment was a minor drainage of the principal stream flowing through the experimental forest and could be considered as a small, independent logging unit. Within each compartment the boundaries between areas of light timber (less than 10 M b.f. per acre), medium timber (10 to 20 M b.f. per acre), and heavy timber (over 20 M b.f. per acre), had been marked and mapped. Eight compartments were logged in the fall and early winter of 1953 and the remain- ing eight, which contained the same treatment combinations as the first eight, were logged in the fall and early winter of 1954. The treatments applied, including the size of tractor to be used for skidding, were assigned without bias. For the eight compartments logged in either of the two years of operation, the combinations of treatments were as follows:

Skidding equipment	Timber marking method	Reserve stand volume level
1. Large tractor (D-8)	Stem selection	High
2. " " "	" "	Low
3. " " "	Group selection	High
4. " " "	" "	Low
5. Small tractor (D-4)	Stem selection	High
6. " " "	" "	Low
7. " " "	Group selection	High
8. " " "	" "	Low

4/ Log scale before skidding by Scribner Rule, including long butts, cutouts for breaks, snag volumes, and underrun due to hidden breaks and defect.

The selection of two tractor sizes (fig. 1) for inclusion in the experiment was prompted by consideration of timber stand damage and watershed damage as well as by the desire to compare their efficiency of operation in the timber and topography of this area. The large tractor is the size commonly used in ponderosa pine operations in Idaho. The small tractor was considered to be the least powerful tractor that could operate successfully under typical conditions. Tractor skidding without pans or arches is typical of most logging in this part of Idaho.

Stem selection as applied here is a timber marking system in which each merchantable tree is appraised as to its probability of dying before logging operations reach the area again. Trees with the highest mortality probability (high-risk trees) are marked for cutting. The implications of this system to the logger are:

1. Since the age or maturity of a tree is considered in the appraisal of its mortality probability, the oldest trees generally rate higher risk classifications. This in turn means that the largest trees are more certain to be cut than smaller, younger trees, and the average volume per cut tree tends to be high and the number of logs per M b.f. low. The effect would be to lower production costs since large logs are generally cheaper to handle.

2. Since stem selection is on an individual tree basis, the marked trees are usually well scattered over an area although they may occur occasionally as small groups. Skidding logs from trees distributed in this way requires numerous skid trails reaching into all parts of the area. Thus it can be expected that more skidding time per turn of logs is required than where logs are concentrated as they are in group clearcuttings. Felling and bucking production rates might also be lower with scattered trees, due to "deadhead" time finding trees and moving equipment, than where group clearcuttings are made.

Technically, group selection is a regeneration method, although it is referred to in this analysis as a marking system. Under this system groups of overmature and mature overstory trees up to an acre in size are removed by clearcutting to create openings for reseeding or planting or to free established pole or seedling-sapling stands. Wherever reserve levels permitted, single scattered high-risk trees also were removed from area between the group cuttings. "Unit Area Control,"[5] as currently practiced in California and Oregon, includes many of the management concepts of the group selection system applied to half of the compartments of this study. The implications of the method to the logger are:

5/ Hallin, William E. 1954. Unit area control--its development and application. California Forest and Range Expt. Sta. Misc. Paper 16, 10 pp.

A.

Figure 1.--The large (A) and small (B) tractors operating on the Experimental Forest, showing the size of timber, the topography, and the decking arms with which each tractor was equipped.

B.

1. Felling, bucking, and skidding activity are confined to relatively small areas within each compartment, leading one to expect that, compared with stem selection, "deadhead" time for fallers would be reduced and their production rates raised accordingly. Skidding production might tend to be greater with high concentrations of logs.

2. For effective application, group selection requires that all sawtimber trees be cut on the designated areas. Thus, even though stands of overmature trees are given highest priority for cutting, it is typical that an appreciable number of small, immature trees must be cut along with them, resulting in more logs per M b.f. than where the removal of large mature and overmature trees is emphasized as in stem selection. The influence of the concentration of logs by group cutting on production rates would be counteracted to some extent by the larger number of logs per M b.f.

Within the general "high" and "low" levels for reserve stand volumes, predetermined volumes per acre to be retained were set up for each of the light, medium, and heavy timber class areas. All sawtree volume over these reserve volumes was removed. A "high" reserve level generally meant a low percentage cut, and a "low" reserve level meant a higher percentage cut.

Table 1 illustrates the average stand volumes which were present before cutting and the cutting intensities applied to arrive at the desired reserve volumes. It also gives some idea of the range in sizes of cut trees.

Note that cut trees averaged definitely larger for stem selection marking than for group selection marking, and that low reserve volumes resulted in cutting intensities ranging from 32 to 50 percent, averaging over 40 percent, while high reserve volumes required cuts of 22 to 32 percent, averaging less than 30 percent.

Man hours, machine hours, and volumes of logs produced were recorded for each timber volume class area of each compartment for the felling and bucking, scaling, and skidding phases. Loading and trucking man-hours and hours of equipment use were not broken down by compartments or volume classes, but were presented as totals for each season's operation.

Fallers worked individually, using 1-man chain saws and axes to fell, limb, and buck. Limbing was done on the three most accessible of the four "faces" of the felled tree; the remaining limbs and broken stubs were trimmed off at the landing. Wherever possible, uphill and downhill felling was practiced to minimize the damage to the residual stand caused by rolling trees and logs. This practice also placed the logs in a more efficient and safe position for "direct-line" skidding. Where group clearcuttings were made, trees were felled into the clearcutting area to confine the area of stand damage. All snags at least 12 inches d.b.h. and 10 feet in height were cut in the felling operation; these were paid for on the basis of the volume of the 16-foot butt log. Wherever possible

Table 1.--Summary of initial stand volumes,[1] cut volumes, and average cut tree volumes by marking methods, reserve levels, and timber volume classes

	Group selection marking						Stem selection marking						All com-part-ments
	High reserve volume			Low reserve volume			High reserve volume			Low reserve volume			
	Light timber	Medium timber	Heavy timber	Light timber	Medium timber	Heavy timber	Light timber	Medium timber	Heavy timber	Light timber	Medium timber	Heavy timber	
Initial stand (M b.f./acre	4.541	16.138	23.062	5.840	14.315	23.527	8.727	16.493	25.757	7.366	16.252	23.120	16.744
Cut volume M b.f./acre	2/	5.139	5.027	1.872	6.454	9.114	2.687	5.310	7.023	3.320	8.177	8.527	5.941
Percent cut	2/	31.8	21.8	32.0	45.1	38.7	30.8	32.2	27.3	45.1	50.3	36.9	
Percent cut (all timber classes)		26.0			40.3			29.6			43.8		35.5
Average cut tree (M b.f.)	2/	0.984	1.090	1.089	1.337	0.915	1.395	1.377	1.391	1.449	1.210	1.191	
Average cut tree (M b.f., all timber classes)		1.025			1.079			1.384			1.226		1.180

1/ Local volume table volumes, Scribner Rule.

2/ Negligible amount of cutting (2 trees) in this class because initial stocking is not yet up to the 6,000 M b.f. per acre reserve volume specified. Data for all such areas are excluded from averages.

32-foot logs were cut. However, due to the overmaturity of most of the timber, considerable breakage occurred and logs to an 8-foot minimum length were taken from the woods.

Tractor operators were instructed to avoid, within reason, any damage to standing trees of all sizes; "siwashing" of logs around trees was to be avoided and reasonable precautions were to be taken where there was danger of barking reserve sawtrees. To minimize soil erosion, skid trails followed ridges as much as possible and the same skid trail was used as often as possible. This served to concentrate the unavoidable damage to reproduction and to localize and reduce soil rehabilitation work. Skidding down draw bottoms was to be avoided at all costs; draws were to be crossed at right angles only. Where contour skidding was necessary, bladed skid trails were prepared. No dozer blades were permitted on the tractors during skidding; blades were replaced by specially designed decking arms (see figure 1).

Logs were skidded in practically all cases to landings located within the light, medium, or heavy timber class area being worked. In only a few cases was it necessary to skid logs from one timber class area to a landing located in a different timber class area. Production rates could therefore be kept separately for each timber class of each compartment.

Before beginning work on the sale, fallers and tractor operators were given pocket-size booklets which briefly described the experiment, set forth felling and skidding practices to be observed, and enlisted their cooperation in completing the installation according to plan. Compartment maps which showed the locations of marked trees and timber class boundaries were also furnished.

Close supervision of all phases of the operation was possible with the combined efforts of foresters representing research, National Forest Administration, the contracting lumber company, and the logging company; one or more of these foresters was on the sale area at all times. Supervision alone cannot be given full credit for the successful installation of the experiment; much of it is due to the keen interest taken by the fallers, equipment operators, and others on the job.

Neither topography, weather, road layout, nor sale terms imposed unusual or atypical conditions for an operation in this part of Idaho, so that production rates as related to timber class, intensity of cut, marking methods, and average cut tree sizes were expected to furnish reasonable estimates of actual rates obtainable elsewhere in central Idaho.

RESULTS

Readers with a bent toward statistics will appreciate that the Ponderosa Pine Production Study was designed particularly for the use of "analysis of variance" techniques,[6] which were applied to several aspects of the felling and bucking, and skidding phases of the operation. Detailed analyses were applied only to data from the medium and heavy timber classes, because several areas of light timber were understocked and afforded no logging data.

Felling and Bucking

Since fallers are paid on a per thousand board feet basis (gross saw scale) dollar costs per thousand board feet are of less interest than log production rates because pay scales are determined by negotiation between union representatives and contractors. Accordingly, production rates (board feet per man-hour) for felling and bucking were analyzed to determine the effect of year of logging (1953 or 1954), marking method, reserve volume levels, timber volume classes, and all the interactions of these factors on them.

Of all these elements, only the marking method--reserve volume level interaction proved significant at the 95 percent confidence level. Further examination showed that the highest production rates occurred with stem selection marking and a high level of reserve volume while the lowest production rates were found where group clearcutting at a high-reserve level was practiced. Intermediate production rates were found under both marking systems where low reserve volumes were retained (table 2).

Table 2.--Felling and bucking production rates (M board feet per man-hour) by marking methods and reserve volume levels[1]

Reserve volume level	Marking method	
	Group selection	Stem selection
	M bd.ft.	M bd. ft.
High	2.216	2.826
Low	2.666	2.464

1/ Data from medium and heavy timber classes only.

This arrangement of production rates could not be explained satisfactorily by relating them to cutting intensities since the volume class--reserve level interaction, which can be considered an expression of intensity of cut, was not significant. The inference can be drawn that nonproductive time was little affected by the conditions of the study.

6/ Snedecor, George W. 1946. Statistical methods. 4th Ed. 485 pp.

An explanation for the differences in production rates was found when the same analysis techniques were applied to cut tree sizes. Again, the only significant factor found was the interaction of marking method and reserve level. Cut trees averaged largest for stem selection--high reserve, lowest for group selection--high reserve, and intermediate for low reserves under both marking methods.

Since average sizes of cut trees paralleled the felling and bucking production rates for the four marking method--reserve level combinations, a regression equation for predicting production rates from average cut tree sizes was derived from pooled data by the method of least squares. The relationship was highly significant and took the form

$$Y = 1.49 + 0.86X$$

where Y is the felling and bucking production rate in M b.f. per hour and X is the volume (in M board feet) of the average cut tree. It appears in graphic form in figure 2.

The results obtained here are in agreement with Hasel's[7] conclusion regarding logging output rates in California ponderosa pine stands: differences in cost (meaning output rather than dollar costs) are due almost entirely to tree-size makeup of stands marked rather than to intensity of cutting.

Tractor Skidding

Production Rates

Analysis of tractor skidding tested the effects of the same factors and combinations of factors on skidding production rates as were tested for felling and bucking.

The large tractor, as expected, showed the higher average production rate for the operation (5.805 M b.f. per hour as compared to 3.985 M b.f. per hour for the small tractor), and maintained the higher rate despite its average skidding distance, as estimated from skid trail lengths (274 feet as compared to 208 feet for the small tractor).

The only other significant effect was the combination of timber class and reserve volume, which has been previously suggested to be an approximation of cutting intensity. Production rates for both tractors were highest in heavy timber cut to a high reserve[8] (table 3) but conflicting output rates occur for all other timber class--reserve combinations.

7/ Hasel, A. A. 1946. Logging cost as related to tree size and intensity of cutting in ponderosa pine. Jour. Forestry 44: 552-560

8/ A comparatively light cut: 22 to 27 percent, table 1 data.

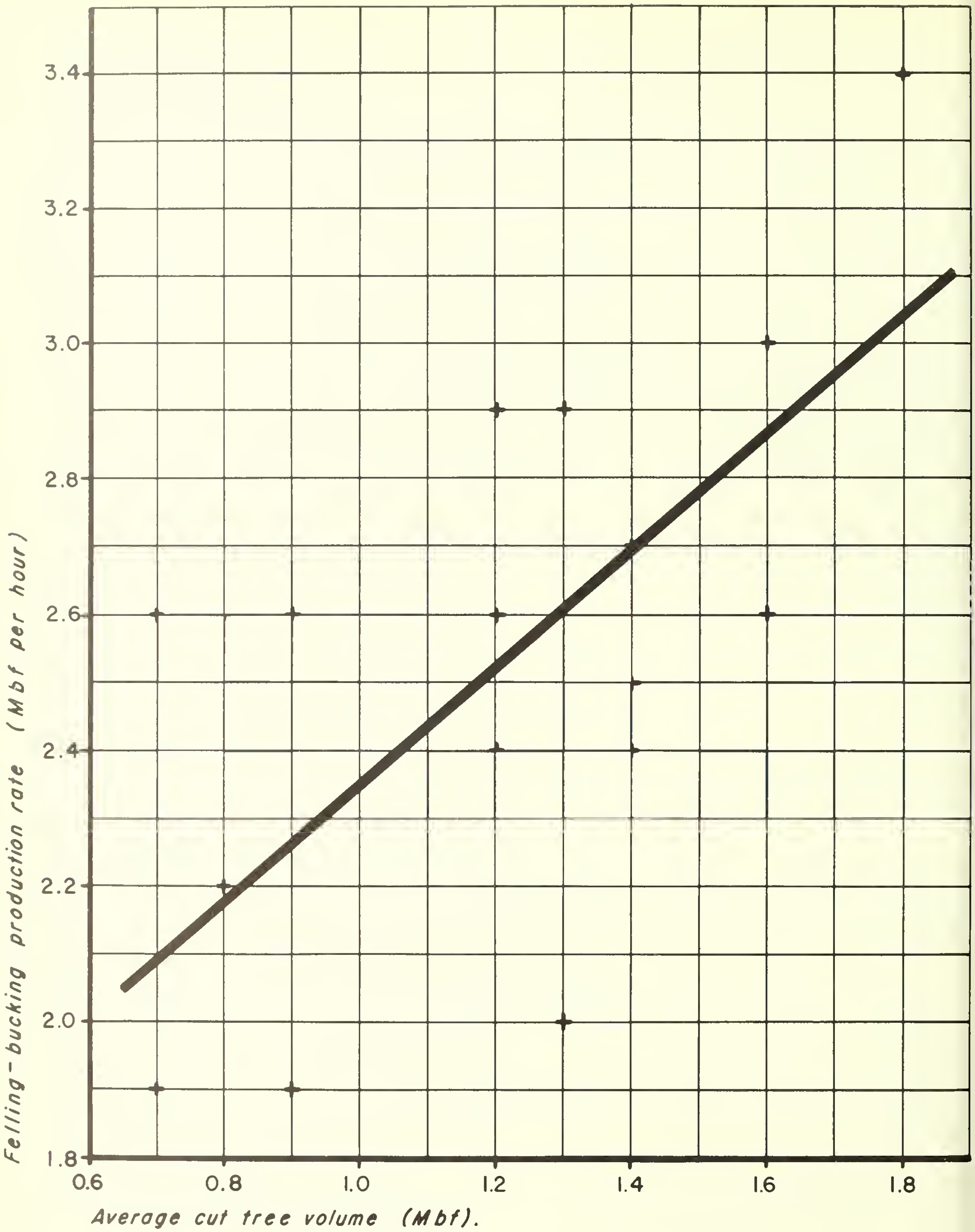

Figure 2. Felling-bucking production rates as influenced by average cut tree size.

Table 3.--Skidding tractor production rates (M b.f. per tractor-hour) by timber classes and reserve levels

Reserve volume level	Small tractor		Large tractor	
	Medium timber	Heavy timber	Medium timber	Heavy timber
	M b.f.per hour	M b.f.per hour	M b.f.per hour	M b.f.per hour
High	3.730	4.602	5.718	7.696
Low	4.371	3.240	4.614	5.189

A partial explanation of the highest production rates can be found in table 4, which shows that skid trail lengths averaged less (especially for the large tractor) in heavy timber than in medium timber. This probably helped boost output where cutting was light but its effect cancelled where cutting became heavy enough to affect tractor maneuverability. Further analysis of this aspect was not considered warranted because of the unreliability of average skid trail lengths as estimates of average skidding distances.

Table 4.--Average skid trail lengths, by tractors, timber classes, and reserve levels

Reserve volume level	Small tractor		Large tractor	
	Medium timber	Heavy timber	Medium timber	Heavy timber
	Feet	Feet	Feet	Feet
High	203	221	331	228
Low	223	186	294	236

Regression analyses were made of the relationship between average cut tree size and skidding output rates, and intensity of cut as related to production. Neither analysis showed a trend definite enough to be considered significant. In these respects, the results obtained in this study differ from those obtained by Hasel (page 9) who found that yarding time for heavy cutting was less than for lighter cutting and that tree size was the most important factor entering into skidding output rates. These factors probably affect skidding output in Idaho ponderosa pine operations in much the same way as in California, but the limitations of the method of study, the irregular topography, and the great disparity of the capabilities of the two tractors tend to obscure the effects of tree size and cutting intensity.

Cost per Thousand Board Feet

Had tree sizes averaged smaller, it is quite possible that the small tractor could have skidded as economically or even more economically than the large tractor. As it was, the small tractor lost appreciable time handling big logs and had more maintenance problems than the large tractor. From the available data,9/ the small tractor's output cost per M b.f. was 1.03 times that of the large tractor.

On these bases, costs for the two tractors do not differ much, but further consideration is necessary. Despite the random assignment of treatments, more favorable road-building chances occurred in the small tractor compartments than in those selected for large tractor operation, with the result that more road per acre of operating area was constructed in these compartments. The amount of main haul road per unit of operating area was essentially the same for both tractors. This road construction has the effect of further reducing average skidding distances for the small tractor. Comparative costs of the two tractors should, therefore, take into account the cost of the "excess" spur road in the small tractor compartments, which was computed as the difference between the actual length of spur road and that which would have been built if the "spur road length per acre" ratio of the large tractor compartments had been applied. When the cost of the computed "excess" road was included, it was found that small tractor skidding cost 1.43 times that of the large tractor.

However, the logging company was so impressed by the possibilities for using less powerful tractors than the large size that they have adopted a practice of using a medium tractor in combination with a large one for logging similar timber and report it a very satisfactory arrangement. The medium tractor is more powerful than the small tractor and, under ordinary circumstances, is faster than the large, but having the large tractor on the same job makes still more power available when difficulties arise.

Loading and Trucking

A Model 41 Northwest loader was used for all loading. For the entire operation, 9.103 M b.f. were loaded per hour of equipment use.

Trucking involved a 72-mile highway haul plus 5 miles of woods roads, with adverse grade occurring only for about 2 miles of the highway. With average loads of 5.941 M b.f., 0.888 M b.f. were delivered to the mill per hour of equipment use.

9/ Includes equipment use cost, labor, and fuel, but only a very small part of maintenance costs due to the company's practice of charging equipment maintenance for all machines against the log camp rather than to individual machines.

Cost Distribution

As a sidelight on an operation which is considered typical, with the minor exception noted of present national forest sales in southwestern and central Idaho, the distribution of logging costs are presented in two tables. Table 5 shows the man- and equipment-hours required to fell, skid, load, and truck a thousand board feet of logs. Except for the highly variable item of trucking, a logging contractor could obtain from these rates a reasonably good estimate of his own costs for a similar operation by employing his own hourly labor and equipment rates.

Table 5.--Man- and equipment-hours per thousand board feet (net log scale)1/

	Labor items	Equipment items
	Man-hours	Machine-hours
Felling (Felling and bucking	2/ 0.465	-
Felling (Scaling	.115	-
Skidding	.878	3/ 0.218
Loading	.455	.110
Trucking	1.136	1.126
Totals	3.049	1.454

1/ Basis: 4,201.070 M b.f.
2/ Chain saw use and maintenance included in contract felling pay rates.
3/ Average rate, small and large tractors. Separate rates are: small tractor, 0.252 hr./M b.f.; large, 0.186 hr./M b.f.

The following tabulation shows the actual dollar costs for this operation as percentages of the cost of logs delivered to the mill. The most variable items, mobilization, roads, and trucking (normally considered direct costs), have been shown separately in the tabulation. Percentagewise reapportionment of costs to exclude one or both of these variable items can be accomplished by subtracting them from 100 percent and recalculating the remaining items proportionally.

		Percent	
Direct logging costs			
Felling and bucking			
Labor	. . . .	10.2	
Supplies and expense	. . . .	.3	
Total	. . . .		10.5
Skidding			
Labor	. . . .	6.5	
Equipment use	. . . .	4.1	
Supplies and expense	. . . .	.6	
Total	. . . .		11.2
Loading			
Labor	. . . .	3.9	
Equipment use	. . . .	2.6	
Supplies and expense	. . . .	.6	
Total	. . . .		7.1
Variable direct costs			
Mobilization	. . . .	1.4	
Main logging road	. . . .	3.3	
Woods roads	. . . .	10.3	
Total	. . . .		15.0
Trucking			
Labor	. . . .	9.1	
Equipment use	. . . .	24.6	
Supplies and expense	. . . .	6.4	
Total	. . . .		40.1
Indirect logging costs			
Camp costs	. . . .	2.5	
General overhead expense	. . . .	9.7	
Supervision	. . . .	2.0	
Employees' welfare	. . . .	1.9	
Total	. . . .		16.1
Total cost of logs delivered	. . . .		100.0

SUMMARY

Installing an experiment designed primarily to test the silvicultural and watershed aspects of two logging methods, two marking methods, and two levels of reserve stand volume in the virgin ponderosa pine type on the Boise Experimental Forest, afforded an opportunity for obtaining data on logging costs as related to a number of variables. Conditions for the logging operation were, with few minor exceptions, typical of national forest sales in central Idaho.

Felling-bucking production rates were found to be highest where stemwise marking with a high level of reserved volume was practiced and lowest rates occurred where groupwise marking to a high reserved volume level was employed. A definite correlation existed between production rates and the size of the average "cut" tree. No other factors or combinations of factors were found to be significantly related to output rates.

For skidding production, the large tractor showed the highest rate, as expected. Both tractors produced at their highest rates in heavy timber stands which were cut to a high reserve volume (a relatively low intensity of cut). In other combinations of timber stands and levels of reserve volume, different patterns of output rates occurred for each tractor. Regressions of production rates over percentage cut and over average cut tree size showed no significant trends due, no doubt, to uncontrolled variation in the experiment. Analysis of dollar costs by tractors showed that the small tractor cost 1.43 times as much as the large tractor per thousand board feet skidded. On the whole, the trees averaged too large in size for economical operation of the small tractor.

Tables are presented to show the distribution of logging costs for a reasonably typical operation in two ways--in terms of man- and equipment-hours per thousand board feet and as percentages of the total cost of logs delivered to the mill.

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Research Paper No. 52

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Research Paper No. 53 October 1957

PHENOLOGY AND OTHER FEATURES OF THE FLOWERING OF PINES, WITH SPECIAL REFERENCE TO *PINUS MONTICOLA* DOUGL.

By

R. T. Bingham and A. E. Squillace
Foresters

NORTHERN REGION
and
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah

Rust-resistant tree No. 19. bagged with cloth sacks to protect controlled pollinated cones from insects and squirrels.

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PHENOLOGY AND OTHER FEATURES OF THE FLOWERING OF PINES, WITH SPECIAL REFERENCE TO PINUS MONTICOLA DOUGL.

R. T. Bingham and A. E. Squillace[1/]

INTRODUCTION

A tree-breeding project (6)[2/] for developing blister rust-resistant (Cronartium ribicola Fischer) and otherwise improved western white pine (Pinus monticola Dougl.) planting stock was begun in the Inland Empire region in 1950. From 1950 through 1955 controlled pollinations were made between as many pairs of rust-resistant selections as possible. Limited ovulate flowering of the young trees used controlled the number of crosses made. In the routine controlled pollination work a fund of information concerning flowering habits of 45 young, rust-resistant white pines was accumulated. This evidence is assembled to increase the general knowledge of flowering in P. monticola and for its direct usefulness in planning future controlled pollination work and seed orchard studies.

P. monticola is among those pines considered as requiring 2 years to mature seed. Actually, three consecutive growing seasons are involved since floral primordia are differentiated in the growing season prior to their appearance and recognition as full-fledged micro- or megasporangiate strobili. The maturing male and young female strobili, hereafter called staminate and ovulate "flowers," first become visible in the bud stage in June of the year following initiation of primordia. They emerge from the bud scales, the staminate flowers shedding pollen and the ovulate flowers becoming receptive to pollination more or less simultaneously, in the period between late June and early July.

Ordinarily the period of anthesis (pollen release) is considered to continue from the time of natural dehiscence of the first few normal microsporangia until the dehiscence of microsporangia in the male flowers of a given tree or stand is complete. The receptive period in ovulate flowers is considered to be the period during which the flower or "conelet" scales are open so that pollen may be air-borne to the micropylar openings of the egg sacs found at the base of the scales. In this respect, ovulate flower stages "partly open" (with scales beginning to open by reflexing downward from a position along the erect axis of the conelet) to "partly closed" (with the outer tips of the conelet scales beginning to swell together and limit pollen access) are considered by the majority of pine-breeders to span the complete period of receptivity.

1/ Bingham is Forester (Silviculture), Division of Blister Rust Control, Region 1, U. S. Forest Service, and Squillace is Forester (Silviculture), Intermountain Forest and Range Experiment Station, U. S. Forest Service, Spokane, Washington.

2/ Numbers in parentheses refer to LITERATURE CITED page 22.

Distinct maxima in pollen release and ovulate flower receptivity occur within stands--the bulk of the microsporangia dehiscing within a few days and the bulk of the ovulate flowers reaching and remaining in stage "flowers maximum" (scales completely reflexed and at right angles to conelet axis allowing maximum pollen access) within a similar period. Once pollination has been effected, the male flowers die and the closed but still erect young ovulate cones continue to enlarge to an over-all length of 1 to 1½ inches, in which stage they overwinter. In the late spring or early summer of the next (third) growing season the pollen tube completes the yearlong process of penetrating the wall of the egg sac, fertilization takes place, and the young cone begins to enlarge rapidly, turning from an erect to a pendulous position. By mid-September of the same season the cones open and shed mature seed.

The thumbnail life history above is adequate for understanding of the results and discussion that follow. If the reader desires a more complete understanding of the processes involved, the following publications are recommended: (1) concerning the general appearance of various flowering stages--(38, 45, 10, 53, 1, and 15); (2) concerning details of the mechanism of pollination in *Pinus*--(13); and (3) concerning embryology of *Pinus*--(18).

REVIEW OF LITERATURE

Phenology, a contraction of the word phenomenology, or the branch of applied meteorology concerned with the influences of climate on the annual phenomena of plant and animal life, is by no means a young science. It probably dates from before 1750 when early botanists, Linneaus included, proposed the systematic recording of the time of appearance of leaves, flowers, and fruits in plants. The application of phenology to forestry has been summed up in two publications by Huberman (20 and 21).

The authors soon realized the hopelessness of completely reviewing even that part of the phenological literature concerned only with forest trees. Early observers lacked uniform criteria for describing annual phenomena and varied in their skill in describing and recognizing floral stages. These factors as well as the bulk and inaccessibility of the older literature caused the writers to restrict their survey mainly to more recent publications on floral phenology of conifers.

In addition to these publications, several important references on general plant phenology should be mentioned. Hopkins' (19) exposition on relationships of plants and climate and his experimental evidence associating the "bioclimatic" character of a local area with the dates of periodic events in plants, and indicating the use of periodic events in plants for determining sowing or harvesting dates, have had wide practical application. His "Bioclimatic Law" that in the United States there is an average 4 days' lag in the occurrence of annual events in plants for each 1° latitude northward, for each 5° longitude eastward, and for each 400 feet increase in elevation is often used and quoted. Garner's (17) work on photoperiodism in respect to initiation of the flowering period showed that duration of light also influences the onset of flowering, a conclusion strengthened by the more recent work of Anderson and Hubricht (4). Thus photoperiodic requirements might be expected to have an important role in floral phenology, especially among exotic plants transplanted from one photoperiodic regime to another.

Among the more comprehensive early American studies that focused attention upon cumulative effects of late winter and spring temperatures in controlling time of flowering were the temperature summations of Blendel (7). Blendel showed that different species require different amounts of heat to perform various physiological functions, including flowering. His summations of positive average daily temperatures between January and May showed that temperature was the principal determinant of flowering time and that approximately the same number of heat units was required to induce the onset of flowering in the same species in either an "early" or a "late" year. Osterwalder (34) presented conclusive evidence of relation of early spring temperature summation to time of blossoming in fruit trees. Lindsey and Newman (25) outlined recent refinements in this method leading to much more sensitive heat summation appraisals.

Notable among phenological treatises dealing with flowering dates of American plants at a given locality were the 45-year Ohio data reported by Smith (44), the 20-year Manitoba data reported by Criddle (9), and the 17- to 30-year data presented by Lindsey and Newman (25). Among the more important contributions concerning phenology of American deciduous trees are included observations by Lamb (22) in the eastern United States, by Wyman (52) at the Arnold Arboretum, Massachusetts, by Mehan (27) at the Ellis College Arboretum in eastern Pennsylvania, and by Silker (42) in southeast Texas.

Also worthy of special mention is the paper by Stout (46) defining the various forms of dichogamy (maturation of male and female flowers at different times) associated with infertility in plants with special reference to American nut trees of the Betulaceae, Fagaceae, and Juglandaceae. This and other work concerning phenologically induced self- or cross-infertility in nut trees is covered later in the discussion of similar phenomena in P. monticola.

Concerning the principal field of literature covered--phenology of pine flowering--it appeared that the best way to review and present the literature in understandable form was by tabular summary. Table 1 facilitates comparisons between individual trees and stands both within and between species, by species, authority, locality, and period of observation. Included are observations on duration of flowering in a given year, on year-to-year variation in time of flowering and associated climatic factors, on consistency of flowering time, and on flowering habit. The noteworthy features of conifer floristics brought out by the table are as follows:

Table 1.--Review of the literature on the phenology of ovulate and staminate flowering in pines

Species	Authority (senior author only)	Date publ.	General locality	Period of observation	Approx. time of first flowering	Duration of flowering: Single trees: Range Male	Fem.	Single trees: Average M.	F.	Stands: Range M.	F.	Stands: Average M.	F.	Delay in flowering: Per 1000' elev.	Per deg. lat.
				Years	Date	- - -								Days - - -	
Pinus															
banksiana Lamb.	Duffield	1953[4/a]	Placerville, Calif.	10	4/14										
	Wright	1953[a]	Philadelphia, Pa.	4	5/6	3-5[5/]		5+							
cembroides Zucc.	Wright	1952	Philadelphia, Pa.	1	6/15			3							
contorta Dougl.	Duffield	1953	Placerville, Calif.	4	5/1										
coulteri D. Don	Duffield	1953	Placerville, Calif.	5	5/15										
echinata Mill.	Dorman	1956	Jefferson, Ala.[a]	1	4/1										
			Range of species	1						6-29		15			?
	Duffield	1953	Placerville, Calif.	3	4/11										
	Zobel	1954	East Texas	3	3/22						11-27		18		? a
elliottii Engelm.	Dorman	1956	Lake City, Fla.[a]	4	1/25										
			Range of species	1		14-20				8-24		16			4½
	Snow	1943	Lake City, Fla.	2					15[a]						
	Zobel	1954	Southeast Texas	3	1/27						10-30		20		
flexilis James	Duffield	1953	Placerville, Calif.	5	5/24										
	Wright	1953	Philadelphia, Pa.	5	5/27	3+-8		7							
griffithii McCl.	Duffield	1953	Placerville, Calif.	8	5/17										
	Wright	1953	Philadelphia, Pa.	4	5/24	7-9		8							
monticola Dougl.	Duffield	1953	Calif. Mtns.[e]	7	7/11										
nigra Arnold	Lamb	1915	Eastern U. S.[a]	?	5/15										
	Wright	1953	Philadelphia, Pa.	4	5/16	6-8		7							
palustris Mill.	Dorman	1956	Ashley, Ark.[a]	1	3/13										
			Range of species	1						7-30		18			10
	Zobel	1954	Kirbyville, Texas	1	3/12								11		
ponderosa Laws.	Cumming	1948	Calif. Mtns.[a]	20			3-7[b]								
	Duffield	1953	Calif. Mtns.[a]	7	5/11									8	
	Roeser	1941	Freemont, Colo.	9	6/16										
radiata D. Don	Duffield	1953	Placerville, Calif.	7	3/13										
	Fielding	1947	Mt. Burr, Australia	1	8/12							53[a]			
	Millett	1944	Canberra, Australia	5	9/8					16-23		18			
			Mt. Burr, Australia	5	7/24					30-68		52[e]			
resinosa Ait.	Duffield	1953	Placerville, Calif.	6	4/26										
	Wright	1953	Philadelphia, Pa.	3	5/9	1-11		7+							
strobus L.	Dorman	1956	Buncombe Co., N. C.	1	5/29							18			
	Duffield	1953	Placerville, Calif.	5	5/20										
	Lamb	1915	Eastern U. S.	?	5/15										
	Wright	1953	Philadelphia, Pa.	4	5/28	6-18		11							
sylvestris L.	Danckelmann	1898	Eberswalde, Germany	21	5/22										
	Doyle	1935	Dublin, Ireland	?				7							
	Duffield	1953	Placerville, Calif.	5	5/1										
	Lamb	1915	Eastern U.S.[a]	?	5/15										
	Minshall	1947	Ottawa, Ontario[a]	10	5/27										4½[b]
	Servas	1955	S. Finland	4	6/6					4-22		9			3½[a]
	Scamoni	1938	Eberswalde, Germany	9		3½									
	Scamoni	1955	Eberswalde, Germany	5	5/6					29-41		38			
	Tiurin	1956	Central Russia[a]	3-7	5/12-6/13										2½
	Wright	1953	Philadelphia, Pa.	4	5/8	5-8+		7+							
tabulaeformis Carr.	Duffield	1953	Placerville, Calif.	1	4/14										
	Doyle	1935	Dublin, Ireland	?						6-28		19			
	Wright	1953	Philadelphia, Pa.	4	4/30	4-10		9							
taeda L.	Dorman	1956	Franklin, Va.[a]	7	4/4										
			Range of species	1											7½
	Duffield	1953	Placerville, Calif.	9	4/12										
	Zobel	1954	East Texas	3	2/28						13-36		20		10[a]
thunbergii Parl.	Duffield	1953	Placerville, Calif.	3	4/20										
	Wright	1953	Philadelphia, Pa.	4	5/11	5-7		6+							
virginiana Mill.	Dorman	1956	Jefferson, Co., Ala.[a]	1	3/15										
			Range of species	1						16-21		18			
	Duffield	1953	Placerville, Calif.	3	4/19										
	Wright	1953	Philadelphia, Pa.	3	5/10	3-8		8							

1/ Other factors found associated with yearly variation in flowering were air temperature (T), rain (R), relative humidity (H), and evaporation rate (E).

2/ Excluding obvious elevational or latitudinal effects, flowering was found consistently early or late among individual trees of the same species in the same locality (A), among stands of the same species in different localities (B), or among stands of different species in the same locality (C).

Year to year variation in time of flowering: Single trees M.	Single trees F.	Stands in one locale M.	Stands in one locale F.	Over range of species	Assoc. ecol. factors: Critical air-temp. period	Assoc. ecol. factors: Other weather factors	Consistency in relative order of blooming	Flowering habit	Notes and remarks
- -	- -	- -	- -	- -	Months	1/	2/	3/	
		39[b]				T[c]	C		[a]50 spp. covered. [b]Variation in time of pollen collection, usually near time of first anthesis. [c]3 years records show effect mean daily temps. on time of flowering.
		14					A,C	S[b]	[a]20 spp. covered. [b]All at least partly synacmous.
		23							
		29				T	C		
									[a]Jefferson, Ala. is about av. lat. for species (Munns, 1938).
				30			B,C		
		21							
			24		Mar.-Apr.	T	C	S	[a]In 2 years observations, reversal of lat. effect seen.
									[a]Lake City, Fla. is about av. lat. for species (Munns, 1938).
13		21		27			A,B,C		
									[a]Length of receptive period--"buds-large" to "flowers-closed" stage--given as about 15 days.
			11		Jan.-Feb.	T	C	S	
		31				T			
		7					A,C	S	
		41					C		
		18					A,C	S	
		59[a]							[a]Sierra Nevada Mtns., lat. 39°N., 7000' elev. but apparently several stands.
				30[a]			C		[a]Range of species as planted in eastern U. S. only.
		15					A,C	S	
									[a]Ashley, Ark. is about av. lat. for species (Munns, 1938).
		21		71			B,C		
							C	S	
							B		[a]Sierra Nevada Mtns. [b]Large trees with many flowers required up to 5 visits for pollination.
		44					B,C		[a]Sierra Nevada Mtns., lat. 39°N., 3000' elev.
		25	27			T[e]	B	S	[e]Flowering commenced 15 days after last spring frost.
		75					C		
		10				7[b]	A		[e]Max. length of pollination over 3-yr. period, but bulk of pollen was collected over 32-43 day period. [b]Weather given as important but factors not specified.
		20			July-Aug.	T,R,E[a]			[a]Soil + air temp. assoc. with time of anthesis; duration of pollination thereafter with amt. sunshine, wind + evap. rate.
		18			July-Aug.	T,R,E[b]			[e]Mt. Burr had extended, cloudy + wet weather. [b]Soil + air temp. assoc. with time of anthesis; duration of pollination thereafter with amt. sunshine, wind + evap. rate.
		24					C		
		4+					A,C	S	
		38					C		
				35			C		
		21					A,C	S	
		27				T	C		5-21 yr. obs. on 10 spp. showed consistency in sequence of blooming and assoc. with temp. units ("Warmesummen").
								S	P. mugo Turra almost completely protogynous at Dublin.
		36					C		
				40[a]			C		[a]Range of species as planted in eastern U. S. only.
16					Mar.-Apr.	T			[a]Single, somewhat sheltered tree. [b]Latitude effect shown is calculated by comparison with Wright, 1953 data.
		12				R,T	C		Climate affected onset but not amount of pollination. [a]Latitude effect shown is calculated by comparison with Scamoni, 1955 data.
					May	T,H			Temp. last 10-14 days prior to flowering critical.
		12			Apr.-May	T,H,R			Temperature 10 days prior to pollen flight critical. Temperature determined time of flight; humidity + wind progress of pollen dispersion thereafter.
		18		33			B		[a]13 stations from S. to N. central Russia from Stalingrad on S. to Archangelsk on N.
		17-					A,C	S	
								A[a]	[a]Completely protandrous, possibly due to cultivation conditions.
		12					A,C	S	
									[a]Franklin, Virginia is at northern limits of the species range (Munns 1938).
		17		46			B,C		
		49					C		
					Mar.-Apr.	T	B,C	S	[a]2 localities (Bastrop Co. + Lufkin) spanning 1-1/3° lat. compared by present authors, notable reversals occurred elsewhere.
		27					C		
		15					A,C	S	
									[a]Jefferson Co. is at the southern limits of the species range.
				46			B		
		13							
		13					A,C	S	

3/ Protandrous (male first) habit (A), protogynous (female first) habit (B), synacmous (simultaneous flowering) habit (S).

4/ Small letters indicate that a note with corresponding letter will be found in the notes and remarks column.

5/ Data centered between columns denotes that authority did not distinguish between staminate and ovulate flowering periods.

(1) The duration of staminate and ovulate flowering in individual pine trees is remarkably uniform both within and between species, averaging about a week in length, with a maximum duration of about 2 weeks.

(2) Flowering in stands of one species is sometimes of considerable duration, staminate flowering extending over a period of one-half to 10 weeks and averaging about 2½ weeks, ovulate flowering extending for 2 to 5 weeks and averaging about 3 weeks.

(3) For each degree latitude northward, most species exhibit a delay in flowering time averaging about 5 days. Thus in the United States most pines except the southern pines have values quite close to Hopkins' (19) mean of 4 days per degree of latitude.

(4) The large variation (4 to 75 days) in year-to-year flowering time of stands at the same locality depends partly on the number of years included in the observation period. "Early" blooming trees like Pinus radiata appear to be subject to the greatest variation in time of flowering.

(5) Temperature is a potent factor determining onset of flowering in a given year.

(6) A number of Pinus species exhibit consistency in respect to the "earliness" or "lateness" of flowering in individual trees. Consistency in the relative order of flowering of different species at the same locality is frequently noted.

(7) Very few clear-cut cases of complete dichogamy are reported for pines. Either partial or complete protandry or protogyny is evident in a few species. The majority, however, are either synacmous or have overlapping male and female flowering periods that should eliminate dichogamy as the major cause of self- or cross-incompatibility.

MATERIALS AND METHODS

The numbers of trees employed and the seasons involved in the phenological and flowering study of western white pine are outlined in table 2. The over-all basis (45 trees) is fairly sound, but the locality (2 to 15 trees) or seasonal bases (7 to 41 trees, 6 seasons of observation) are less strong. Phenological observations were made on each individual tree that flowered during the years shown, with particular attention to the start, maxima, and end of staminate and ovulate flowering. The useful form, figure 1, slightly modified from the original developed by the Institute of Forest Genetics, Placerville, California, was used in recording phenological observations by individual trees. Notes on dichogamy, position of male and female flowers, or on other features of flowering were appended. To aid in interpreting the data the starting, maxima, and ending dates of staminate and ovulate flowering were plotted by locality and observation year, as in figure 2. To facilitate comparison, dates were numbered consecutively with June 1 as day number 1.

Table 2.--Basis of the observations, numbers of trees observed, by localities and seasons

Locality	Elevation	Latitude	Year of observations						
			1950	1951	1952	1953	1954	1955	Total
	Feet	°N.	Number of trees						
Soldier Creek	2,700	47°10'			2	2			2
Crystal Creek	2,850	47°00'	14	8	13	15	5	6	15
Middle Fork St. Maries River	2,900	47°00'	4		4	2			4
Gold Center	2,950	47°00'	6	1	7	6	1		8
Lower Elk Creek	3,000	46°49'		2	3	3	1	2	3
Emerald Creek	3,000	46°58'	1			3			3
Upper Elk Creek	3,300	46°52'			2	5			5
White Rock	5,000	47°00'	1	2	5	5			5
Totals			26	13	36	41	7	8	45

RESULTS AND DISCUSSION

Time and Duration of Flowering Period

Among the 45 *P. monticola* trees observed over the period 1950 to 1955, average date of anthesis at low elevations (2,700 to 3,300 feet) was June 27, at high elevations (5,000 feet) July 8. In the average year first receptive flowers at low elevations appeared June 29; at high elevations, July 7. Earliest pollen flight observed in the 6 years was June 10, 1952; latest, July 12; earliest receptive ovulate flowers June 10; latest, July 14.

Tables 3 and 4 sum up many features of staminate and ovulate flowering in western white pine as observed in this study. In respect to the duration of flowering in individual trees, the shortest and longest periods of pollen shedding were observed to be 4 and 14 days, respectively; of ovulate flower receptivity 4 and 25 days, respectively. Stands within the 8 localities studied had average pollination periods ranging from 6 to 12 days (grand average 8.5 days based on 45 different trees), and average periods of ovulate flower receptivity ranging from 4 to 13 days (grand average 9.5 days based on 34 different trees). The duration of flowering in *P. monticola* individuals and stands is quite similar to that of many other pines, as shown in table 1.

Another interesting fact related to duration of flowering in western white pine brought out by figure 2 was the prolonged period of ovulate flowering in the most fruitful individuals. Trees number 19 and 20 (among the heaviest fruiters) show the prolonged ovulate flowering period. Notable exceptions to the generalization are tree 27, a light fruiter with a prolonged ovulate flowering period, and tree 58, a heavy fruiter with a relatively

Species ______________ Date ________ Year ______________

Plot ______________ Tree no. ________ Elev. ______________ feet

Pollen	Conelets	Cones
Not yet flying	Buds small	Mature
Starting	Buds large	Opening
Flying (max.)	Buds opening	Open
Mostly shed	Fl. partly open	Falling
All shed	Maximum	Fallen
	Partly closed	
Dates collected	Closed	
	Enlarging	

Notes:

M-1924-R1

Figure 1.--Modified Institute of Forest Genetics form used for recording phenological observations.

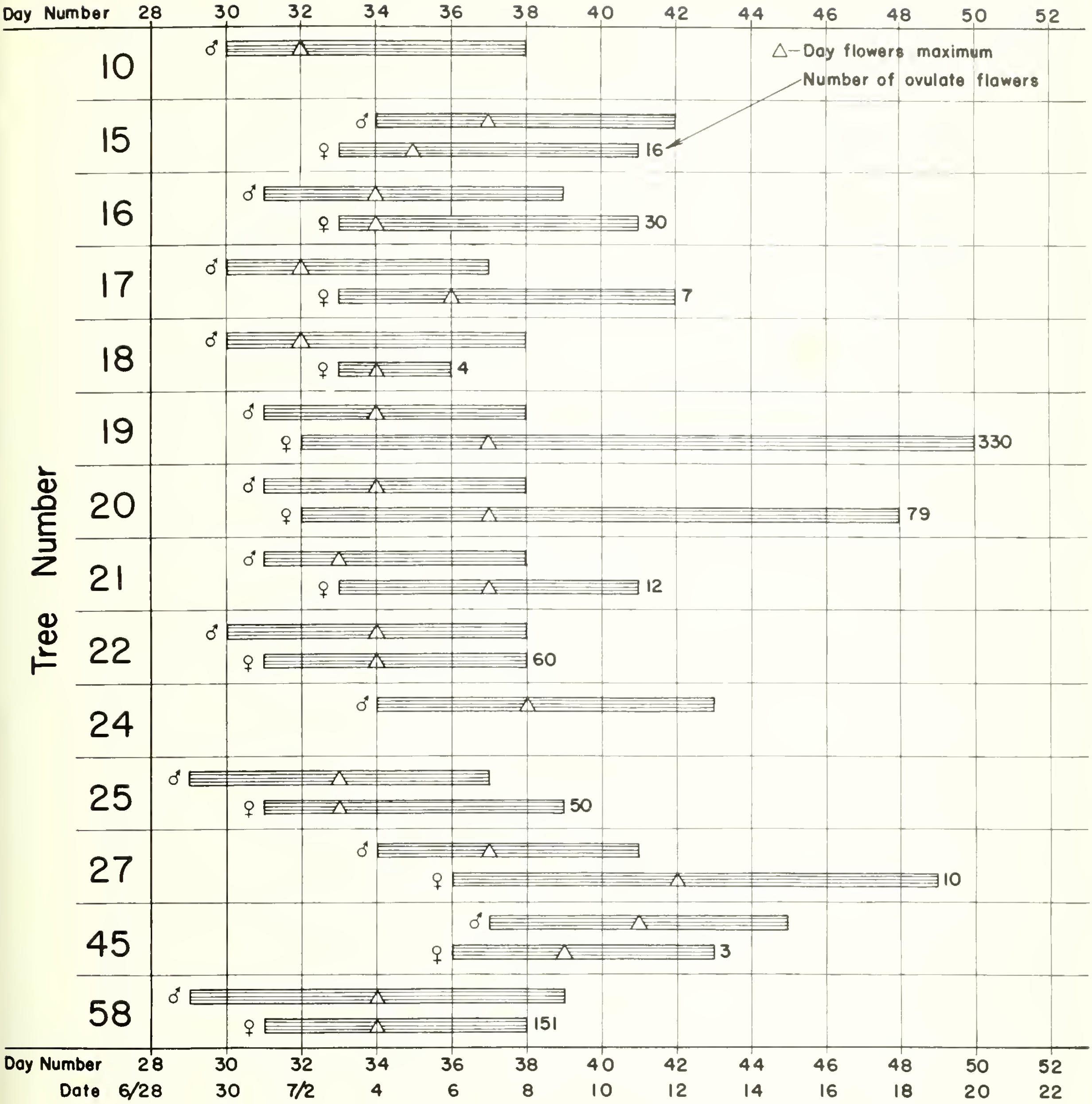


Figure 2.--Duration and maxima of ovulate and staminate flowering, Crystal Creek trees, year 1950.

short ovulate flowering period. Of the three most fruitful trees, numbers 19, 20, and 58, the period of ovulate flower receptivity was longer than average in selections 19 and 20. Both trees bore large numbers of ovulate flowers, many of them on inner and lower branches or in portions of the crown not exposed to direct sunlight. The sheltered flowers developed slowly and prolonged the flowering season.

Ščepotjev (40) noted the almost identical phenomenon in Juglans regia L. where he found flower ripening on the inner vs. the outer branches differing by as much as 4 to 10 days, thus extending the flowering season. Orr-Ewing (33) found prolongation of the flowering season in Pseudotsuga menziesii (Mirb.) Franco due to late ripening of the flowers on lower and northerly parts of the crown. Lengthening of the flowering season caused by successive ripening of ovulate flowers has been noted specifically for Pinus sylvestris (13), for P. ponderosa (10), for the four principal southern pines in East Texas (53), for Larix spp. (24), and for Picea abies (51). Sarvas (37) pointed out that in conifers and birches in southern Finland the years of most prolonged pollen dissemination were the years of most abundant pollen production.

Elevation and latitude, as they affect mean temperature, also affect the onset and duration of flowering as noted for many pines (table 1). Considering elevation, its effect on P. monticola was best demonstrated in this study by comparing flowering at the one high-elevation locality (White Rock, 5,000 feet) with that at the other seven low- or medium-elevation localities (2,700 to 3,300 feet). Tables 3 and 4 show that during 4 years when observations were made at White Rock, staminate flowering was later on the average of 11 days, ovulate flowering 9 days, or about 5 days later per 1,000 feet increase in elevation.

Elevation had another effect on flowering of P. monticola. Although year-to-year climatic variation had little, if any, effect on duration of flowering in individual trees except possibly at the higher elevations, the difference in time of onset of flowering in early vs. late years was much less at high- than at low-elevation localities (figure 3). The flowering seasons plotted in figure 3 were the earliest (1952) and the latest (1953) encountered in the 6-year study. At Gold Center, the low-elevation locality nearest White Rock, the difference between average dates of maximum flowering in the 2 years was approximately 15 days, while at White Rock (only 4 miles east but 2,050 feet higher) it was 8 days.

Wright (51) commented on a related phenomenon concerning telescoping of the over-all or all-species flowering season during later than average years at Philadelphia and at Ottawa (as reported by Minshall (29)). Ottawa lying some $5\frac{1}{2}^{o}$ latitude to the north of Philadelphia had a later flowering season every year, but the effect of the later-than-average individual year caused more compression of the over-all season at Ottawa than at Philadelphia. In other words, duration of the flowering season of several species telescoped in cold, late springs, more so at colder than at warmer latitudes. Similarly in P. monticola year-to-year variation in the time of onset of flowering

Table 3.--Phenology of staminate flowering, by locality 1950 through 1955

Locality	Elevation	Year	Basis trees[2]	Starting time[1]			Ending time[1]			Length av. period	Time maximum[1]		
				Earliest individual	Latest individual	Av.	Earliest individual	Latest individual	Av.		Earliest individual	Latest individual	Av.
	Feet		No.							Days			
Soldier Creek	2,700	1952	2	14	14	14	21	21	21	8	17	17	17
		1953	2	33	33	33	41	41	41	9	36	36	36
Crystal Creek	2,850	1950	14	29	37	32	37	45	39	8	31	50	35
		1951	5	25	26	25	28	33	31	7	26	30	28
		1952	12	10	21	15	18	29	24	10	15	24	19
		1953	15	30	38	34	37	47	42	9	33	40	37
		1954	5	29	33	31	35	40	38	8	32	36	34
		1955	6	32	38	36	43	46	44	9	36	42	39
Middle Fork St. Maries River	2,900	1950	4	33	35	34	37	41	39	6	35	38	36
		1952	4	20	23	22	29	29	29	8	24	26	26
		1953	2	33	36	34	41	44	42	9	37	38	38
Gold Center	2,950	1950	5	31	40	37	41	46	44	8	37	43	40
		1952	7	24	25	24	29	31	30	7	26	28	27
		1953	6	37	40	39	43	48	46	8	40	43	42
		1954	1	35	35	35	42	42	42	8	38	38	38
Lower Elk Creek	3,000	1951	2	18	25	22	28	38	33	12	23	30	26
		1952	3	11	13	12	20	25	23	12	14	20	18
		1953	3	31	36	33	36	41	39	7	32	37	35
		1954	1	27	27	27	35	35	35	9	30	30	30
		1955	2	28	35	32	41	41	41	10	36	38	37
Emerald Creek	3,000	1953	3	37	39	38	43	47	45	8	40	42	41
Upper Elk Creek	3,300	1952	2	23	23	23	28	28	28	6	25	25	25
		1953	5	36	40	38	40	46	44	7	37	43	41
White Rock	5,000	1950	1	42	42	42	50	50	50	9	47	47	47
		1951	2	39	39	39	45	49	47	9	41	41	41
		1952	5	33	35	34	40	43	42	9	37	38	38
		1953	5	40	43	42	46	53	50	9	43	47	46
Totals and avgs.			[2]45							8.5			

1/ Time in days reckoned from base date of June (i.e. June 1 = day 1).

2/ Total number of different trees observed.

Table 4.--Phenology of ovulate flowering, by locality 1950 through 1955

Locality	Elevation	Year	Basis trees 2/	Starting time 1/			Ending time 1/			Length av. period	Time maximum receptivity 1/		
				Earliest individual	Latest individual	Av.	Earliest individual	Latest individual	Av.		Earliest individual	Latest individual	Av.
	Feet		No.							Days			
Crystal Creek	2,850	1950	12	31	36	33	36	50	42	10	33	42	36
		1951	8	19	27	24	28	36	32	9	23	31	27
		1952	10	10	20	15	20	34	27	13	16	26	20
		1953	14	31	37	35	37	51	44	10	34	43	39
		1954	4	29	34	32	37	42	40	9	31	37	35
		1955	6	33	36	35	42	45	44	10	38	41	39
Middle Fork St. Maries River	2,900	1950	2	33	34	34	41	44	42	9	36	37	36
		1952	3	23	23	23	29	32	30	8	26	27	26
		1953	2	33	36	34	41	46	44	11	37	40	38
Gold Center	2,950	1950	4	37	44	40	45	55	50	11	40	47	43
		1951	1	39	39	39	45	45	45	7	42	42	42
		1952	3	23	26	25	31	34	33	9	28	31	29
		1953	5	36	40	39	46	51	50	12	43	45	44
		1954	1	35	35	35	45	45	45	11	39	39	39
Lower Elk Creek	3,000	1951	2	25	25	25	28	29	28	4	26	27	26
		1952	3	13	17	14	21	28	25	12	16	20	19
		1953	3	29	34	32	36	41	39	8	34	37	36
		1954	1	26	26	26	35	35	35	10	30	30	30
		1955	2	32	35	34	38	43	40	7	35	38	36
Emerald Creek	3,000	1950	1	37	37	37	45	45	45	9	40	40	40
		1953	1	42	42	42	48	48	48	7	45	45	45
Upper Elk Creek	3,300	1953	2	37	37	37	41	46	44	8	38	40	39
White Rock	5,000	1950	1	44	44	44	55	55	55	12	49	49	49
		1951	2	35	36	36	42	51	46	11	39	42	40
		1952	5	30	33	32	40	46	43	12	35	40	37
		1953	5	40	43	41	46	53	49	9	43	47	45
Totals and avgs.			34							9.5			

1/ Time in days reckoned from base date of June 1 (i.e. June 1 = day 1).

2/ Total number of different trees observed.

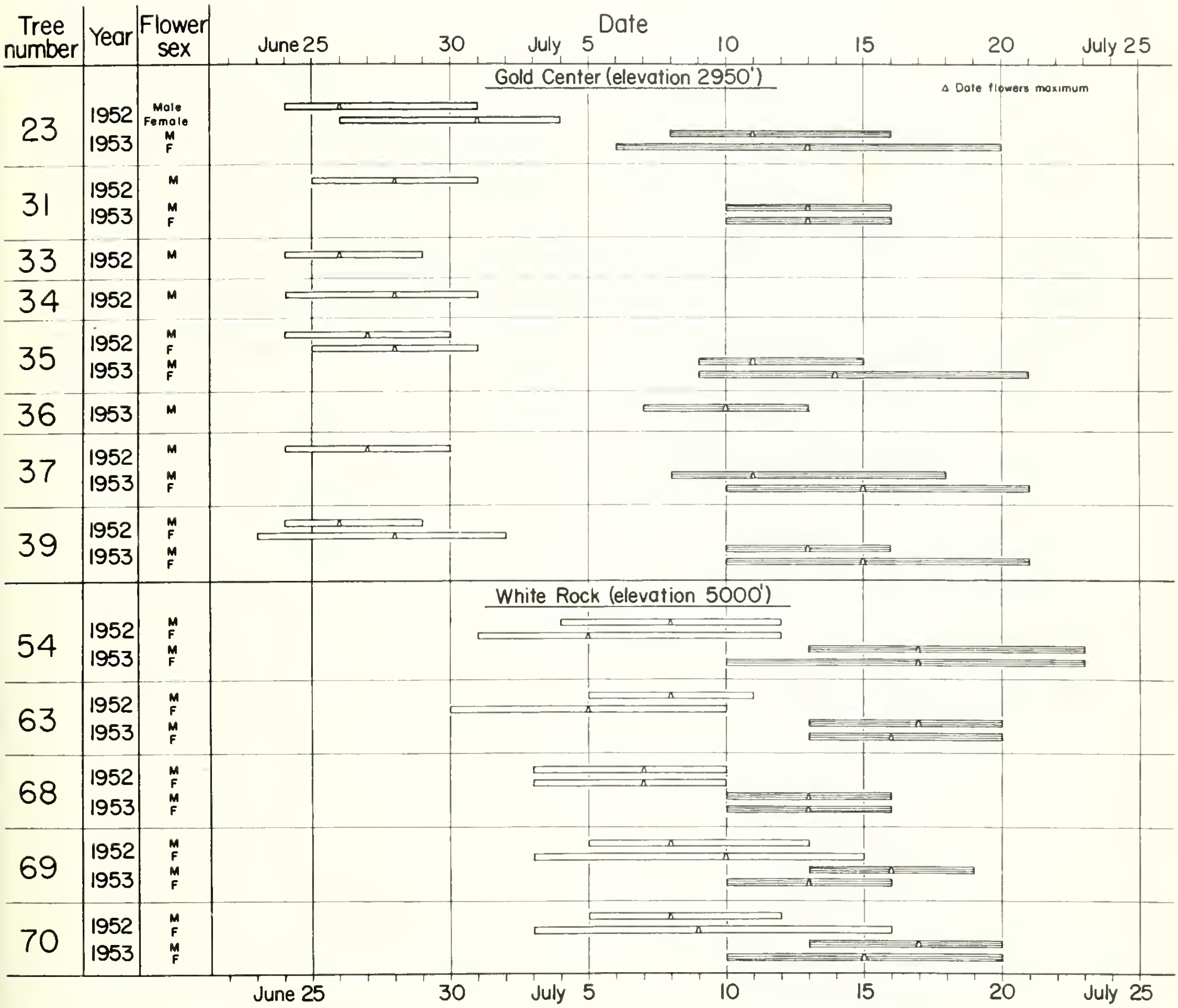


Figure 3.--Time, duration, and maxima of flowering of adjacent low and high elevation areas during an early (1952) and a late (1953) season.

associated with earliness or lateness of individual seasons was telescoped more at the colder, high elevations than at the warmer, low elevations.

The range of latitude sampled in this study (only $1/3^{o}$) did not permit analysis to determine the effect of latitude on time of flowering of P. monticola, but effects of latitude on the time of flowering of a number of other pines have been reported in the literature and are shown in table 1.

Consistency in Sequence of Flowering

The relative consistency in sequence of flowering of individuals of different species in the same locality has fascinated man since ancient times. It is one of the most completely documented phenomena concerning flowering of plants. The order of blooming in forest trees has also received considerable attention (1, 44, 52, 42, 27, and table 1). Consistency in sequence of flowering of individual trees of one species in one locality, or in stands of one species at nearby localities, has received far less attention (table 1) and will be the subject of results and discussion that follow.

Certain individual P. monticola trees were found to be consistently early or late in time of onset of flowering, in respect to other trees in the same locality. The sum of localized microclimatic or hereditary differences holding between different trees in the same locality seemed to have a similar net effect on time of flowering, year after year. Figure 2, plus the bulk of the phenological data plotted in the same manner but not shown, and table 5 serve to bring out this point. Figure 2 shows that the beginning of anthesis and female flowering in trees 25 and 58 occurred a few days earlier than in the average Crystal Creek tree; and that the onset of anthesis and female flowering in trees 24 and 27 occurred a few days later than in the average tree, while similar phenomena in trees 17 and 21 occurred nearer to the average date for the locality. Dates of first anthesis of the 6 trees, during the 6 years 1950 to 1955, were grouped for comparison in table 5. In the three seasons when trees 25 and 58 could be compared with trees 24 and 27, the former pair commenced pollination 5 to 8 days sooner. Since the trees all lie at the same elevation and within one-half mile of each other on the same soil type, and since aspect, stand density, and other visible features of the site apparently were not associated with time of flowering, the authors concluded that the differences in flowering time were mostly heritable.

General observations of this sort have been reported for a number of species (table 1), but the more critical observations of Matthews (26) deserve special mention here. Matthews in making morphological investigations on 11 Larix leptolepis trees, all on flat ground in a 200-foot row, noted that despite environmental uniformity certain of the trees were consistently different in respect to times of first pollen release, maximum pollen release, and first flower receptivity. Hereditary effects were indicated.

Table 5.--Dates of first anthesis in phenologically early, average, or late blooming trees

Tree No.	Phenological group	Date of first anthesis					
		1950	1951	1952	1953	1954	1955
25	Early	June 29	June 20 1/	June 11	June 30		July 2
58		June 29	June 25	June 12	June 30	June 29	July 5
17	Average	June 30	June 25	June 13	July 3	June 30	July 8
21		July 1	June 25	June 9	July 4		July 5
24	Late	July 4			July 6		
27		July 4		June 20	July 6		

1/ Bore only ovulate flowers in 1951; ovulate flowering date substituted.

The sequence of flowering of P. monticola at various localities within a small geographic area was even more firmly fixed. Table 6 shows the sequence in first anthesis at different localities, 1950 through 1955. During 6 years of observation in the 7 localities that lay in the elevational belt between 2,700 and 3,300 feet--Lower Elk Creek, Crystal Creek, Soldier Creek, Middle Fork of the St. Maries River, Upper Elk Creek, Emerald Creek, and Gold Center--the sequence of dates of first anthesis in these localities was in the order just given. It is difficult to appraise the effect of small elevational differences on time of flowering. Lower Elk Creek, for instance, was 300 feet higher than Soldier Creek and 150 feet higher than Crystal Creek, yet was always first in the relative order of flowering. Apparently within small elevational zones local microclimatic differences, other ecological variables, and heredity combined to exert a greater influence on flowering than did elevation.

Year-to-Year Variation in the Time of Flowering

In P. monticola it was noted that within a given locality fairly great year-to-year variation occurred in time of staminate and ovulate flowering (tables 3 and 4). For instance, in Crystal Creek in the 6 years 1950 to 1955 average time of maximum pollination varied between June 19 and July 9 (i.e. between day number 19 and 39, reckoning day number from a June 1 base date). Over the same period maximum ovulate flower receptivity varied between June 20 and July 9. This amounted to a total variation of about 3 weeks in the 6 years. Annual variation in time of flowering of forest trees has been well documented (table 1) and is associated largely with differences in temperature caused by widespread annual climatic variation or with differences in latitude or altitude.

Table 6.--Relative order of flowering at nearby localities

Locality	Elevation	Time of first anthesis by years											
		1950		1951		1952		1953		1954		1955	
		Day[1/]	Relative order	Day	Relative order	Day	Relative order	Day	Relative order	Day	Relative order	Day	Relative order
	Feet												
Lower Elk Creek	3,000			23	1st	14	1st	32	1st	30	1st	36	1st
Crystal Creek	2,850	31	1st	26	2nd	15	2nd	33	2nd	32	2nd	36	1st
Soldier Creek	2,700					17	3rd	36	3rd				
Middle Fork, St. Maries River	2,900	35	2nd			24	4th	37	4th				
Upper Elk Creek	3,300					25	5th	37	4th				
Emerald Creek	3,000							40	5th				
Gold Center	2,950	37	3rd			26	6th	40	5th	38	3rd		

1/ Reckoned from the base date of June 1 (i.e. June 1 = day 1).

In P. monticola, as in many other species, time of flowering in a given year was found to be rather rigidly controlled by temperature of the several weeks immediately preceding flowering. Over 6 years, time of flowering within localities was highly and significantly correlated with average May and June temperatures, as shown in figure 4. The regression equation, Y = 20.3 days - 5.2 days x X degrees F. (i.e. for each degree Fahrenheit that May and June temperatures departed from normal, time of flowering varied approximately 5 days) was calculated to express the relationship.

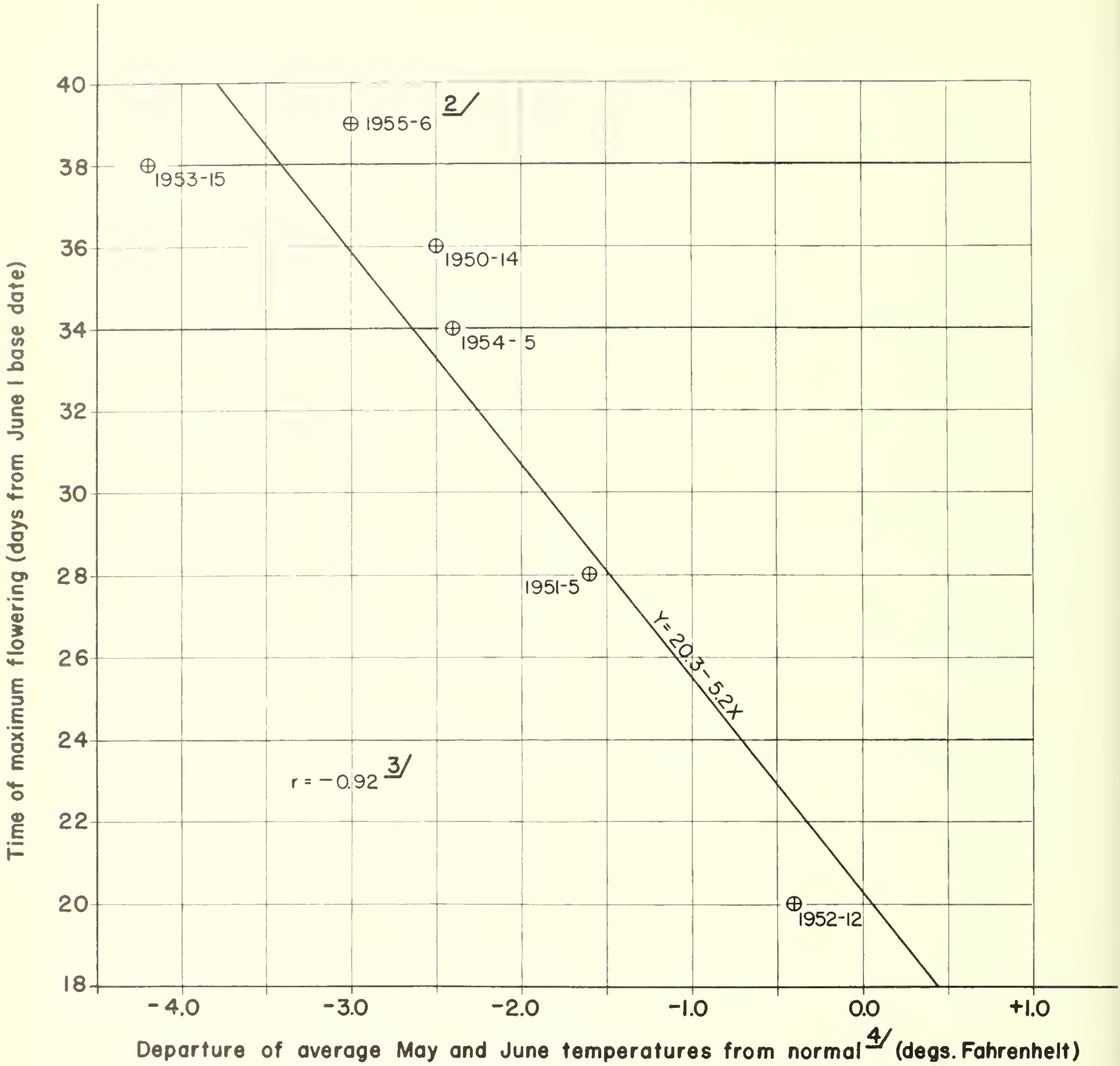
The meteorological aspects of the flowering time of trees in different seasons have been explored by Blendel (7), Dancklemann (11), Osterwalder (34), Lindsey and Newman (25), Misic (30), and many others, by the method of heat summation. Temperature effects have also been appraised by Minshall (29), Duffield (14), Clapper (8), and Scamoni (39). All of these workers have shown that time of flowering was closely associated with temperature.

Timing and Overlap of Periods of Staminate and Ovulate Flowering

During the same season most individual trees within localities were remarkably similar in respect to times of pollen shedding and ovulate flower receptivity. Ordinarily, within a given area, departure of individual trees from the average date of first pollen shedding amounted to no more than 2 or 3 days, rarely more than 4 days. Similarly, all individuals within localities reached the time of first ovulate flower receptivity within a period of 1 or 2 days, rarely more than 3 days (fig. 2).

More important, within most individual trees and individual stands, times of maximum pollination and maximum ovulate flower receptivity were practically coincident, often occurring on the same date, but with maximum receptivity usually occurring about 1 or 2 days after maximum pollination (fig. 2, tables 3 and 4). From a phenological standpoint it appeared that the majority of trees were almost completely self- and cross-compatible.

In order to obtain a quantitative expression of phenological control over either selfing or crossing, the minimum and average numbers of days on which selfing or crossing was possible were computed for the trees in each locality (table 7). It was noteworthy that among 33 trees observed repeatedly through 2 to 6 seasons (on the average of 3 times per tree) not a single instance of complete dichogamy occurred. In individual trees having an average flowering period of 8½ to 9½ days (tables 3 and 4) the observed minimum overlap in periods of pollen shedding and ovulate flower receptivity was 3 days, the average overlap 7 days. Neither were there phenological barriers to crossing, the trees within a given locality being more or less completely crossable in a given season. Among 691 natural crosses that could have occurred within 8 localities in the years 1950 through 1955, in only one instance would a cross (or its reciprocal) have been impossible. Average number of days during which crossing could have taken place within areas was 6 days.



1/ Average of times of maximum staminate and ovulate flowering, Crystal Creek area.

2/ Year and number of trees observed.

3/ Correlation coefficient (r) significant at the 1-percent level of probability.

4/ Average of May and June departures published by the U. S. Weather Bureau, Northern Division, Idaho.

Figure 4.--Relation of spring temperature and time of flowering.1/

Table 7.--Phenological controls on selfing and crossing, by locality 1950 through 1955

Locality	Year	Selfs: Minimum	Selfs: Average	Selfs: Basis	Crosses: Minimum[1/]	Crosses: Average[2/]	Crosses: Basis
		Days		No.	Days		No.
Crystal Creek	1950	4	6.7	12	2	6.1	156
	1951	4	6.0	5	4	5.5	35
	1952	5	9.1	9	[3/] -1	7.1	111
	1953	5	7.2	14	1	5.6	196
	1954	6	7.2	4	4	6.0	16
	1955	8	8.5	6	6	7.9	30
Middle Fork	1950	4	5.5	2	1	5.2	11
	1952	7	7.0	3	7	7.0	9
	1953	9	9.0	2	6	6.0	2
Gold Center	1950	3	4.3	3	2	3.7	14
	1952	6	6.0	3	4	6.0	18
	1953	7	7.8	5	4	6.8	25
	1954	8	8.0	1	-	-	-
Lower Elk Creek	1951	4	4.5	2	4	4.0	2
	1952	8	10.0	3	5	8.7	6
	1953	5	6.3	3	5	5.7	6
	1954	10	10.0	1	-	-	-
	1955	7	7.0	2	7	5.5	2
Emerald Creek	1953	5	5.0	1	2	4.0	2
Upper Elk Creek	1953	4	5.0	2	2	4.6	8
White Rock	1950	7	7.0	1	-	-	-
	1951	4	7.5	2	7	5.5	2
	1952	6	8.0	5	6	8.1	20
	1953	4	7.4	5	4	6.2	20
Total number selfs or crosses				96			691
Total number diff. trees				33			43
Averages			7.1			6.0	

1/ Minimum number of days cross or reciprocal cross (whichever greater) possible.

2/ Average of all possible crosses and reciprocal crosses.

3/ This cross would have failed by 1 day; a tree bearing only pollen had begun shedding 1 day after ovulate flowers closed on one potential mate.

These data strengthen the conclusion of Bingham and Squillace (5) that no major phenological barriers to natural selfing occur in P. monticola. While it is true that the large bulk of pollen is released during a relatively few days (36, 37, and 39) and that in some species a relatively small difference in timing of maximum pollination and ovulate flower receptivity conceivably could limit self- or cross-pollination, this is certainly not true for P. monticola. The overlap in periods of male and female flowering for the average of 7 out of 9 days of the flowering season practically precludes the possibility that none of the ovulate flowers will attain maximum receptivity during the period of maximum pollen flight. Most pines, and for that matter most conifers, seem to be similar in this respect. Table 1 shows that most pines have been found synacmous, or at most only slightly protandrous or protogynous in flowering habit. Notable exceptions occur among introduced conifers--in Larix spp. (23, 24, and 26) and in Pinus mugo and P. tabulaeformis (13)--but nothing was found regarding performance of these species in their natural habitats.

In hardwoods, notably nut trees of the genera Corylus, Castanea, Carya, and Juglans, sterility due to phenological differences in male and female flowering is well documented and deserves special mention (2, 3, 8, 32, 41, 43, 46, 47, and 49). Even so, while Vilkomerson (49), Clapper (8) and Nienstaedt (32) variously noted the existence of protandrous and protogynous individuals in Castanea, Nienstaedt stated that ample overlapping of flowering periods occurred and that dichogamy could not explain the pronounced self-incompatibility frequently observed for the genus. Similarly in pecans, where complete ranges of pollination and ovulate flower receptivity are given (3 and 43), overlapping of flowering periods is seen among certain varieties generally classified as dichogamous. Thus it would seem that in both pecans and chestnuts sterility is at least partly due to other than phenological barriers.

CONCLUSIONS

Duration of flowering in most pines, P. monticola included, is probably somewhat longer than generally believed. Individual pines release measurable amounts of pollen for ½ to 3 weeks, and stands of one species in one locality for 1 to 5 weeks. Onset of flowering is delayed by increasing altitude and latitude, the effects of latitude apparently being more pronounced in continents having "continental" vs. "oceanic" climates (table 1).

Consistent earliness or lateness in the flowering of individual P. monticola trees has been noted. While this is important in timing controlled pollination work, it probably has little effect on the course of natural cross-pollination. Relative order of blooming is strongly fixed by locality and may have some significance in evolution of ecotypes.

Year-to-year variation in time of onset of flowering in pines ranges up to 2½ months, varying with the species and the number of years of observation. Six years' observations of P. monticola produced about 3 weeks' variation in time of flowering, and as with most pines this variation was strongly associated with spring temperatures.

The belief that pines are generally dichogamous has little basis in fact. In most instances where flowering of individuals or stands of one species has been more than casually observed, pines have been found to be synacmous in flowering habit, or at most only slightly protandrous or protogynous. In *P. monticola* stands, and apparently in stands of most other pines, little if any phenological cross-sterility could exist. Self-sterility, where occurring, will have to be explained on the basis of barriers other than phenological.

SUMMARY

In 45 young *Pinus monticola* trees where flowering was closely observed for periods up to 6 years, the following results were obtained:

(1) Average dates of first anthesis at low and high elevations for the species (3,000 and 5,000 feet) were June 27 and July 8, respectively.

(2) The period of pollen dissemination in stands at eight localities averaged 8½ days, the period of ovulate flower receptivity 9½ days.

(3) Very fruitful individuals, due to successive ripening of ovulate flowers, had prolonged flowering periods.

(4) Flowering was delayed about 5 days per 1,000 feet increase in elevation, about 6 days per degree F. departure of May and June temperatures below normal.

(5) At high elevations differences in date of onset of flowering in "early" vs. "late" seasons were smaller than at low elevations.

(6) Certain individual trees were found to be consistently a few days "early" or "late" in time of onset of flowering, in respect to other trees in the same locality. Sequence of flowering between localities was found to be very firmly fixed.

(7) Time of onset of flowering varied over a period of 20 days during 6 years of observations.

(8) Time of flowering in a given year was rigidly controlled by temperature of the several weeks immediately preceding flowering.

(9) Within individual trees and within localities, maxima of pollen shedding and ovulate flowering were for practical purposes coincident. No phenological barriers to either selfing or crossing were found to exist in the 45 trees tested.

(10) Many of the above findings hold equally well for many of the other pines.

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SEEDING-DEPTH TRIALS WITH BITTERBRUSH (*PURSHIA TRIDENTATA*) IN IDAHO

By

Joseph V. Basile and Ralph C. Holmgren
Range Conservationists

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

SEEDING-DEPTH TRIALS WITH BITTERBRUSH (PURSHIA TRIDENTATA) IN IDAHO

Joseph V. Basile and Ralph C. Holmgren
Division of Range Management Research

Bitterbrush (Purshia tridentata (Pursh) DC.), a palatable shrub species, hows promise of becoming useful for artificial browse revegetation on depleted ig-game winter ranges in southwestern Idaho.

As part of a cooperative interagency browse revegetation research program egun in 1949, several test plantings were made to determine optimum depth for eeding bitterbrush. The game ranges on which the plantings were made are oderately steep, south-facing slopes; the soils are loose, coarse sandy loams erived from underlying granite. Winter snows make up two-thirds of the 22-inch verage annual precipitation. Summer rains generally occur as infrequent, highly ocalized thunder showers of short duration. An annual type vegetation predomi-ates, with cheatgrass (Bromus tectorum L.) as the main constituent.

METHODS AND RESULTS

Bitterbrush seed were planted at two or more depths in late fall each year rom 1949 through 1955, with the exception of 1953. Because little was known bout bitterbrush seeding the early studies were exploratory, and the study de-ign varied from year to year. As information was accumulated and newly gained nowledge was incorporated in each succeeding trial, the designs became more omplex. The results from each year's planting are presented below, immediately ollowing the description of method and design for that particular test.

Nonstratified seed were used in all trials. Except for the use of etramine-treated seed in the 1954 and 1955 trials, no special treatment or rotection was given any seed.

Individually Sown Seed

Three Depths

In November 1949, bitterbrush seed from a lot that had shown a viability f 92 percent in the laboratory (excised embryo germination) were planted at hree depths: 1/2 inch, 1½ inches, and 2½ inches. One hundred seeds were lanted singly by hand in each of two plots for each depth. The seeds were ever closer than 3 inches from each other.

Emergence of seedlings occurred in April 1950. Numbers of emerged seed-ings were 41 and 32 in plots seeded at 1/2-inch depth, and 14 and 17 in plots eeded at 1½ inches. No seedlings emerged from the 2½-inch seedings. Emergence was earlier from the lesser depth: over 90 percent of the seedlings that came up from 1/2 inch emerged before April 12, whereas only 58 percent of those from 1½ inches emerged by that date.

During the summer an attempt was made to recover the seeds from spots where seedlings did not emerge. Only 70 seeds were found. Distribution of the recovered seeds and the percentages that apparently had germinated but not emerged were as follows:

	Seeding depth		
Depth	1/2"	1½"	2½"
No. of seeds	27	25	18
Percent germinated	70	84	100

Eight Depths, Two Seed Sizes

In the fall of 1950 the study was repeated using eight planting depths: 0, 1/4, 1/2, 3/4, 1, 1¼, 1½, and 2 inches. Two lots of seed were used, one with large seeds (about 14,500 per pound) and one with small seeds (about 18,500 seeds per pound). Tests by the excised embryo technique indicated viability of these lots to be 89 and 91 percent, respectively. There were two randomized blocks of plots of 50 singly sown seeds for each depth x seedlot combination. The total number of seedlings emerging was about the same for the two seedlots, 123 and 122. Since no significant block or seedlot differences appeared, the results shown in table 1 are data combined from both block and both seedlots.

Table 1.--Emergence and mortality of bitterbrush seedlings from 200 seeds at each of 8 planting depths

	Seeding depth (inches)							
	0	1/4	1/2	3/4	1	1¼	1½	2
				Number of seedlings				
Total emergence	2	48	94	59	21	12	9	0
Emergence before March 27	2	46	60	16	2	0	0	-
Alive in midsummer	0	8	52	42	9	4	6	-
				Percent mortality				
Before March 27[1/]	100.0	71.7	23.3	0	0	-	-	-
After March 27[2/]	-	46.7	35.0	28.8	57.1	66.7	33.3	-

[1/] Percent mortality based on seedlings emerged before March 27.

[2/] Spring and early summer mortality based on seedlings alive on March 27 or emerging subsequently.

The highest rate of emergence in this trial was from seed placed 1/2 inch elow the ground surface. A change of 1/4 inch in either direction from this epth resulted in little more than one-half the number of seedlings produced rom the 1/2-inch depth. Greater deviations from the 1/2-inch depth resulted n progressively lower emergence.

As in the previous trial, emergence occurred earlier from seed planted t the lesser depths. Seventy-five percent of the total emergence from depths f 1/2 inch or less occurred before March 27, whereas only 27 percent of the eedlings from 3/4 inch, and 10 percent of those from 1 inch, had emerged by hat date. This early emergence from depths of 1/2 inch or less was detrimental, owever, in that 45 percent of these seedlings had died before March 27, in conrast with no mortality until that time from seeds planted at depths of 3/4 inch nd 1 inch. Many of the seedlings that died before March 27 had been lifted out f the ground by frost heaving; the remainder appeared to have been frozen. one of the mortality that occurred after that date was attributed to frost.

The month of April was dry: there was no precipitation between March 30 nd April 28. The cause of seedling losses occurring after March 27, except or a few obviously the result of insect damage, was presumed to be this drought, ince most of the mortality occurred during April. Survival through this period as not related to seeding depth.

The wide difference in seedling numbers before March 27 between plots eeded at 1/2 inch and 3/4 inch was materially reduced by midsummer. There as no significant difference in numbers of living seedlings from these two epths on July 9. The original advantage of the lesser depth was lost largely s a result of early-season mortality.

Two Depths, Three Seedbed Conditions

In the fall of 1951, a test was conducted to compare results from seeding epths of 1/2 inch and 1 inch on two sites and with three seedbed conditions. ite 1 is a steep slope (50%) with a residual soil. Site 2, a few rods distant rom site 1, is a gently sloping (20%) alluvial fan. Three seedbed conditions ere created on plots that were (1) relatively undisturbed, (2) scalped, and 3) scalped and leveled.

Ten replicate blocks of five plots each were selected on each site. Ten eeds were sown individually in a 10-inch circular area in the center of each ½-foot diameter plot. One plot in each block represented the first seedbed ondition, in which the plot was disturbed only to the extent required to open en narrow holes 1 inch deep, place a seed in each hole, and press their walls ogether. Two other plots in each block were scalped to provide the second eedbed condition, in which the surface 2-inch layer of soil was removed to estroy the plant cover and remove residual weed seeds, a measure found necesary to minimize competition for soil moisture.[1/] On one of these, seeds were

[1/] Holmgren, Ralph C. 1956. Competition between annuals and young bitterrush (Purshia tridentata) in Idaho. Ecology 37: 370-377.

planted 1 inch deep, and on the other 1/2 inch deep. The remaining two plots in each block were also scalped, and the sloping surface was then made level by excavating the uphill side, pulling the soil out to form a flat shelf about 2½ feet across (third seedbed condition) on which seeds were planted at depths of 1 inch and 1/2 inch. This was done to reduce insolation on the seed spots in late winter and early spring with the intention of delaying the date at which soil temperature favorable for germination would occur. The test was repeated in 1952 on site 1 only, but with both seeding depths on the undisturbed soil as well as on each of the two types of scalped plots.

The average numbers of seedlings that emerged from the variously treated plots in the two years' trials are shown in table 2. In the first year, on both sites and on both forms of scalped seedbed, emergence from the 1/2-inch depth was significantly greater ($P < .01$) than from the 1-inch depth. There were no significant differences ($P > .05$) in number of emerging seedlings as a result of manipulating the slope gradient of the seedbed, however. Unfortunately, it was not possible to get to the plots early enough to determine whether the variation in slope or the difference between sites had any relation to date of emergence, and hence to possible damage by frost.

Table 2.--Average number of seedlings emerging in spring from plots where 10 seeds had been planted the previous fall at 1/2-inch and 1-inch depths

	Undisturbed		Scalped		Scalped and leveled	
	1/2 inch	1 inch	1/2 inch	1 inch	1/2 inch	1 inch
	Average number of seedlings					
	(1952 results from 1951 seeding)					
Site 1	not seeded		1.8	6.8	1.9	6.8	2.8
Site 2	not seeded		6.1	8.4	1.3	9.0	1.2
	(1953 results from 1952 seeding)					
Site 1	5.5	4.7	5.7	3.4	6.9	5.9

On site 1, numbers of seedlings from the 1-inch depth on undisturbed soil were essentially the same as from that same depth on scalped plots. On site 2, on the other hand, there were significantly more ($P < .05$) seedlings from 1 inch on undisturbed plots than from the same depth on either of the two scalped plots. The significant site x seedbed condition interaction might be explained by the difference in texture of the surface inch of soil on the two sites. The soil of site 1 forms a firmer crust than the soil of site 2 as it dries out. The soil of site 2 is similar except that it contains an abundance of very coarse sand particles in the surface inch or so. Presumably the relatively high rate of emergence from undisturbed soil on site 2 reflects the eas h which seedlings could pierce this coarse-textured soil. Removal of this rse-textured layer by scalping exposed a soil similar to that on site 1, l resulted in greater crusting and less emergence.

On site 1 in the second year, seedling emergence was again greater from ' inch than from 1 inch. The differences were not as marked, however, as ey had been the first year; the only significant difference ($P < .05$) between ths appeared on the seedbeds scalped but not leveled.

<u>Seed Spots with Varying Numbers of Seed</u>

Emergence from singly planted seeds apparently is greatest from the 1/2- ch depth, but in some years frost heaving may cause considerable mortality ong seedlings from this depth. Since no loss from frost heaving was observed om plantings at greater depths, it appeared possible to minimize this mortal- y factor by sowing deeper than 1/2 inch and still insure high emergence by ving seeds in small groups rather than singly. To explore this possibility, e following study was conducted.

In November 1954, eight blocks of scalped plots were seeded on each of two tes comparable except for exposure: site 1 faces south and site 2 faces west. ch block contained 48 seed spots, arranged in six rows of 8 each. To each w was assigned at random one of six planting depths ranging at 1/2-inch inter- ls from 1/4 inch to 2-3/4 inches. Each seed spot within a row represented a fferent seed-group size, also assigned at random. Seed groups contained 1, 2, 6, 8, 12, 16, or 24 seeds.

This study was repeated the following year on the south slope only, with sentially the same results.

Frost Heaving

Seeds from 41 percent and 23 percent of the spots seeded at the 1/4-inch pth on the south- and west-facing slopes, respectively, were found heaved t of the soil by frost action before or at about the time germination started. r this reason, results from the 1/4-inch depth are omitted from most of the llowing discussion. Seeds from other depths were not heaved, nor were edlings from any depth.

Pattern of Emergence

Emergence was first noted on March 30, 1955, and plots were examined every to 5 days thereafter during the period of seedling emergence. Initial emer- nce tended to be early at lesser depths and larger group sizes, and progres- vely later at greater depths and smaller group sizes (table 3).

Table 3.--Days after March 29, 1955, when emergence was first noted from seed planted the previous fall in groups of 1 to 24, at five depths, on south and west exposures

Number of seeds in spot	Seeding depths (inches) and exposures									
	3/4		1-1/4		1-3/4		2-1/4		2-3/4	
	S	W	S	W	S	W	S	W	S	W
	Number of days[1/]									
1	9	13	27	27	-	49	-	-	-	-
2	6	18	13	18	27	-	-	-	-	-
4	6	13	9	13	18	23	23	-	-	-
6	6	13	9	13	13	18	23	-	-	-
8	6	9	9	13	13	23	18	-	-	-
12	1	6	6	13	13	13	13	49	30	-
16	1	6	1	9	13	18	23	27	35	-
24	1	6	6	9	9	13	13	27	18	-

[1/] For example, 1 represents March 30; 13, April 11; 27, April 25; 49, May 17.

Each half-inch increment in seeding depth resulted in a delay in date of initial emergence. These delays increase with increasing depth, and probably include the time required for the soil to become warm enough for germination plus the time required for hypocotyl growth through increasing distances. In practically every case initial emergence was later on the west than on the south slope, probably because the daily duration of direct sunlight was shorte on the west.

The more seeds per spot, the more quickly initial emergence was observed. It is notable that the smaller seed spots at greater depths gave no emergence at all.

The pattern shown in table 3 remained relatively constant well into the period of seedling emergence, but was no longer evident by the time emergence was completed. There was considerable variation between treatments in elapsed time between first and last dates of emergence, but this time variation was not related to depth or seed numbers.

Total Seedling Emergence

Total emergence was unaffected by aspect. Of the 384 spots seeded on eac site, seedlings emerged from 134 and 133 spots on the south and west exposures respectively. Distribution of successful spots (those from which one or more seedlings emerged) among the various depth x number combinations was essential the same on the two sites, except that there was more emergence from the great depths on the south exposure than on the west. Spots with 4 or more seeds had emerging seedlings from 2¼ inches on the south-sloping site, while only those ots with 12 or more seeds had any emergence from that depth on the other te. From the 2-3/4-inch depth the only emergence was on the south exposure, d this from spots with 12, 16, and 24 seeds.

Total emergence resulting from the various depth x number combinations e shown in figure 1. The low emergence at 1/4 inch was caused by loss of eds; the seeds in approximately one-third of the spots at this depth were aved out of the ground by frost. The highest emergence rates were, in de-easing order, from the 3/4-, 1¼-, and 1-3/4-inch depths, and the differences tween each of these were highly significant ($P < .01$). Seed planted at the - and 2-3/4-inch depths resulted in a negligible number of successful spots.

The larger seed-group sizes produced more successful spots than the smaller es. Combined data for all depths, except 1/4 inch, show that the greatest ccess was obtained from spots seeded to 24 seeds, followed in order by those which 16, 12, and 8 seeds were planted; each was significantly different from e other ($P < .05$). Spots with 6 and 4 seeds each produced essentially the me results, and these were not significantly different from results obtained th 8 seeds. Spots with 1 and 2 seeds yielded the poorest results.

Seedling Mortality

On each observation date it was noted that some of the seedlings had died nce the previous observation. The rate of loss was heaviest the first spring, on after emergence. Mortality at that time was due largely to moth larvae d damping-off organisms. Subsequent mortality was ascribed mainly to grass-ppers, rodents, and drought. Aspect had a significant effect on mortality, ich was 30 percent after two growing seasons on the south exposure and 62 rcent on the west exposure; the reason for this difference is not known. thin sites, mortality of seedling groups was not related to depth at which ed was sown, to number of seeds per seed spot, nor to any combination of pth and seed number (figure 2).

The average number of seedlings within successful spots was more or less oportional to the number of seeds that had been planted. Seedlings per group nged in number from one per spot to as many as twenty. No evidence was found indicate any relation between original numbers of seedlings within spots d subsequent loss of whole seedling groups; percentagewise, the loss of seed-ng groups was about the same among those with one or a few seedlings as among ose with several.

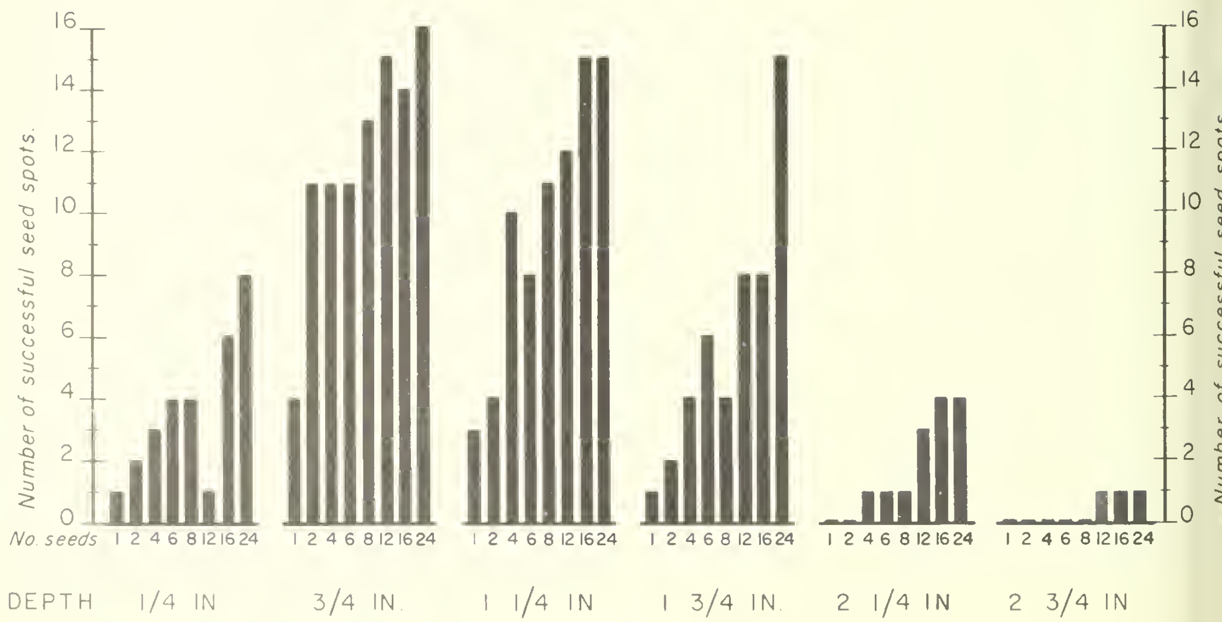

Figure 1.--Number of seed spots with successful emergence of one or more bitterbrush seedlings, spring 1955. Seed spots planted at depths and with number of seeds as indicated in the lower margin. Data from two sites; each combination of depth and number of seeds repeated eight times on each site.

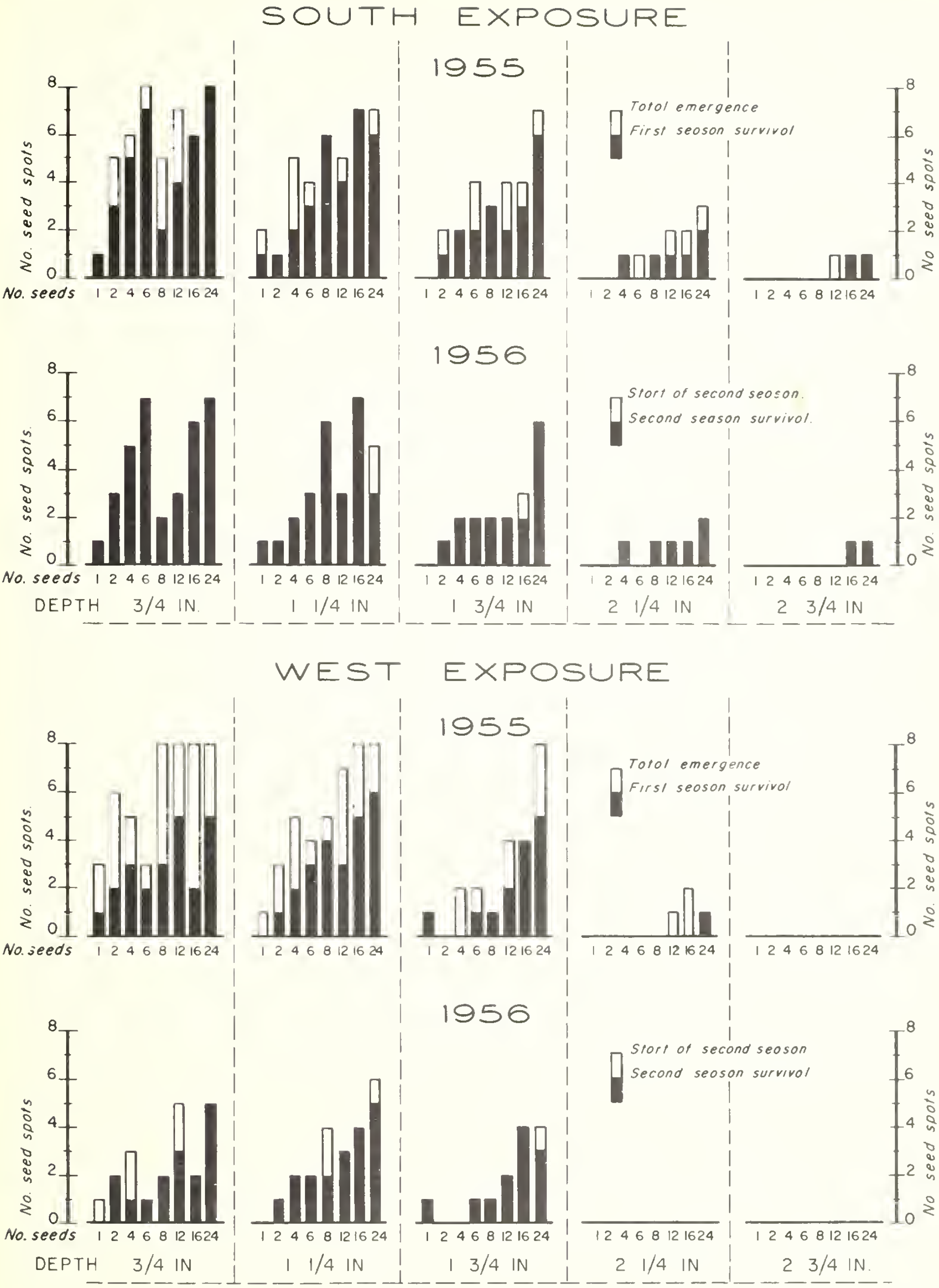

Figure 2.--Seedling survival as shown by number of seed spots with one or more seedlings at beginning and end of first two growing seasons. Each combination of depth seed-group size was replicated eight times on each of two exposures.

SUMMARY AND CONCLUSIONS

Bitterbrush was seeded in the field at two or more depths in five different years. With increasing depth there was increasing delay in date of emergence. This was beneficial in one year, when frost-heaving resulted in loss of some seedlings from 1/4- and 1/2-inch seeding depths, and in three years when many seeds from 1/4 inch were heaved out of the ground before they germinated.

Seedlings from individually placed seeds never emerged from depths of 2 inches or more, although seeds planted singly at 2½ inches appeared on excavation to have germinated.

Where bitterbrush seeds are planted singly, as they are in drill rows, a depth of 1/2 inch probably is optimum for best emergence in the coarse sandy loams of certain southwestern Idaho game winter ranges. In some years frost damage may cause partial loss to seedlings coming from this depth, but the delay in emergence and the resultant protection from frost that can be obtained by seeding at greater depths will probably no more than compensate for the reduction in number of emerged seedlings that accompanies an increase in depth.

Where steep slopes necessitate spot seeding, a seeding depth of 3/4 inch is recommended. From this depth, in three separate years, no seed spots or seedlings were ever damaged by frost. A reduction in number of successfully emerging spots can be expected from this depth, as compared with 1/2 inch, but this can be overcome by increasing the number of seeds per spot. The extra seed is additional seeding expense, but seed costs little compared with labor. Increasing the number of seeds per spot would enhance the success and thereby strengthen the economic feasibility of a revegetation project.

For spot seedings, the most economical way to get seedlings well distributed over the area would appear to be by seeding on small, prepared seedbeds (i.e. scalped areas about 2 feet across) separated from each other by the distance that mature shrubs of the desired stand density would be. Each scalp would contain three seed spots a few inches apart, and each spot would contain 6 to 8 seeds at a depth of 3/4 inch. A larger number of seeds per spot would increase emergence but the accompanying advancement in date of emergence might result in some seedling mortality from frost.

Of course, even with the best emergence considerable mortality can be expected, since seedlings are subject to many adverse factors during their first growing season. Neither seedling mortality nor failure of seed spots after emergence appears to be related to numbers of seed planted, depth of seeding (if deep enough to prevent frost damage), or numbers of seedlings growing together in the same seed spot. Similar studies were reported by Hubbard,[2/] who, in six bitterbrush seeding trials in California, did not find seedling survival to be related to planting depth. It follows, then, that while careful depth control is necessary for maximum emergence, other means of increasing survival must be sought in southwestern Idaho.

[2/] Hubbard, Richard L. 1956. Effect of depth of planting on the emergence of bitterbrush seedlings. Calif. Forest and Range Expt. Sta. Research Note 113.

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SPRUCE SPIDER MITE INFESTATIONS IN NORTHERN ROCKY MOUNTAIN DOUGLAS-FIR FORESTS

By

Philip C. Johnson
Division of Forest Insect Research

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah

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SPRUCE SPIDER MITE INFESTATION IN NORTHERN ROCKY MOUNTAIN DOUGLAS-FIR FORESTS

Philip C. Johnson
Division of Forest Insect Research

INTRODUCTION

Epidemic infestations of the spruce spider mite, *Oligonychus ununguis* Jacobi) (Acarina: Tetranychidae), with attendant severe host tree damage ere observed early in August 1957 in Douglas-fir stands on the western lopes of the Big Belt Mountains east of Helena, Montana, and within the elena National Forest. Subsequent surveys employing aerial observation nd ground examinations disclosed other extensive infestations of the mite n various parts of Montana and southern Idaho. The sudden appearance of hese infestations over such wide areas, the apparent severe nature of the ite feeding on the host trees, and the seeming relationship between the ccurrence of the mite infestations and large-scale operations to control he spruce budworm (*Choristoneura fumiferana* (Clem.)), occasioned consider-ble interest and some concern among foresters and timberland owners in the ffected areas.

Because of this unusual occurrence it is considered timely to present nformation on this particular species. The material presented has been ssembled from scattered published and unpublished references, from the reely offered experience of several acarologists and entomologists, and rom field observations of the 1957 mite infestations.

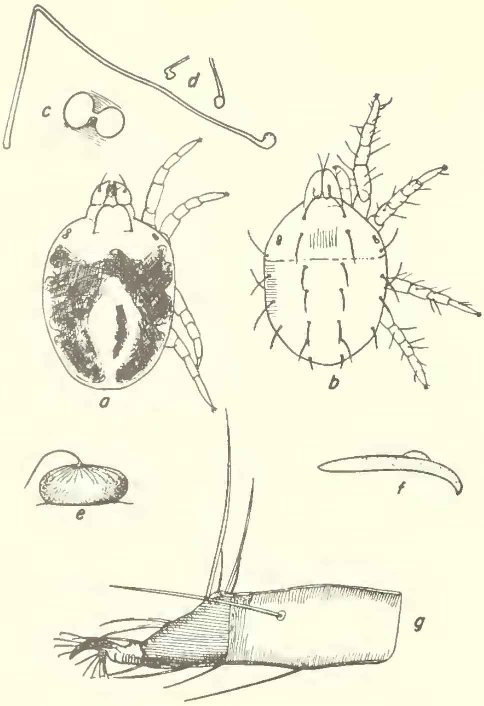
THE SPRUCE SPIDER MITE

DESCRIPTION

The spruce spider mite is an arthropod belonging to the class Arach-nida which includes the 8-legged spiders, scorpions, mites, and ticks. It is not an insect, which is a 6-legged arthropod belonging to the class Hexapoda.

The spruce spider mite has been recognized in entomological literature under several synonyms: *Tetranychus ununguis* Jacobi, 1905; *Paratetranychus ununguis* Zacher, 1913; *Oligonychus ununguis* Hirst, 1920; *T. uniunguis* Ewing, 1917; *Neotetranychus uniunguis* McGregor, 1919; *P. uniunguis* McGregor, 1950; *O. americanus* Ewing, 1920; *P. americanus* McGregor, 1950; *P. alpinus* McGregor, 1936; and *P. pini* Hirst, 1924 (17).[1/]

1/ Numbers in parentheses refer to LITERATURE CITED, page 13



The life stages of the spruce spider mite consist of egg, larva (provided with three pairs of legs instead of four), two nymphal stages, and the adult. Adult mites are oval, 8-legged animals, sparsely covered with long setae, and have piercing and sucking mouthparts. The body appears dark green or nearly black except for a middorsal pale streak (fig. 1). The propodosoma and legs are flesh-colored and the eyespots are conspicuous. Coloration of the male and female is similar.

Figure 1.--Oligonychus ununguis (Jacobi). a. Adult female color pattern. b. Adult female, dorsal view showing spines. c. Eyes. d. Collar tracheae. e. Egg in lateral view. f. Penis. g. Tarsas I. All greatly enlarged. (Courtesy Connecticut Agricultural Experiment Station.

The adults are small, their average length being 0.40 mm. for females and 0.32 mm. for males; average width at widest portion 0.25 mm. for females and 0.15 mm. for males. They are scarcely visible to the naked eye except when they move about fairly rapidly over the host plant (3, 11).

The globular, shiny eggs are amber colored (pale when first laid), sometimes reddish, depressed or flattened, striated on the sides, and have a central single hair or seta. Viewed dorsally, the egg diameter averages 0.15 mm.

The newly hatched larva is very uniformly flesh-colored, later turns to a dark green. The larva is 6-legged.

Both nymphal stages (protonymph and deutonymph) resemble the adult mite in general size, shape, and color.

LIFE HISTORY

The life history of the spruce spider mite as reported by Garman (10) and by Peterson and Hovey (16) agrees with that made from observations in Montana in 1957, as interpreted by Morgan.[2/] The mite overwinters in the egg stage, with winter eggs being laid singly, or in masses, on the lower surface of the Douglas-fir twigs. Eggs begin to hatch in late April, the date depending upon air temperatures. Several mite generations develop throughout the summer. Individual summer generations develop rapidly, sometimes with as few as 14 elapsed days between egg and adult stages. As a result, overlapping of summer generations is a common occurrence.

All active stages feed on the host plant and spin a very fine web. Some observers have noted heavy webbing by the spruce spider mite on the twigs and among the needles. Webbing on Douglas-fir did not appear abundantly in most of the infested foliage examined from the Montana outbreak of 1957. Occasional samples exhibited fairly abundant webbing.

Winter eggs are deposited on the fir twigs during the period July through September. By the end of October few adult mites are still alive.

HOSTS

The spruce spider mite is a pest of coniferous forest trees and certain ornamental evergreens. It has damaged spruce trees in Canada (5), spruce, red pine, and cedars in Connecticut (10, 11), and pine in Ohio (14). In 1930 an outbreak of this mite killed a large number of lodgepole pine trees in eastern Oregon (6). It has been identified on Douglas-fir Christmas trees in British Columbia and Alberta,[3/] and in northern Idaho, Montana, and Colorado but without any evident damage.

The favorite hosts of the mite are reported by Pritchard and Baker to be *Juniperus*, *Cupressus*, *Thuja*, *Chamaecyparis*, *Libocedrus*, and *Picea*; also it has been collected from redwood and sequoia in California (17).

Mature Douglas-fir trees along the Madison River in Yellowstone National Park, Wyoming, became heavily infested by the spruce spider mite in 1929, but the infestation declined in 1931 with no significant tree mortality. Other infestations, presumably by the same mite, were recorded in 1929 on Douglas-fir

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2/ Verbal confirmation by C. V. G. Morgan, acarologist, Fruit Insect Section, Science Service Laboratory, Canada Department of Agriculture, Summerland, B. C.

3/ Confirmation of Canadian occurrence records was supplied by correspondence from technicians of the Laboratories of Forest Biology, Science Service, Canada Department of Agriculture at Vernon, B. C., and Calgary, Alberta, Canada.

trees at Jackson Hole, Wyoming, and on spruce trees between West Thumb and Old Faithful in Yellowstone National Park, Wyoming (7, 9). These constitute the first records of Douglas-fir forests as a host of the spruce spider mite

The host in the known forest outbreaks of the mite has been blue, or Rocky Mountain, Douglas-fir, Pseudotsuga menziesii var. glauca (Beissn.) Franco. No mite outbreaks have thus far been recorded from forests of typic or Coast, Douglas-fir, P. menziesii var. menziesii (Mirb.) Franco.

INJURY

External evidence of mite damage to Douglas-fir host trees is almost wholly limited to foliage discoloration, or chlorosis, caused by the mites' feeding on needles. The spruce mite feeds voraciously in the larval, protonymphal, deutonymphal, and adult stages. All are equipped with sucking mout parts consisting, in part, of short, minute stylets that are inserted into t epidermal and palisade cells of the fir needles. Mites extract the chlorophyll content of these cells and use it as primary food. Inasmuch as the chlorophyll is not replaced, the cells die. If enough cells are thus destro ed, the needles die.

Chlorosis develops on the needle surface at the point of feeding. If mite feeding is not too severe, undamaged needle surface areas having a norm green color will be interspersed with chlorotic areas, giving the needles a mottled coloration. Acarologists commonly refer to this as "salt and pepper mottling. Tree crowns containing these needles, even in abundance, are only slightly discolored. The function of the needles is not greatly impaired, a damage to the tree may be restricted to a small reduction in radial and long tudinal increment for the year.

When needles are entirely yellow or buff colored from very heavy mite feeding, they may die and drop from the tree. Partial loss of foliage in th manner causes severely reduced increment, and complete foliage loss may caus death of the tree. Mites are fully capable of killing trees in this manner, but to date such killing of Douglas-fir has been insignificant.

In the 1957 infestation of the spruce spider mite in Montana, 464,800 acres of Douglas-fir forest showed only the mottled, or "salt and pepper," type of damage indicative of light to moderately heavy feeding. An estimated 334,000 acres were entirely discolored by very heavy mite feeding. Th eventual tree mortality, if any, from this feeding is yet to be ascertained.

Symptoms of mite damage in the Montana outbreak appeared with simultane ous suddenness everywhere throughout the 798,800 infested acres. The host tree damage appeared to have developed more heavily in dense, even-aged, immature fir stands, but many adjacent stands having similar characteristics were not damaged. The outbreak was composed of numerous, scattered, localiz infestations made up from those containing only a few mite-damaged trees to those where all the trees were damaged on areas up to 1,000 acres or more.

Accompanying the needle chlorosis are other symptoms that are not direct-y indicative of host tree damage, but that serve mainly to substantiate the resence of the spruce spider mite. These are the meager though sometimes bundant webbing on the twigs and needles, the dirt and filth on the twigs and eedles usually associated with spruce spider mite activity, cast larval and ymphal skins, the shells of hatched, or predatorized eggs, and summer or win-er eggs. Twigs and needles on infested trees along unsurfaced roads are fre-uently coated with dust enmeshed in the webbing.

Associated with spruce spider mite damage is a probability of increased usceptibility of pole- or sawlog-size host trees to attacks of the Douglas-ir beetle, Dendroctonus pseudotsugae Hopk. Trees weakened physiologically, s from mite-caused chlorosis, may be attacked and killed by the beetle more requently than healthy trees. Under favorable conditions, the subsequent illing of mite-damaged trees by the beetle could result in greater economic oss than the loss of increment or tree mortality directly attributable to he mite.

SPRUCE SPIDER MITE INFESTATIONS

OCCURRENCE

Four epidemic outbreaks of the spruce spider mite have been recorded in ocky Mountain Douglas-fir forests. These include the outbreak in Jackson ole, Wyoming, in 1929, about which little is known; that along the Madison iver in Yellowstone National Park, Wyoming, in 1929; one in Colorado in 1949; nd the most recent one in several national forests in Montana and Idaho in 957.

The Madison River outbreak of 1929, reported by Evenden (7), resulted in ather severe tree injury from very large numbers of what was erroneously dentified as the clover mite Bryobia praetiosa Koch.[4] He recorded the ter-nination of the outbreak in 1931 from natural causes (9). The mite-infested rea was contiguous to a narrow strip of lodgepole pine forest 150 yards x 10 niles previously sprayed with lead arsenate[5] by ground equipment to control lamaging infestations of the lodgepole sawfly, Neodiprion burkei Midd., and the pine tube moth, Argyrotaenia pinatubana Kearf. (2). This spraying was done luring June and July in 1924, 1925, 1926, and 1927 in the pine strip extending from West Yellowstone, Montana, to Madison Bridge. The mite infestation in 1929-31 was centered near the bridge and probably covered no more than 1,000

4/ Evenden in his 1943 report refers to this mite species as Oligonychus amercanus Ewing (obviously a typographical error and meant to be O. americanus Ewing), now synonymous with O. ununguis (Jacobi).

5/ Powdered arsenate of lead, 3,800 pounds; fish oil, 140 gallons; and water, 60,800 gallons.

acres. Evenden states (8) that, "This is the first record which we have of this pest becoming a serious enemy of forest trees. Though the foliage of the infested trees was severely injured, no control measures were recommended due to the expense of the operation, and because it was believed no permanent damage to the trees would follow."

An outbreak near Evergreen, Colorado, in 1949 covered 100 acres of Rocky Mountain Douglas-fir. The area had been aerially sprayed with DDT[6/] in 1948 to control an infestation of the Douglas-fir tussock moth, Hemerocampa pseudotsugata McD. Chlorosis from mite feeding was severe, but no tree mortality was reported as a result of the outbreak which lasted one year.[7/]

Another outbreak, presumably by the spruce spider mite, occurred in 1956 in the Lincoln National Forest near Lost Lodge, New Mexico. The mite infestation covered 50 acres in a Douglas-fir stand sprayed for spruce budworm control in 1955. The outbreak continued unabated in 1957, but no tree mortality occurred in either year.[8/]

The spruce spider mite infestations of 1957 were by far the most extensive and the most spectacular in the suddenness of their appearance, their probable over-all effect on the infested fir forest, and their possible impact upon future forest insect control policies involving use of certain insecticides. These infestations were scattered in several large blocks of the Helena, Lewis and Clark, Deerlodge, and Beaverhead National Forests in Montana and of the Boise and Payette National Forests in Idaho. The Montana infestion in 1957 covered areas totaling about 798,800 forested acres, all of which were part of 885,000 acres of Douglas-fir type treated by aerially applied DDT insecticide[9/] in July 1956 for control of the spruce budworm.

The 1957 mite infestations in Idaho totaled 22,000 acres, all of which were a part of 476,000 acres of fir forests sprayed with DDT for spruce budworm control in 1956.

6/ Technical DDT, one pound; auxiliary hydrocarbon solvent, 1.25 quarts; and #2 fuel oil to make one gallon at 60°F. Applied from airplanes flying fr[om] 200 to 400 feet above the forest canopy as a mist, with particle size from ab[out] 150 to 250 microns, at the rate of one gallon of mixed insecticide when the ma[jority] of the budworm larvae were in the 5th and 6th instars to achieve 95+ percent budworm mortality.

7/ Confirmed in correspondence from Dr. N. D. Wygant, entomologist, Rock[y] Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Fort Collins, Colorado.

8/ Confirmed by Dr. Calvin L. Massey, entomologist, Rocky Mountain Fore[st] and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Albuquerque, New Mexico.

9/ See footnote 6, above.

Some spruce spider mite damage, extent unknown, was observed in August)57 on Douglas-fir trees within spruce budworm control units aerially sprayed .th DDT in July 1955 in Yellowstone National Park, Montana-Wyoming, and on ıe Boise and Payette National Forests, Idaho.

The spruce spider mite increases in numbers during hot weather and becomes ıite damaging to host plants during periods of drought. During such times it ɔpears to escape the population-inhibiting influence of predaceous mites and ısects.

Severe infestations may also build up following the spraying of host trees .th DDT to control insect pests. DDT is not toxic to the spruce spider mite. ɔme acarologists have hypothesized that DDT may even affect the reproduction ɔtential and the living habits (4) of the mite or cause physiological changes ı the sprayed tree which increases its desirability as a mite host. DDT is .ghly toxic to the predaceous typhlodromid mites and to the primary insect :edators of the spruce mite.

The spruce spider mite infestations in Montana and Idaho apparently devel-ɔed in 1957 as the combined result of (1) the killing of the predators by DDT ɔraying in 1956, (2) the occurrence of an unseasonably warm May in 1957 that ɪvored the rapid development of spruce spider mite populations, and (3) ade-ıate food in the form of extensive pure stands of dense Douglas-fir forests. ıe mite outbreak in Yellowstone National Park in 1929 may also have occurred ɔllowing the previous use of an insecticide which, too, killed the mite pred-:ors, although this probably was not recognized as a possible cause of the ıtbreak at that time.

Assuming that the spruce spider mite infestations of 1957 in Montana and laho were related to the aerial use of DDT for insect control in Douglas-fir ɔrests, it was the first recorded widespread occurrence on 7 million acres of .r forests in the western United States similarly treated with DDT between)47 and 1956.

DURATION

Duration of epidemic outbreaks of the spruce spider mite in Douglas-fir ɔrests cannot be forecast accurately until additional experience is gained or ıtil more is known of the factors governing their occurrence. The outbreak ɜported at Yellowstone National Park lasted 3 years, but foliage damage was ɔnfined to the first 2 years. No record is available of the duration of the ɪckson Hole outbreak, but it apparently was short-lived since mention of it ıs made only in 1929. The outbreak of 1949 in Colorado subsided after one ɜar.

It appears that natural outbreaks, or those following single applications : certain insecticides nontoxic to the spruce spider mite, may not persist for ɔre than 1 or 2 years. Successive insecticide applications for insect pests ı fir forests could conceivably maintain a prolonged mite outbreak if the ɔplications were spaced at 2-year intervals or less and if environmental fac-ɔrs favored the increase of the mite.

It may be possible to forecast the duration of a mite epidemic for one additional year by measuring the abundance of winter eggs during the period September to April. The relative abundance of eggs and their viability might serve as a guide in determining whether mite infestations will be light or heavy the following summer. No studies have been made yet to correlate the abundance of winter eggs with the amount of resultant host tree damage that might result.

Viable eggs can be recognized by their turgidity and uniform color. Par tially deflated or colored eggs indicate that predators have fed upon the con tents. Inasmuch as such eggs will not hatch, abundance of them would indicat a downward trend or possibly even the termination of an existing mite infes- tation.

NATURAL CONTROL

Spruce spider mite populations usually are maintained at endemic levels by normal weather conditions and by the effectiveness of several insect and acarine predators. Spruce spider mite populations develop more rapidly in th presence of drought conditions and where the host plants grow in dry sites or on poor soil. Absence of these conditions undoubtedly tends to keep popula- tions at levels low enough to prevent host plant damage. Peterson and Hovey (16) report that extreme temperatures, strong winds, heavy rains, and very hi humidities help to check the increase in spruce spider mite populations.

Among the most effective predators are (1) the predaceous mites of the genus Typhlodromus (Acarina: Phytoseiidae), (2) the ladybird beetle Stethorus picipes Casey (Coleoptera: Coccinellidae), (3) a small gall midge (Diptera: Cecidomyiidae), and (4) minute pirate bugs (Hemiptera: Anthocoridae). Typh- lodromid mites were collected early in November from parts of the 1957 Montan spruce spider mite infestation. Their presence indicated that populations of these predaceous mites were reestablished following their supposed decimation by DDT insecticide in 1956.

APPLIED CONTROL

WASHING

Infestations of the spruce spider mite can be easily controlled on orna- mental evergreens during the summer where water under pressure is available. Thorough washing of the foliage of infested trees with a forceful solid strea of water will break up the webbing and wash the mites away (15). Several rep titions of the treatment may be necessary.

Washing is believed to effect mite control in two ways: (1) by the sepa ration of the pest and its host and (2) by the breaking up of the webbing whi gives predaceous mites and insects freer access to the residual spruce spider mites (4).

CHEMICALS

Most of the contemporary insecticides are ineffective in controlling pider mites. In fact, the use of certain of these killing agents often fos-ers mite outbreaks by destroying the insect and acarine predators. A number f chemical formulations have been developed, however, that are effective mite illers, or acaricides.

The organic phosphates such as TEPP, parathion, and malathion[10/] were dopted as acaricides soon after their introduction. Their repeated use on ome agricultural crops, however, has resulted in the appearance of phosphate-olerant strains among certain mite species. This required a new approach to ite control and led to the development of nonphosphate acaricides.[11/] These enerally have proved highly effective in controlling mite infestations. Col-ectively they are called "selective miticides" inasmuch as they are highly oxic to mites but not to insects. For this reason, their use is not harmful o beneficial insects among which are bees and numerous insect parasites and redators. The nonphosphate acaricides are also noted for their persistency, or their relative low toxicity to man and other warm-blooded animals, and for he fact that they have not induced any resistance to them by various species f spider mites (18, 19, 20, 21).

Certain of the nonphosphate acaricides,[12/] in addition, can prevent mite utbreaks because of their specific toxicity to mite eggs and nymphs. They re less effective against adult mites.

Chemical control of the spruce spider mite on ornamental plants can be ccomplished easily with any of the standard acaricides. Not only are they ufficiently toxic, but they can be applied at the recommended dosages from he ground by garden type or commercial spraying equipment to infested plants hat are ordinarily accessible (15, 16, 20). Neiswander (15) reports the dust-ng of 46 acres of a nursery in Ohio by airplane in 1951 to control spruce pider mite infestations on arborvitae, spruce, juniper, and yew ornamental lants. Good control was achieved by applying a 10-percent Ovotran dust from he air at the rate of 30 to 35 pounds per acre.

The prevention or control of extensive forest infestations of spruce pider mite by chemicals, on the other hand, presents some problems which may rove difficult to overcome. One of the more obvious obstacles is the compar-tive inaccessibility and the rough topography of many of the Douglas-fir for-sts of the Rocky Mountains. These characteristics effectively preclude the

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10/ To avoid using long and complicated technical names of insecticides nd acaricides, the common names of these materials are used here from the ist compiled by the Committee on Insecticide Terminology of the Entomological ociety of America for use in the JOURNAL OF ECONOMIC ENTOMOLOGY (Haller, H. L. 957. Common names of insecticides. Jour. Econ. Ent. 50(2): 226-228).

11/ Aramite, Chlorobenzilate, Dimite, Kelthane, Sulphenone, and others.

12/ Ovex (Ovotran, Estomite, etc.), Mitox, Genite, Tedion, and Fensone.

application of acaricides from the ground. Their application from aircraft has so far appeared impractical because of the high dosage rates of most present day acaricidal formulations. Many of these formulations have been designed for use in ground spraying or dusting equipment to control mites in fruit orchards. Most of them are aqueous suspensions requiring the spraying of 600 to 1,200 gallons of formulated mixture per acre. This per acre dosage usually contains from 3 to 20 pounds of the 15- to 18-percent wettable powder form of the acaricidal toxicant. These formulations obviously are unsuited for dispersal by aircraft.

Oil solutions appear to be more suitable to application by aircraft. Brown (1) states that

> When wettable powders are applied in aqueous suspensions of approximately 0.1% concentration, the amount required for adequate coverage is of the order of 100 gal/acre, varying according to the crop. When the insecticide is applied in oil solutions from aircraft, in concentrations of approximately 5%, an area dosage of about 2 gal/acre is sufficient; a similar result may be obtained if concentrated suspensions are employed....Increasing fineness of atomization...and decreasing volatility of the carrier, allow even smaller amounts to achieve adequate coverage on foliage.

Each of the known forest infestations of the spruce spider mite has been short-lived. Applied control measures, even if available, probably would not have shortened their duration. The damage to the forest, even during such short periods, can be great enough, however, to consider seriously means of preventing these mite outbreaks with the use of acaricides.

Since the origin of spruce spider mite outbreaks appears to be associate with the use of certain aerially dispersed insecticides, principally DDT, for forest insect pest control, it has been suggested that insect control and spider mite prevention be combined in one operation. This might be done by the addition of acaricidal chemicals to the insecticide used for insect control. The development of a combination acaricide-insecticide for aerial dispersion must necessarily involve a number of considerations, several of which are listed:

1. Acaricidal and insecticidal materials should be tested in the laboratory and under field conditions to determine their respective toxicity to the spruce spider mite and to the insect pest in question.

2. Both materials should exhibit compatibility with each other and with solvents or other ingredients of the formulation.

3. The formulation must be capable of dispersion as a mist with spray systems now in general use for forest pest insecticides.

4. The formulation probably should not exceed the acute oral toxicity o DDT for warm-blooded animals or the median lethal water concentration of DDT for fish, and should be less if possible.

5. Phytotoxicity of the formulation should not exceed that of the stand-rd DDT-oil solution now used for forest insect aerial spraying.

6. Dosage of the formulation should achieve the desired mite and insect ill with a single application,if possible, of no more than 1 gallon per acre.

7. The acaricidal element of the formulation should embody residual oxicity.

8. The cost of the acaricidal additive should not make the cost of the ormulated mixture uneconomical for forest pest control.

The above considerations are for situations requiring the continued use f insecticides that have demonstrated an association with followup spider ite outbreaks. The problem of preventing these outbreaks might be solved ore simply by using insecticides for forest pest control that do not encour-ge subsequent mite activity. This can only be done when such toxicants are eveloped.

SUGGESTED STUDIES

The increasing widespread use of aerially dispersed DDT insecticides or forest pest control has revealed what appear to be isolated instances of emporary disturbance in the natural balance of forest fauna. Some of it is haracterized by the upsetting of the host-predator relationships of some conomically important pests. Development of spruce spider mite infestations ollowing spruce budworm control operations in Douglas-fir forests may be one xample of such a disturbance.

The present outbreak of the spruce spider mite suggests that it is ossibly a potentially serious forest pest capable of causing intolerable ncrement loss or significant tree mortality in fir either by itself or from ollowup attacks of the Douglas-fir beetle. Until more definite knowledge s obtained about the capabilities of the mite as a pest, there will be some oncern about continued use of some aerially dispersed insecticides in pest ontrol programs.

Needed information probably will come from research on spruce spider ite epidemiology involving such studies as the following:

(1) The recognition of, and the ability to measure, endemic and epi-emic populations of the mite.

(2) The amount and nature of the host tree damage caused by various opulation levels of the mite.

(3) The factors associated with the occurrence of epidemic mite opulations.

(4) The development of feasible applied techniques to prevent or ontrol mite infestations in the forest.

In addition, continued study is needed to determine the toxicity of acaricides to the spruce spider mite, the acute toxicity levels of these materials to terrestrial and aquatic fauna of the forest and to man, and the adaptability of their formulations to present forest aerial spraying technique.

SUMMARY

Infestations of the spruce spider mite in Douglas-fir forests had been little-known prior to 1957. In this year scattered mite infestations were reported on nearly 800,000 acres of Douglas-fir forests in Montana and 22,000 acres of similar forests in southern Idaho. The infested forests were part of 885,000 acres of Douglas-fir forest type in Montana and 476,000 acres in southern Idaho that had been aerially sprayed with DDT in 1956 to control infestations of the spruce budworm.

Spruce spider mite biology and life history are described from literature, unpublished experiences of consultant entomologists and acarologists, and from field observations in 1957. The cause and extent of host tree chlorosis resulting from mite feeding is discussed. What appears to be a relationship between the use of DDT in forest insect control and the subsequent appearance and duration of spruce spider mite infestations is noted.

Acarine and insect predators are shown to be effective in the natural control of spruce spider mite populations. The use of certain nonphosphate acaricides in combinations with insecticides is suggested as a means of acco plishing control of existing forest insect infestations and preventing follo up spider mite outbreaks. The possibility of using insecticides that do no foster subsequent mite activity is also mentioned.

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EFFECTS OF STOCKING ON SITE MEASUREMENT AND YIELD OF SECOND-GROWTH PONDEROSA PINE IN THE INLAND EMPIRE

By

Donald W. Lynch
Forester

(A Dissertation submitted in partial fulfillment of the requirements for the Degree of Doctor of Forestry in the School of Forestry of Duke University.)

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah
Reed W. Bailey, Director

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EFFECTS OF STOCKING ON SITE MEASUREMENT AND YIELD OF SECOND-GROWTH PONDEROSA PINE IN THE INLAND EMPIRE

By

Donald W. Lynch

INTRODUCTION

To a forester, the term site embodies an appraisal of all the environmental factors of an area that combine to determine its productive capacity for a specific forest species. Since the term reflects the influence of many variables, the more important of which are soil, moisture, temperature, and length of growing season, the measurement of site has proved to be complex and often inaccurate.

Site has been evaluated, for example, on the basis of the soil profile alone by correlating certain soil properties with the measured success of a tree species growing thereon. To the degree that soil characteristics reflect the combined influence of the many factors of the environment, they are valuable in delimiting divisions of productivity. The success of the edaphic approach has varied with locations and species.

Another method of site evaluation has been the use of plant indicators--ground species that have been found consistently associated with a particular quality of forest growth. A thorough knowledge of the ecology of plant associations is, of course, essential to the success of this method. Because of the variability and complexity of plant associations, only broad divisions of site quality are usually expressed, using such descriptions as "good," "medium," or "poor." Both the soil and the plant indicator methods of forest site appraisal are especially useful on areas that do not at the moment support forest growth or which support uneven-aged or disturbed stands.

On areas where even-aged, undisturbed stands of timber are growing, the direct measurement of forest growth has been by far the most used and most dependable index to site quality. The one measure of growth found to be most independent of stand factors and consequently most reliable for site evaluation has been height of the dominant stand in relation to its age. The relationship of height and age has been expressed in the familiar term "site index," which refers to the height in feet of the dominant stand at a chosen index age--commonly 50 years, but in ponderosa pine, 100 years. Thus the well-known family of site curves has evolved which shows dominant heights over a range of age for each of several site indices.

Foresters realize, however, that site index is not a panacea for site evaluation under all conditions. They read site index to the nearest foot, but they know that it is not that accurate; an unknown error must be accepted because of the many undetermined variations such as stand density, genetical strain of the species, insect and disease depredation, and ground fires. One of the most important of these variables and one that can be measured is stand density.

Dominant stand height has commonly been considered rather independent of stand density and therefore reliable as a measure of site quality. Forestry literature abounds with references to this independence of height to stocking for many species and conditions. Yet, many other examples have been reported where stand density has either stimulated or retarded height growth. Among those species that have exhibited this phenomenon is ponderosa pine (*Pinus ponderosa* Laws.). Observations of ponderosa pine in the Pacific Northwest, by the writer and by others, have confirmed the fact that dense stocking materially reduces height growth on poor sites and that this reduction is sufficient to impair the accuracy of site quality measurements.

The first objective of the present study is to show the magnitude of the effects of stocking on the height of ponderosa pine and to develop adjusted site index curves for use in stands having various degrees of stocking. The proper evaluation of site is basic to the prediction of forest yields--one of the foremost problems in forest management.

The second objective of this study is to present a method of growth prediction for second-growth ponderosa pine which is especially applicable to understocked stands.

HEIGHT AND STAND DENSITY--A REVIEW OF LITERATURE

The commonly accepted fact that dominant stand height is quite independent of stand density is supported by several well-designed spacing studies for several forest species. Bramble et al. (1949) reported a study of planted red pine (Pinus resinosa Ait.) in Pennsylvania on a good site. Planted at four spacings ranging from 5 x 5 feet to 10 x 10 feet, the dominant stands were the same height after 2 years. No indications of stagnation occurred regardless of spacing. Ware and Stahelin (1948) made similar observations on plantations of three southern pines, slash pine (Pinus elliottii Engelm.), loblolly pine (Pinus taeda L.), and longleaf pine (Pinus palustris Mill.) in Alabama where seven spacing treatments ranged from 4 x 4 feet to 16 x 16 feet. Although considerable differences in volume growth and products were apparent in stands having different spacings after 14 years, height of dominant trees was not affected. Here again, the site index was high and tree dominance well expressed throughout.

Slash pine was experimentally planted in Louisiana at the rate of 250, 1,150, 1,600, and 2,500 tre to the acre, and after 14 years there was no difference in dominant heights due to stocking (Mann and Whitaker 1952). In a 9-year-old plantation of jack pine (Pinus banksiana Lamb.) in Michigan, Rudolf (1951) reported no differences in dominant height due to spacings that varied from 1½ x 1½ feet to 9 x feet. The plantation was on a good site for jack pine, and 9 years was not sufficient time for even ve close spacing to cause stagnation. Another plantation of jack pine in lower Michigan spaced from 4 x 4 feet to 10 x 10 feet had equal dominant heights after 25 years (Ralston 1953).

The significant facts in each of these plantations are that the sites were good and dominance was well expressed either by virtue of the good sites or because of inherent growth characteristics of the species.

That density of stocking does affect height growth of certain forest trees under certain condition is also well documented. The effects, however, are not always in the same direction; some species reac by being taller than average under condition of dense stocking whereas others are stunted. The paradox can be explained by the inherent growth habits of the species concerned and by the quality of the site on which they grow.

Gaiser and Merz (1951) found that in even-aged white oak (Quercus alba L.), over a wide range of site quality, dense stands contained taller trees than open stands. Given the space, the crown of this broadleaf species tends to extend outward rather than upward. Also, working in oak forests, Gevorkiant and Scholz (1944) found height growth retarded in understocked stands. They developed a method of site evaluation based on volume rather than height.

In a red pine plantation in northern Lower Michigan, spacings were 4 x 4, 6 x 6, 6 x 8, and 8 x 9 feet. Ralston (1954) reports that after 35 years dominant heights ranged from 25.4 feet in the 4- x 4-foot spacing to 31.5 feet in the wide spacing. The soil was Grayling sand, one of the poorest red pine soils of the region. Another spacing study reported by Adams and Chapman (1942) involving jack pine, red pine, eastern white pine (Pinus strobus L.), pitch pine (Pinus rigida Mill.), and Scotch pine (Pinus sylvestris L.) showed that close spacing retarded height growth of red pine and eastern white pine, species more exacting in site requirements, to a greater degree than it did in jack, pitch, and Scotch pine, species better adapted to poorer sites.

Effects of density on height are also sometimes apparent in natural stands. Turner (1943) observe that in even-aged old field loblolly pine and shortleaf pine (Pinus echinata Mill.), dense clumps were taller than adjacent open clumps. Tree crowns were smaller in the dense clumps, and growth was concentrated in the terminal shoots. Old fields are generally very favorable sites for these southern pines. Clumps of red pine in Michigan were observed by Shirley and Zehngraff (1942) to be taller in the center where density was greatest. Soil conditions apparently were better in the denser stands because the ground was shaded.

Thinning studies have provided opportunities to measure height growth under various degrees of stocking. A very dense 5-year-old jack pine stand in Minnesota was thinned to various spacings. Roe and Stoeckeler (1950) report little effect on height growth due to spacing after 5 years, but they observed large differences in diameter growth and crown size. Jack pine heights seem consistently to be less affected by stand density than heights of red pine. Engle and Smith (1952) report that height growth of both an overstocked natural stand of red pine and a 40-year-old plantation with a 5- x 5-foot spacing was improved 10 years after a moderate thinning.

Turning to ponderosa pine, Weaver (1947) gives an account of a 40-year-old stagnated stand on a poor site in eastern Washington, a portion of which had been thinned by fire at the age of about 10 years. The unthinned portion of the stand had a height of 12.3 feet as compared to 32.2 feet for the thinned portion. In the Southwest, Krauch (1949) found that in thinning trials of ponderosa pine stand both the crop and the noncrop trees were on the average 2 feet taller in the thinned plots than in the unthinned plots for each 10 years following thinning. Moisture is the most important factor limiting growth in this locality.

In a natural stand of ponderosa pine in northern California, Baker (1953) observed wide variations in stocking due to distance from the seed source. On apparently uniform site, height growth was superior in the open portion of the stand. In summarizing ponderosa pine thinning studies in the Pacific Northwest, Mowat (1953) discusses height stunting in overcrowded stands and its effect on site evaluation.

Two general observations are possible from the several reports reviewed. First, the effect of density of stocking on height growth varies with the species concerned and is related to their basic growth habits and abilities to express dominance. Second, when height growth is retarded by density of stocking, it is most apparent on poor sites where root competition is high.

THE PONDEROSA PINE TYPE IN THE INLAND EMPIRE

Ponderosa pine is the most important forest species in the Inland Empire, an area rather indefinitely bounded by the Continental Divide in Montana, the desert of central Washington, the Salmon River in central Idaho, and the Canadian border. Second only to western white pine (*Pinus monticola* Dougl.) in lumber quality, ponderosa pine surpasses white pine in gross value of product because of its abundance and wide distribution. In the Inland Empire, ponderosa pine grows in nearly pure stands on the lower foothills and valley floors where precipitation ranges from 15 to 30 inches per year, in an altitudinal range of 1,500 to 3,500 feet (fig. 3). It thrives on coarse, well-drained soils, such as sandy alluvium, gravelly or sandy till, and loams having high stone content. On the poorer, drier sites, ponderosa pine stands have very little understory of brushy species and are famous for their parklike appearance. As sites improve, understory brush becomes more plentiful. Figure 1 shows a comparison of a 120-year-old stand with site index 83 having only grass and needles on the forest floor and a 90-year-old stand of site index 100 with a rather dense understory of brush and Douglas-fir reproduction. As moisture conditions improve, either because of higher altitudes or favorable exposures, pure ponderosa pine stands give way to Douglas-fir (*Pseudostuga menziesii* var. *glauca* (Beissn.) Franco) and other more mesophytic species. Often the ponderosa pine stands found on such sites are subclimaxes resulting from past fires; as the stands close and environmental conditions change, an understory of Douglas-fir appears. Other common associates of ponderosa pine are lodgepole pine (*Pinus contorta* Dougl.), western larch (*Larix occidentalis* Nutt.), and grand fir (*Abies grandis* (Dougl.) Lindl.).

Mature stands of ponderosa pine are typically uneven-aged. The species is long-lived and generally reproduces well in openings, so that most stands contain several age classes often present in small, even-aged clumps. The stocking, too, is irregular; frequent openings, sparse stands, and very dense clumps appear on every acre.

Early logging activity in the Inland Empire upset the natural stand development by subjecting large areas to clear-cutting and burning; as a result, many even-aged stands of second-growth pine have replaced the virgin stands. Some of these stands are in the 80- to 90-year age class and are reaching the lower limits of saw log merchantability. Others are suitable size for pulpwood, posts, and poles; they are being recognized as a valuable timber asset to this region. Although generally even-aged, these second-growth stands still reflect the irregular growth habit of the species by being extremely variable in stocking. Frequent ground fires have further accentuated the irregularity of stocking. Figure 2 shows a comparison of two stands, both approximately 55 years old, which have had different densities during their lives, which have resulted in differences in tree size and condition. Because moisture is nearly always the most important limiting factor to the growth of ponderosa pine in this region, site quality varies with every ridge, swale, and change of exposure, and thus produces still another form of irregularity.

FIELD MEASUREMENTS

SOURCE OF DATA

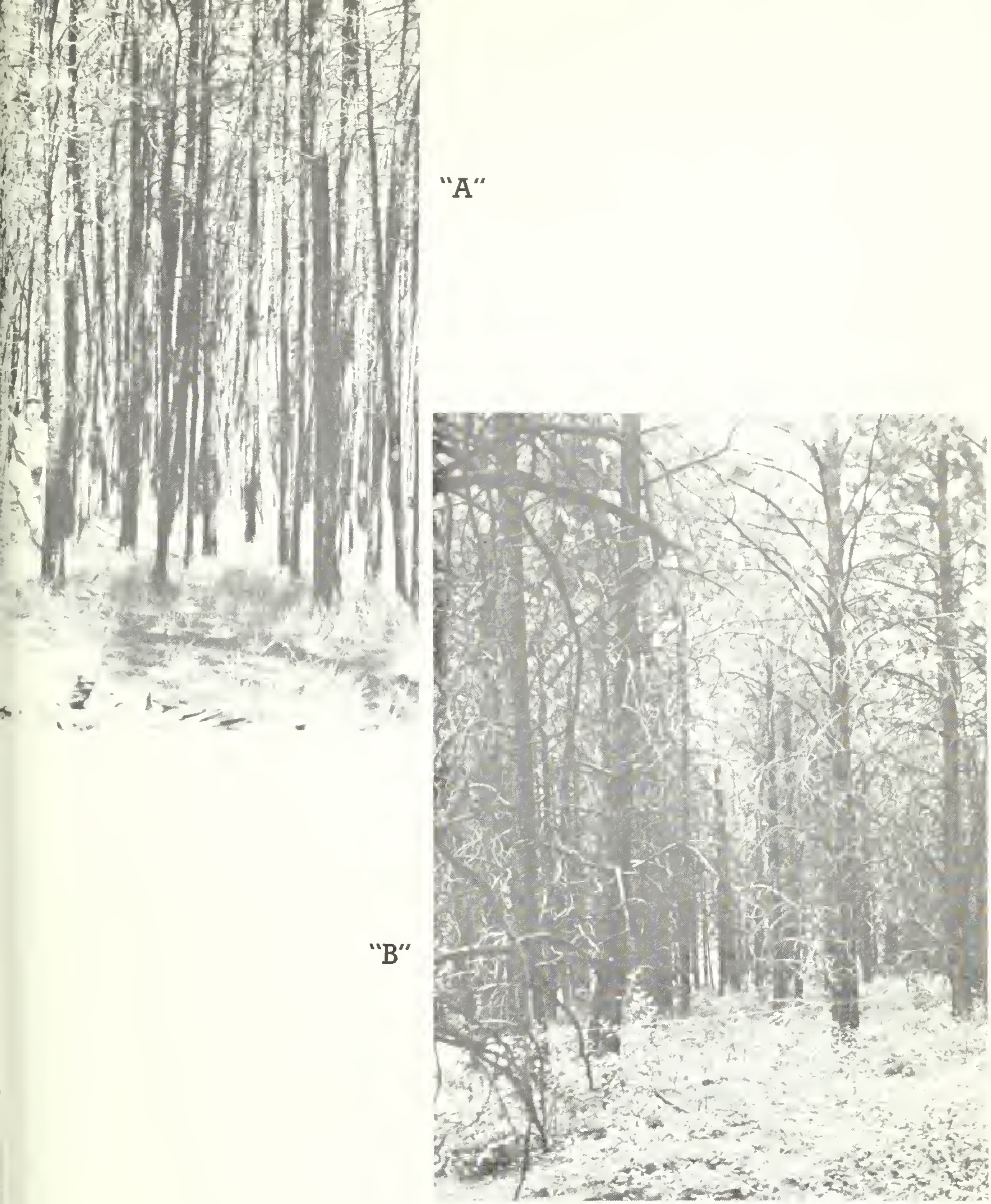
Data for this study were gathered from temporary sample plots located in even-aged stands of second-growth ponderosa pine throughout the Inland Empire. Figure 3 is a map of the region showing the ponderosa pine type and the sample plot locations. Each plot was carefully selected for its uniformity of site, age, and density, but in the aggregate the plots represent a range in ages from 25 to 125 years, site indices from 40 to 130, and stand densities from very open to dense thickets. Because the variables--age, site, and stocking--were to be evaluated in site and yield determinations, it was important that

"A"

"B"

Figure 1.--A shows a 90-year-old stand of ponderosa pine of site index 100 with an understory of brush and Douglas-fir reproduction typical of good sites. B shows another stand of the same species, age 120, site index 83, having only grass and needles on the forest floor--a condition characteristic of stands on medium and poor sites.

"A"



"B"

Figure 2.--These two stands of ponderosa pine, 55 years old, have had different densities during their lives, which have resulted in differences in tree size and condition. A shows a stand with 2,500 trees per acre whose stocking percentage is 115. B shows a stand with 400 trees per acre with a stocking percentage of 83. This stand occupies a better site than the one shown in A, as the surface vegetation indicates.

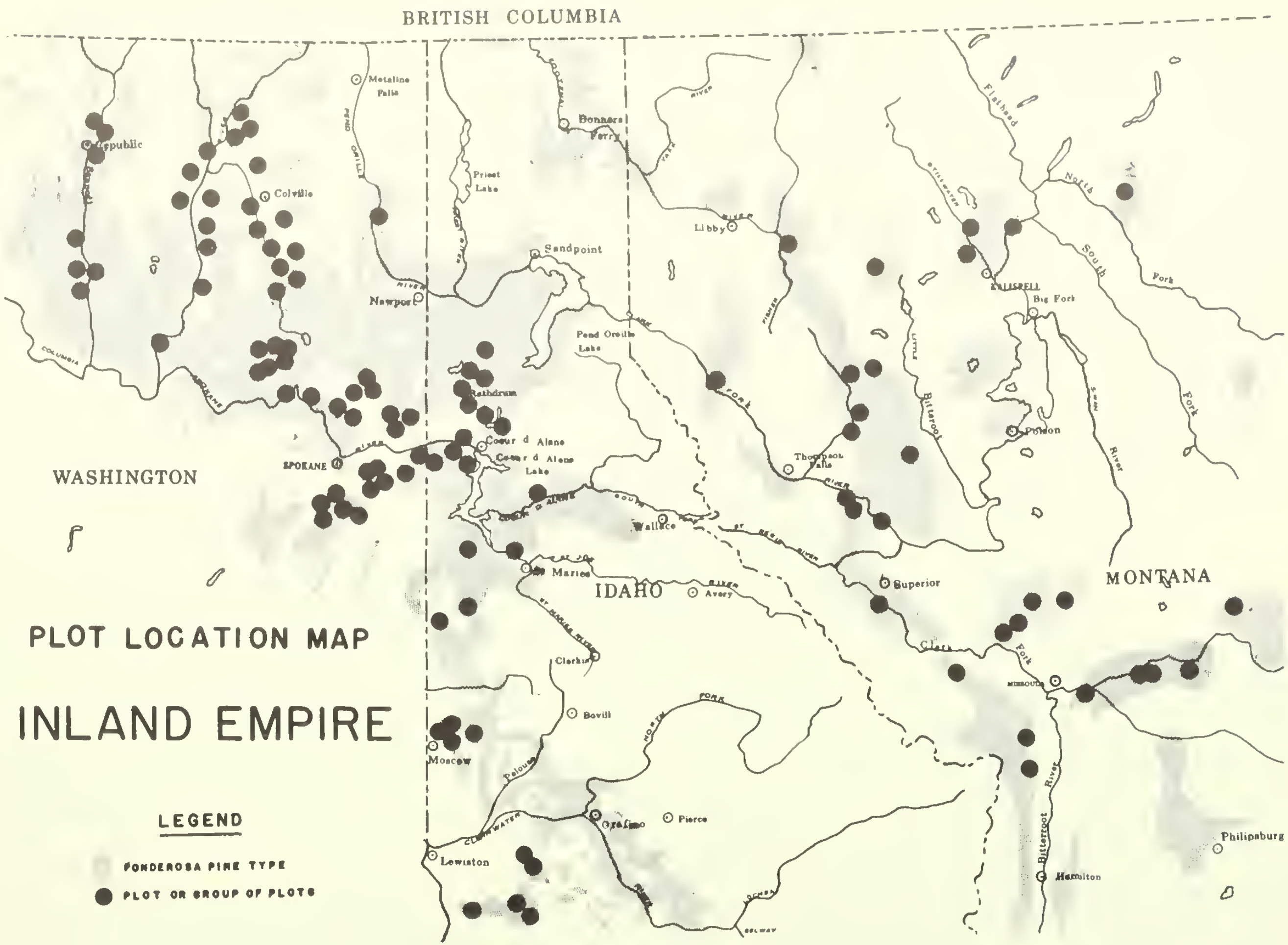


Figure 3.--Map of the Inland Empire showing the ponderosa pine type and the location of plots or groups of plots measured in this study.

each plot represent uniform conditions of each. A plot of average stocking, for example, could not be a combination of a dense clump and an opening, because density effects on growth would then be obscured. To find plots having uniform stocking was a difficult phase of the study.

Plot sizes ranged from one-fortieth of an acre to one acre; the majority were one-fifth acre in size. Attempt was made to have from 80 to 100 trees per plot; thus, tree size governed plot size. Small plots were confined to dense, young stands.

During the field seasons of 1953 and 1954, 72 sample plots were measured specifically for this study. In addition, data from 49 other plots measured by the writer in the same region in connection with another study were used (Lynch 1954). Finally, 86 Inland Empire plots were selected from among those measured for Meyer's interregional yield study for even-aged ponderosa pine (Meyer 1938). These 207 plots form the basis for the present study, each plot supplying the following data:

1. Age of dominant stand.
2. Curve of height over diameter based on 20 to 30 measured heights.
3. Stand tally of all trees 0.6-inch d.b.h. and larger by crown classes.
4. Miscellaneous information on soil and surface vegetation.

Site index for each plot was determined from Meyer's (1938) site curves, using dominant height read from plot height curves for average d.b.h. of all dominant and codominant trees. All plot data, such as basal area, volume, and number of trees, were converted to an acre basis.

PAIRED PLOTS

The irregularity of stocking in second-growth ponderosa pine stands gives an opportunity to observe striking differences in height on adjacent stands of the same age and apparently on the same site but with different densities. Very abrupt changes in stocking are found frequently and are probably caused by past ground fires as well as by irregular seeding. Significant differences in growth predictions can result from errors in site evaluation caused by such variations in stand densities. Differences in site index estimates as great as 20 units are often obtained from these adjacent stands which, judged on the basis of soil, slope, aspect, and surface vegetation are growing on identical sites. Referring to normal yield tables, one finds that a spread of only 10 site index units gives differences in growth predictions as high as 24 percent. Such variations, of course, have economic significance.

To evaluate the effect of stocking on height, hence on site index determination, requires an independent and true measure of the site quality. The two possible independent measures--soil profile and indicator plants--have not been explored sufficiently in this region to be used. A system of paired plots was therefore adopted in which two plots were selected side by side, identical in age and apparent site quality, but differing in stocking. One plot in each pair, designated as the plot, supplied all the usual measurements for the study, while the adjacent plot, referred to as the control, supplied an independent measure of site index. Great care was taken to select pairs that were believed to be on the same actual site. Each control was required to have average stocking.

It was difficult to find areas that fulfilled the requirements of paired plots. In two seasons' field work only 24 such pairs were found that were judged suitable. Figures 4 and 5 show stands representative of the sharp changes in stocking and height with otherwise identical characteristics. Only in a forest type in which root competition is a major critical factor would such marked differences occur.

The 24 plots, with their controls, form the basis for the site curve adjustments in this study. All 207 plots were used in the general site index equation.

ADJUSTING SITE INDEX BY STAND DENSITY

MEASURING DENSITY

Of the several measures of stand density that have been used, tree-area ratio, proposed by Chisman and Schumacher (1940), is especially applicable to a group of plot data. It consists of a quadratic equation, fit by the method of least squares, to plot data expressed on a unit area basis using such variables as sum-of-diameters, sum-of-diameters-squared (or plot basal area), height, age, or other variables that might affect stocking. The calculated equation expresses density of stocking as a proportion of the average density of stocking represented by the aggregate plot data.

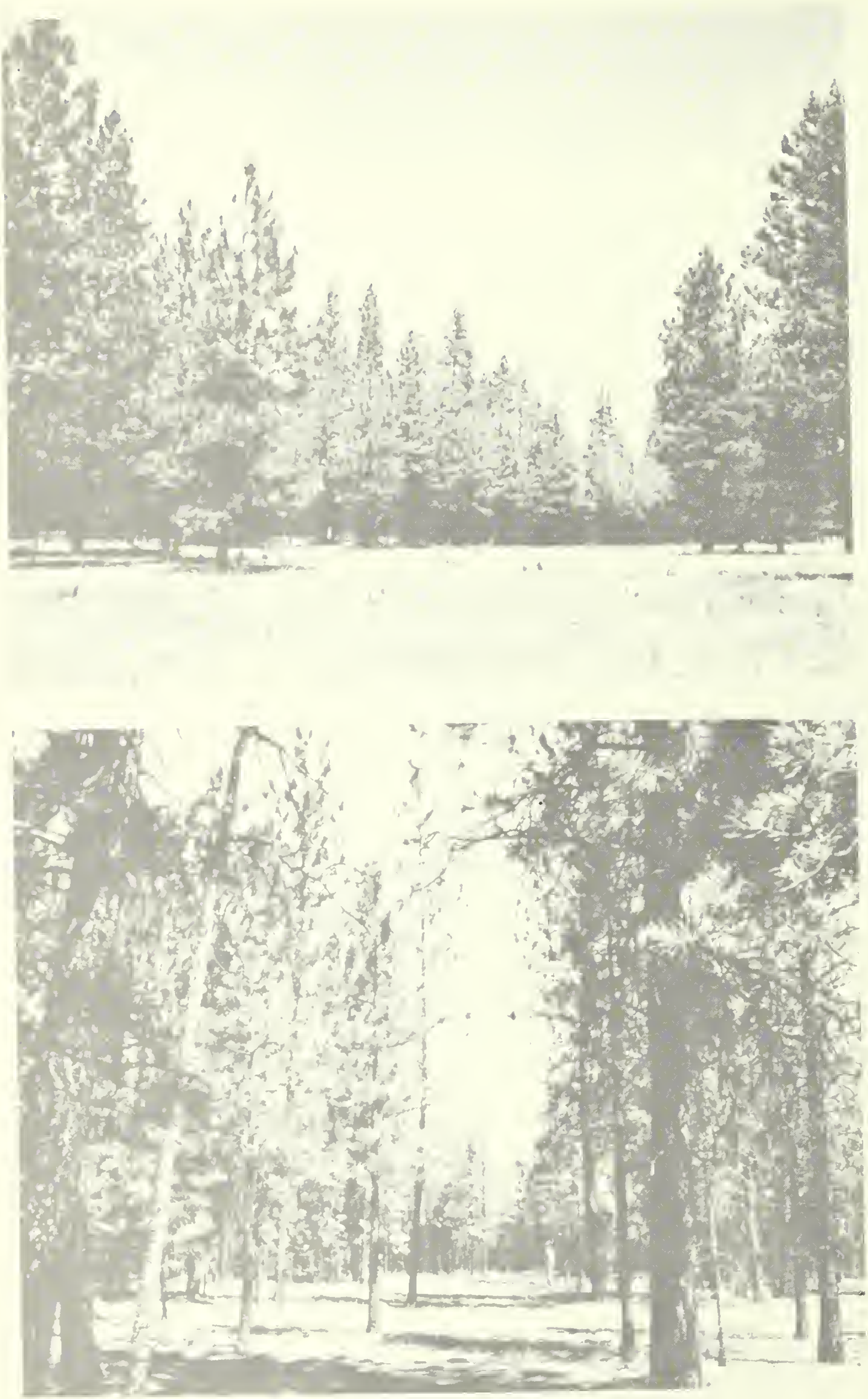


Figure 4.--Two views of even-aged ponderosa pine, about 40 years old, showing considerable differences in heights between open grown trees and trees in dense stands.

Figure 5.--This 25-year-old even-aged stand of ponderosa pine shows a striking difference in height due to stocking.

The tree-area ratio equations used by Chisman and Schumacher (1940) on loblolly pine plot data and the one used by Gaiser and Merz (1951) on white oak data contained these variables: sum-of-diameters, sum-of-squared-diameters, and number of trees. The expressions were found to be independent of site index and age for those particular forest types. Lexen (1939) used the tree-area ratio for a space-requirement study of ponderosa pine in the Southwest in which he reduced the equation to sum-of-squared-diameters only, that being the most significant variable.

It was suspected that stocking of ponderosa pine stands in the Inland Empire might vary with site and age; accordingly, the two variables, height and age, were included in the tree-area ratio expression. Basal area was used rather than sum-of-squared-diameters giving the equation,

$$S = b_1(N) + b_2(B) + b_3(BH) + b_4\left(\frac{BH}{A}\right) + b_5\left(\frac{B}{A}\right)$$

where S = stocking percentage
N = number of trees per acre
B = basal area per acre
A = age of dominant stand
H = height of dominant stand
b_1 to b_5 = coefficients to be computed.

A more detailed explanation of the stocking equation is given in Appendix I.

Number of trees per acre was found to be the least significant of any of the variables and was dropped from the equation. After calculating the regression coefficients, the equation became:

$$S = 0.2918(B) + 0.0065(BH) - 0.6467\left(\frac{BH}{A}\right) + 29.7520\left(\frac{B}{A}\right).$$

Factoring out B, the equation takes the form,

$$S = B\left[0.2918 + 0.0065(H) - 0.6467\left(\frac{H}{A}\right) + 29.7520\left(\frac{1}{A}\right)\right] \quad (1)$$

in which the expression within the brackets is the stocking per square foot of basal area.

The stocking percentage calculated by equation (1) is the ground area that a stand of given age, height, and basal area would have utilized in an average-stocked stand relative to the actual ground area of the stand itself. A stocking percentage of 100, as used in this study, indicates a density equa to the average of all the data represented. It should not be confused with 100 percent of normal, becau not all the stands chosen in this study were fully stocked as they are in a normal yield study.

Examples of the stocking percentages calculated by equation (1) from normal yield table data for second-growth ponderosa pine (Meyer 1938) appear in table 1. They are generally above 100, showing that the stocking of the plots measured for the normal yield study was higher than that of the plots in the present study, except in the older ages of the poorer sites.

Table 1.--Stocking percentages calculated from normal yield table data for second-growth ponderosa pine for four age and six site classes

Age	Stocking percentage when site index is: 50	60	70	80	90	100
			Percent			
40	109	115	117	119	120	121
60	103	107	109	111	111	112
80	95	98	101	103	104	105
100	90	94	97	99	101	102

EFFECT OF DENSITY ON SITE INDEX MEASUREMENT

Having determined a suitable measure of stocking, it was possible to compare heights of trees on paired plots on the basis of stocking. Designating the site index of a plot as Ip and the adjusted site index measured on an adjacent average-stocked control as Ic, the difference between the two site indices may be written as (Ic-Ip). Plotted over stocking, as is shown in figure 6, A, these site differences are greatest on the densest plots. A freehand straight line through the plotted points shows that as stockings approach 100 percent, differences in site indices approach zero.

Plotting the site differences on plot site index (Ip), shown in figure 6, B, indicates that differences are greatest on poor sites; as sites increase to site index 75, the differences approach zero, as the freehand straight line shows.

On the basis of some experiences with other species (Gaiser and Merz 1951; Turner 1943; Shirley and Zehngraff 1942) it might be expected that dense stocking on good sites would produce taller than average trees. In no instance was this condition observed or measured on paired plots in this study. For two reasons, stunting does not occur in dense ponderosa pine stands on good sites: first, very dense stands seldom become established on good sites because of the severe competition of associated vegetation; second, trees in these stands express dominance readily and thin themselves effectively before stagnation occurs.

It might further be expected that in stands having less than average stocking trees would be shorter than in average-stocked stands. MacKinney *et al*. (1937) found that in data from 68 plots of loblolly pine ranging in density from 80 to 120 percent height was reduced to some extent both by dense stocking and by open stocking. Heights were maximum at a stocking percentage of 100; the effects of stocking were not correlated with site.

No relationship between sparse stocking and height could be detected in ponderosa pine stands regardless of site quality. Open grown ponderosa pines apparently reach normal heights and at the same time produce larger diameters and crowns than trees in closed stands.

The effects of stocking on height of second-growth ponderosa pine in the Inland Empire can be summarized as follows:

1. Dominant heights are reduced on poor sites as stocking percentages increase above 100. If stocking percentages are below 100, heights are unaffected regardless of site.

2. Height stunting is intensified as site quality diminishes below site index 75. If site indices are above 75, heights are unaffected regardless of stocking.

To show these relationships of stocking and site quality on height, the factor (S-100)(75-Ip) was chosen. It increases as stockings increase above 100 and as plot site indices decrease below 75. If this factor, designated hereafter as Z, is taken as zero when either (S-100) or (75-Ip) is zero or negative, the desired conditions as enumerated above are met. To express the relationship of Z to differences in site indices of paired plots, the following formula was developed. (See Appendix II for details of the solution):

$$\log\left(\frac{Ic}{Ip}\right) = b_1 Z + b_2 Z^2 \qquad (2)$$

where Z = (S-100)(75-Ip)
and b_1 and b_2 = coefficients to be calculated.

Site indices for 52 plots (including the 24 used in the paired plot analysis) were adjusted by equation (2). A graph of this equation is shown in figure 13.

Having adjusted the site indices on all plots whose densities were above 100 and whose plot sites were below 75, all 207 plots could be pooled for a general site index analysis. Site curves were constructed on the basis of an equation that contained site index itself as one of the independent variables. Site was included to allow any differences in growth habits from site to site to be reflected in the shape of the curves. Reciprocal of age was a second variable; index age was taken at 100 years.

A second innovation in the site index equation was the inclusion of the variable Z to provide for site corrections for dense stands on poor sites. The site index equation with its calculated coefficients was determined to be:

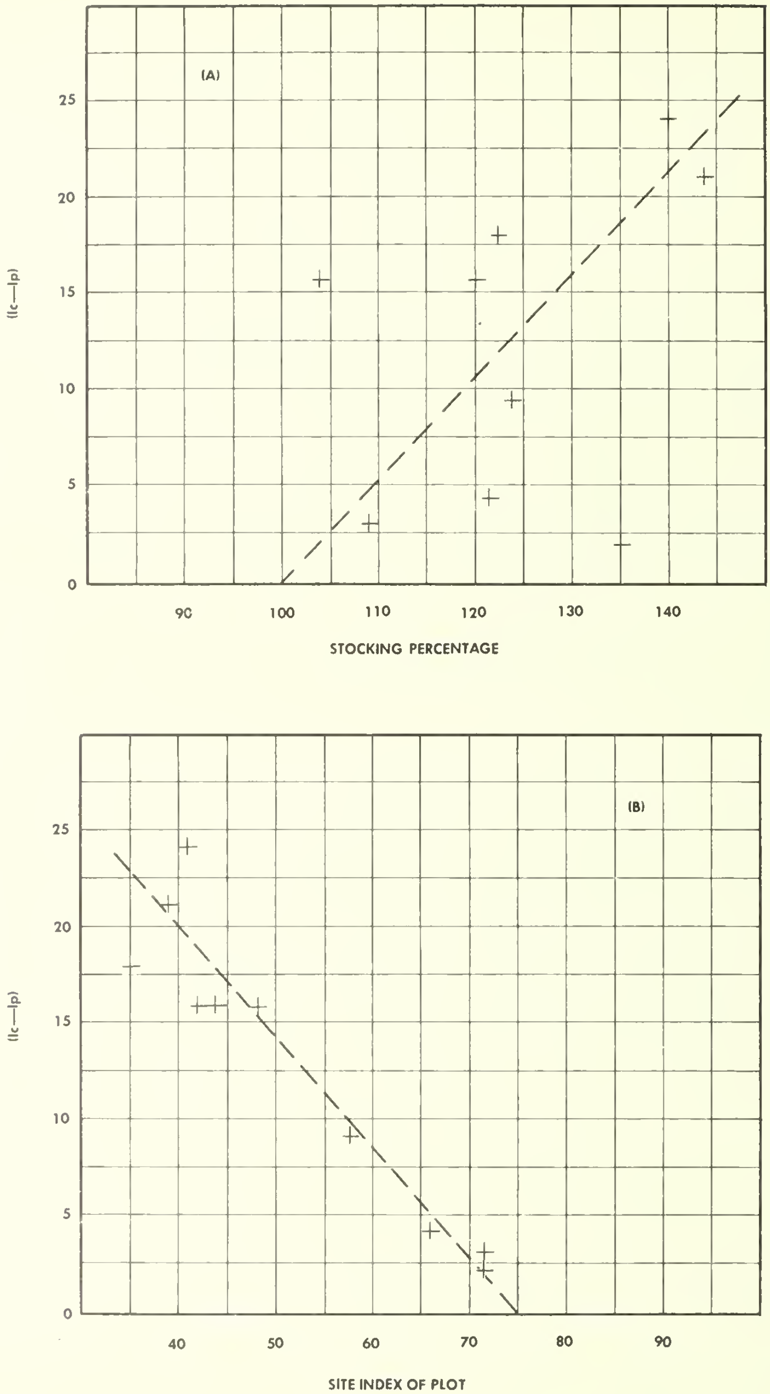


Figure 6.--A Differences in site indices between plots and adjacent average-stocked controls (Ic-Ip) are plotted on stocking percentage of the plot. They are greatest on the densest plots, and differences approach zero as stocking approaches 100. B The differences are plotted over the observed site indices of the plots. They are greatest on poor sites; as sites increase to site index 75, the differences approach zero.

$$\log H = \log I - 0.6437\left(\frac{100}{A} - 1\right) + 0.2432 \log I\left(\frac{100}{A} - 1\right)$$

$$- 0.000361(Z) + 0.00000012(Z^2) \qquad (3)$$

where H = dominant stand height
I = site index
A = dominant age
Z = (S-100)(75-Ip).

A more complete discussion of equation (3) is given in Appendix III.

Figure 7 A, B, and C presents sets of site curves for stocking percentages of 100 or less, 110, and 120.

The set of site curves for average stocking (100 or less) is comparable to the set from Meyer's bulletin. The two have been compared in figure 7 D. It will be noted that Meyer's curves are higher at the two extremes of age, but are lower in the central range. They are generally flatter in shape than the revised curves and vary less in shape from one site index to the next. These normal site curves have been criticized for use in the Inland Empire because they tend to underestimate site index in young stands. The curves from the present study will correct this fault to some extent and generally should be more suitable for use in the Inland Empire.

The early work of Behre (1938) should also be mentioned. His preliminary normal yield tables were constructed especially for northern Idaho and adjacent areas, and were used until superseded by Meyer's work. Behre's site curves differ from Meyer's by being lower on good sites and higher on poor sites for young ages. They vary considerably from the site curves of the present study.

The major difference between all former site curves and the present ones, of course, appears in sites below 75 for stocking percentages above 100. By using the appropriate set of curves, chosen on the basis of density of the stand in question, site index can be measured more precisely.

PREDICTING GROWTH IN PONDEROSA PINE STANDS

As a stand of timber develops, its change and growth can be described by such fundamental variables as age, dominant height, number of trees, basal area, and average d.b.h., as well as by such derived variables as volume in cubic feet and board feet. Predicting growth means predicting each of these variables for some future date.

The normal yield table method of growth prediction is simply to read from a table the present volume for the appropriate age and site; then, from the same table, read the volume at the future age and take the difference as volume growth. If a stand is understocked as determined by a comparison of observed basal area to normal, a percentage correction is applied to the initial and final volumes. The tables do not provide for stocking changes in understocked or overstocked stands. Herein lies the major weakness of normal yield tables for growth prediction. Stand densities do change, even in the span of one decade, to the extent that serious errors can be made in predicting growth of nonnormal stands if these changes are not considered. Understocked stands increase in density with time, and overstocked stands decrease. The changes are most rapid in young stands and in stands having density extremes.

As stocking approaches average for a particular species, site, and age, the changes of stocking with age are very slow. These characteristics of approach to normality have been measured in many forest types (Chaiken 1939; Briegleb 1942; Wellwood 1943; Watt 1950). Various methods have been used to adjust for changes in normality with the passing of time, most of which involve a percentage adjustment depending upon the age and initial stocking of the stand.

The process presented here was suggested by F.X. Schumacher, who applied the method to growth prediction of even-aged loblolly pine stands in an unpublished paper from Duke University, School of Forestry, (Schumacher and Coile, 1954).

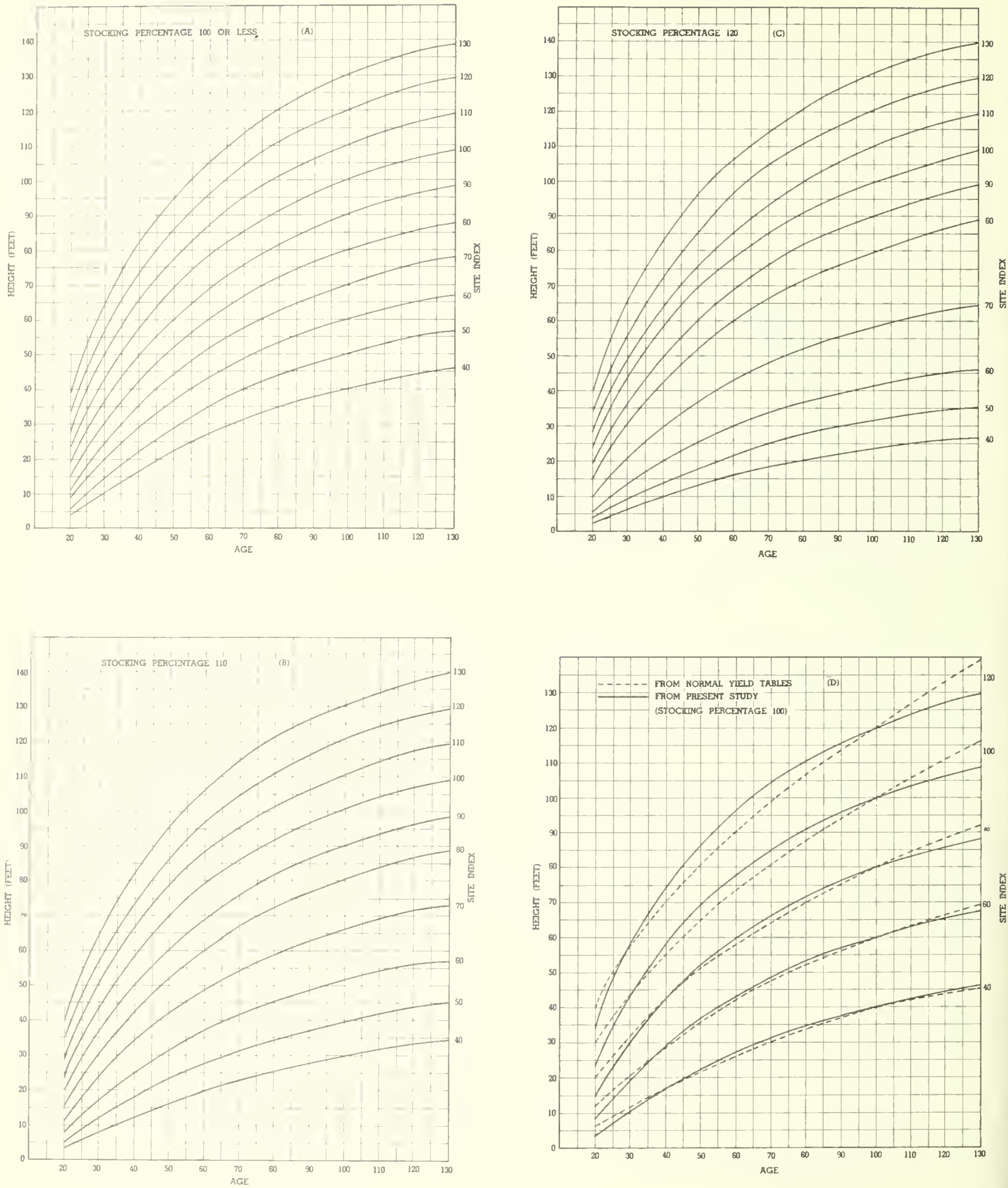


Figure 7.--Site curves: A for 100 percent or lower stocking, B for 110 percent stocking, C for 120 percent stocking, and D comparing Meyer's curves for normal yield study site with those of the present study for average stocking.

FUTURE STOCKING

For the growth prediction portion of this study, the stocking equation (1)[1/], was modified somewhat by eliminating the variable BH and recomputing the coefficients for the remaining variables. The revised form of the equation, shown below, was better adapted to predicting future basal area:

$$S = B\left[0.5663 - 0.2715\left(\frac{H}{A}\right) + 15.2858\left(\frac{1}{A}\right)\right]. \quad (4)$$

The portion of equation (4) within the brackets is, as before, the stocking per square foot of basal area and may be designated s, as in the following:

$$s = 0.5663 - 0.2715\left(\frac{H}{A}\right) + 15.2858\left(\frac{1}{A}\right). \quad (5)$$

In the prediction process, future age, A_1, of course, is readily obtained, and future height (H_1) is predicted from site curves. Therefore, s_1, or future stocking per square foot of basal area, can be computed from future age and height by equation (5).

An expression for predicting future stocking (S_1) that provides for rapid changes in stocking for young stands with extremes of density and that provides for slower changes as age advances and as stocking approaches 100, is the following:

$$\log S_1 = 2 + (\log S_0 - 2)\frac{A_0}{A_1}$$

where S_1 = future stocking
S_0 = present stocking
A_1 = future age
A_0 = present age.

This equation is derived and discussed in detail in Appendix IV, and plotted in figure 14 B.

From S_1 and s_1, future basal area can be determined from the relationship shown in equation (4) where

$$S_1 = B_1 s_1$$

$$\text{or } B_1 = \frac{S_1}{s_1}.$$

Figure 8 shows basal area plotted on age for site indices 50 to 100. Each graph contains curves of basal area on age for various initial basal areas at indicator-age 30. Knowing present basal area, age, and site, future basal area can be read for ages up to 120 years.

FUTURE NUMBER OF TREES

The number of trees in a stand is a function of the age, the basal area, and the height. To express this relationship in a linear equation, the logarithmic transformation of height and basal area and the reciprocal transformation of age are required. The equation, derived in detail in Appendix V, is:

$$\log N = b_0 + b_1(\log H) + b_2\left(\frac{1}{A}\right) + b_3(\log B) \quad (6)$$

where N = number of trees per acre
H = dominant height in feet
A = age in years
B = basal area per acre in square feet
b_0 to b_3 = coefficients to be computed.

1/ p. 10.

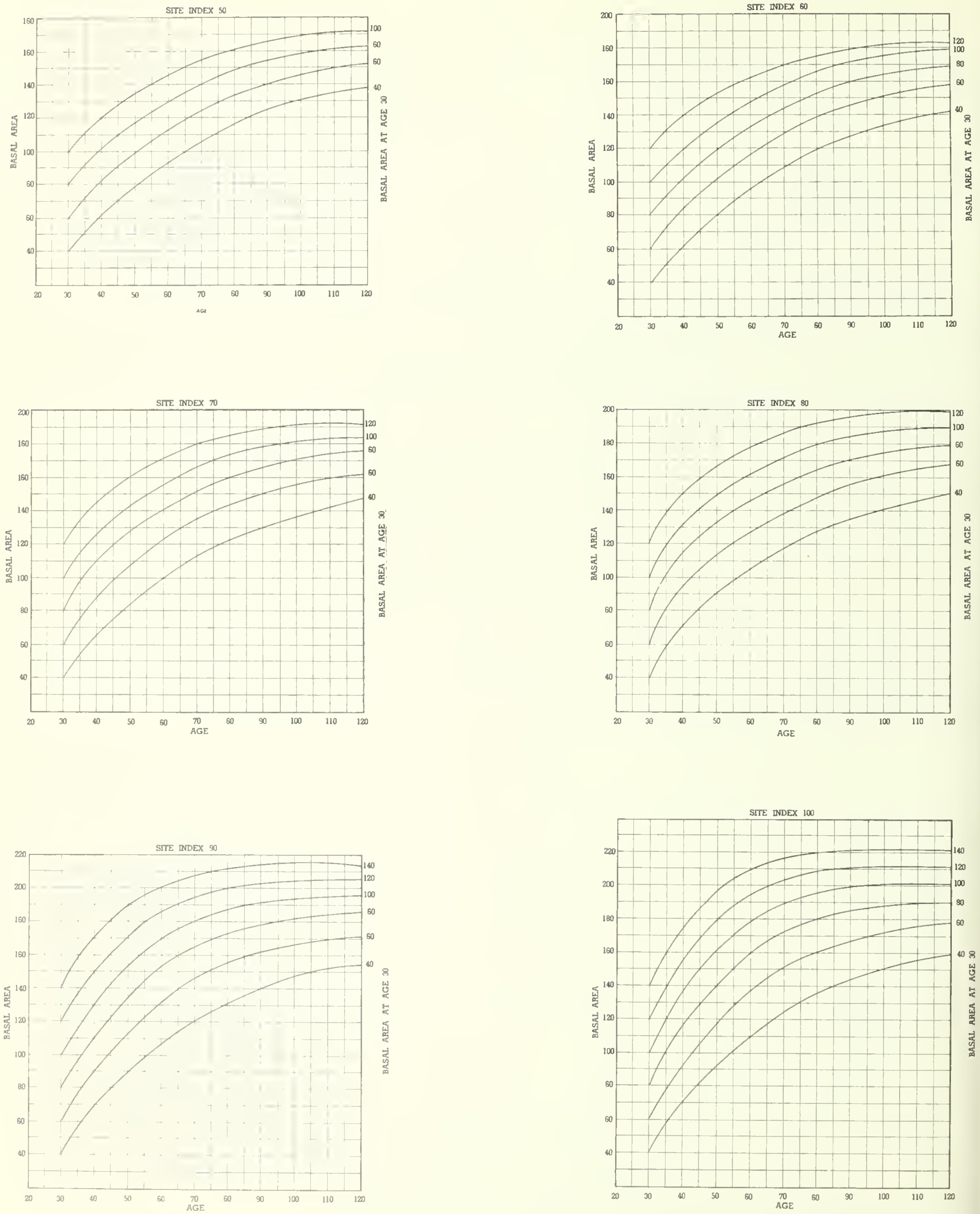


Figure 8.--Curves of basal area on age for various initial basal areas at age 30 and for site indices 50, 60, 70, 80, 90, and 100.

Using subscripts 1 and 0 to designate future and present, respectively, as before, the difference between future and present log N can be written,

$$\log N_1 - \log N_0 = \log\left(\frac{N_1}{N_0}\right)$$

$$= b_1 \log\left(\frac{H_1}{H_0}\right) + b_2\left(\frac{1}{A_1} - \frac{1}{A_0}\right) + b_3\left(\log\frac{B_1}{B_0}\right)$$

in which the constant, b_0, drops out.

The coefficients for equation (6) were computed from the basic data from the 207 plots of this study; from these coefficients the completed form of the above equation was determined as follows:

$$\log\left(\frac{N_1}{N_0}\right) = -2.6078\left(\log\frac{H_1}{H_0}\right) - 11.2150\left(\frac{1}{A_1} - \frac{1}{A_0}\right) + 1.4579\left(\log\frac{B_1}{B_0}\right). \quad (7)$$

It is apparent that the ratio of future number of trees to present number is dependent upon height, age, and basal area, the values of which can be predicted. A graphic presentation of equation (7) appears in figure 9 for site indices from 50 to 100. Separate curves are drawn for various initial basal areas over a range of age from 30 to 120 years.

If a stand on site index 60, for example, contains 500 trees with 60 square feet of basal area at indicator-age 30, then at age 50, 56 percent of these, or 280 trees, should still survive. The graphs may be used for any initial age. For example, the 50-year-old stand with indicator-age basal area of 60 has 56-percent survival, and at age 70 has 43 percent. Then, 43/56 or 77 percent of the 280 trees at age 50 should survive at age 70.

Having estimated future basal area and number of trees per acre, the average basal area per tree of the future stand can readily be determined. By means of a standard basal area table or, more conveniently from the graph in figure 10, average d.b.h. in inches can be read for any average basal area in square feet.

FUTURE CUBIC-FOOT VOLUME

Total cubic-foot volume of a tree, inside bark, is basic to the determination of other measures of volume, such as the board-foot or the cord. Cubic-foot volume on an acre basis is a function of the square of the average stand diameter, the height of the dominant stand, and the number of trees on the acre. In equation form it is:

$$\log V = b_0 + b_1(\log D^2) + b_2(\log H) + b_3(\log N)$$

where V = cubic volume per acre
D = diameter of tree of average basal area in inches
H = dominant height in feet
N = number of trees per acre
b_0 to b_3 = coefficients to be computed.

Based on the data from the 207 plots of this study, the volumes of which were computed from a table by Meyer (1938), the computed equation is:

$$\log V = -2.6950 + 1.0203(\log D^2) + 0.9704(\log H) + 0.9996(\log N). \quad (8)$$

The coefficient of log N was not a significant departure from 1. (See Appendix VI, for the details of developing this equation.) If height and average diameter are constant, cubic volume of a stand is in direct proportion to the number of trees. Treating this coefficient as unity, the average volume per tree, v, can be expressed as:

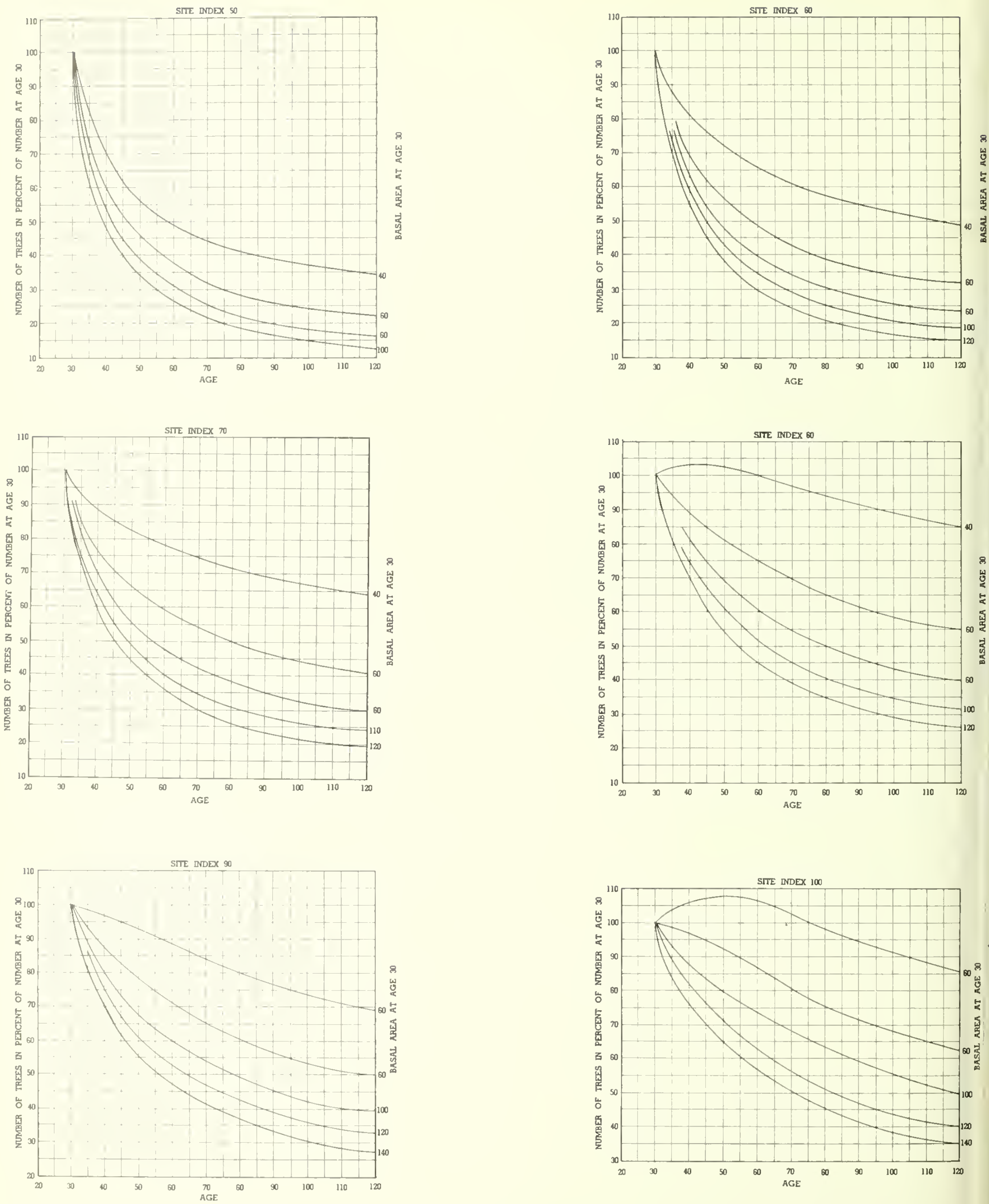


Figure 9.--Curves showing change in relative number of trees for various ages and initial basal areas and for site indices 50, 60, 70, 80, 90, and 100.

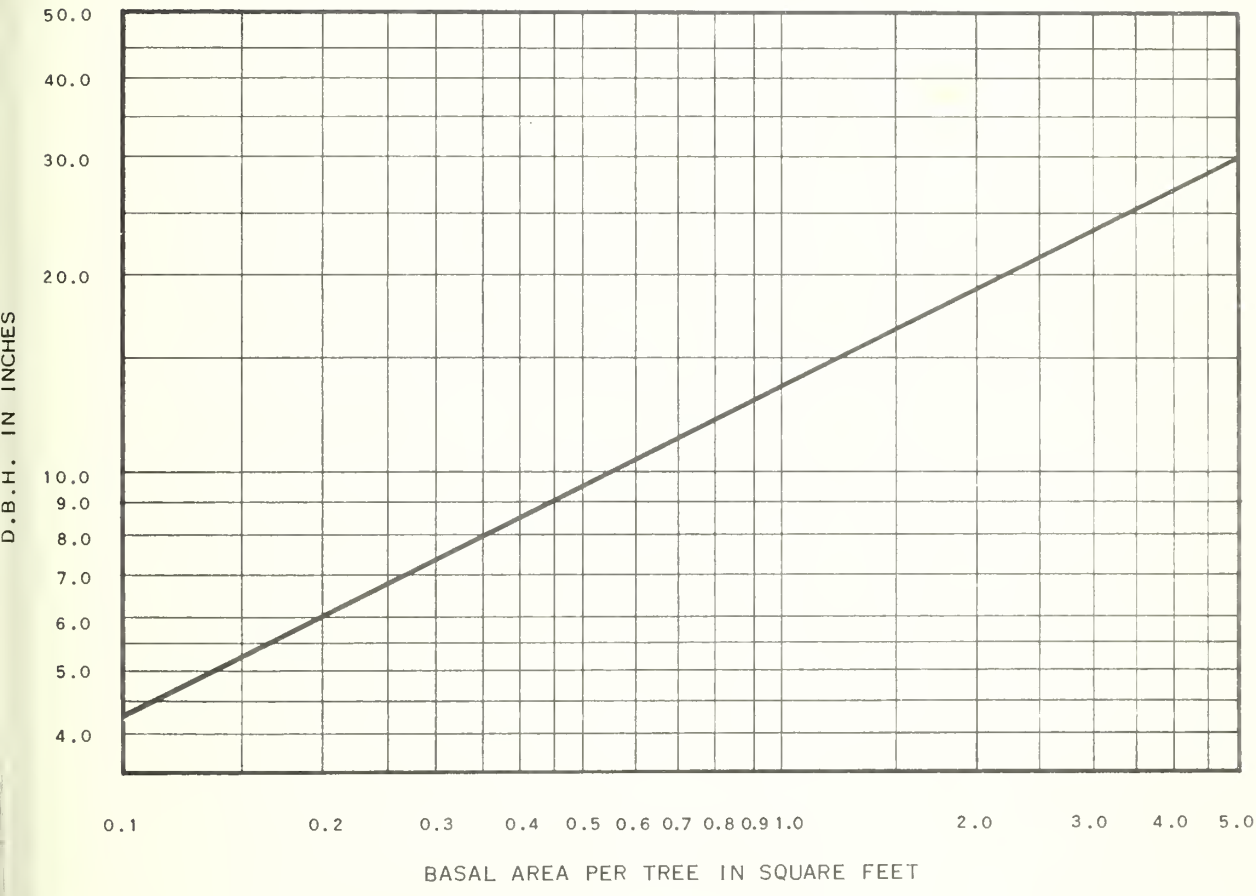


Figure 10.--Average stand d.b.h. in inches in terms of average basal area per tree in square feet.

$$\log V - \log N = \log\left(\frac{V}{N}\right) = \log v \qquad (9)$$

$$= -2.6950 + 1.0203(\log D^2) + 0.9704(\log H).$$

Equation (9) is shown graphically in figure 11 for various average diameters and for various heights. Having predicted future average diameter and height, the average cubic-foot volume per tree can be read from the graph in figure 11. Multiplying this volume by the future number of trees gives an estimate of future cubic-foot volume per acre.

FUTURE BOARD-FOOT VOLUME

Other measures can be derived from cubic-foot volume per acre. In the present economy of the Inland Empire, the only other unit of measure needed is volume in board feet. Since there is no market for pulpwood, second-growth pine saw logs are often cut to diameters as small as 10 inches. Therefore, converting factors have been computed for changing total cubic-foot volume per acre to board-foot volume per acre in trees 10 inches d.b.h. and larger.

Board-foot volumes were computed by the International 1/4-inch rule to a variable top from a volume table developed for use by the Forest Survey in the Intermountain region.

The ratio of board feet in trees 10 inches d.b.h. and larger to cubic feet of all trees can be expressed linearly as

$$\log R = b_0 + b_1\left(\frac{1}{D^2}\right) + b_2\left(\frac{H}{D^2}\right)$$

where R = board-foot/cubic-foot ratio
D = diameter of tree of average basal area
H = dominant height
b_0 to b_2 = coefficients to be computed.

This equation is developed in Appendix VII.

Based on actual ratios from 121 plots (the other 86 plots had no trees as large as 10 inches), the computed equation, with two of the variables coded for convenience, is:

$$\log(R \times 100) = 2.7256 - 0.6501\left(\frac{100}{D^2}\right) + 0.6730\left(\frac{H}{D^2}\right). \qquad (10)$$

Equation (10) is shown graphically in figure 12 for various average diameters and dominant heights. It should be kept in mind that these ratios are not for trees having these dimensions, but rather are for stands whose average diameters and dominant heights are those shown.

YIELD OF AVERAGE-STOCKED STANDS

It is interesting to compare the yields of average-stocked stands (stocking percentage 100) determined in this study with Meyer's (1938) normal yield tables. Table 2 shows dominant heights and average-stand diameters by age classes and site classes for all trees 0.6 inch d.b.h. and larger. On an acre basis the table also shows basal areas, number of trees, cubic volume of all trees above 0.6 inch d.b.h., and board-foot volume in trees 10 inches d.b.h. and larger.

Table 2 can be used to predict yields if the stands concerned happen to be 100 percent stocked. For predicting growth in under- or overstocked stands, the method described in the previous section of this report should be used.

In general, the basal areas shown in table 2 are smaller than Meyer's for younger ages but continue to rise slowly for ages up to 120, whereas Meyer's basal areas level off at as early as 60 years on poor sites. In stands above site index 90 Meyer's basal areas are higher throughout the range of age shown in table 2.

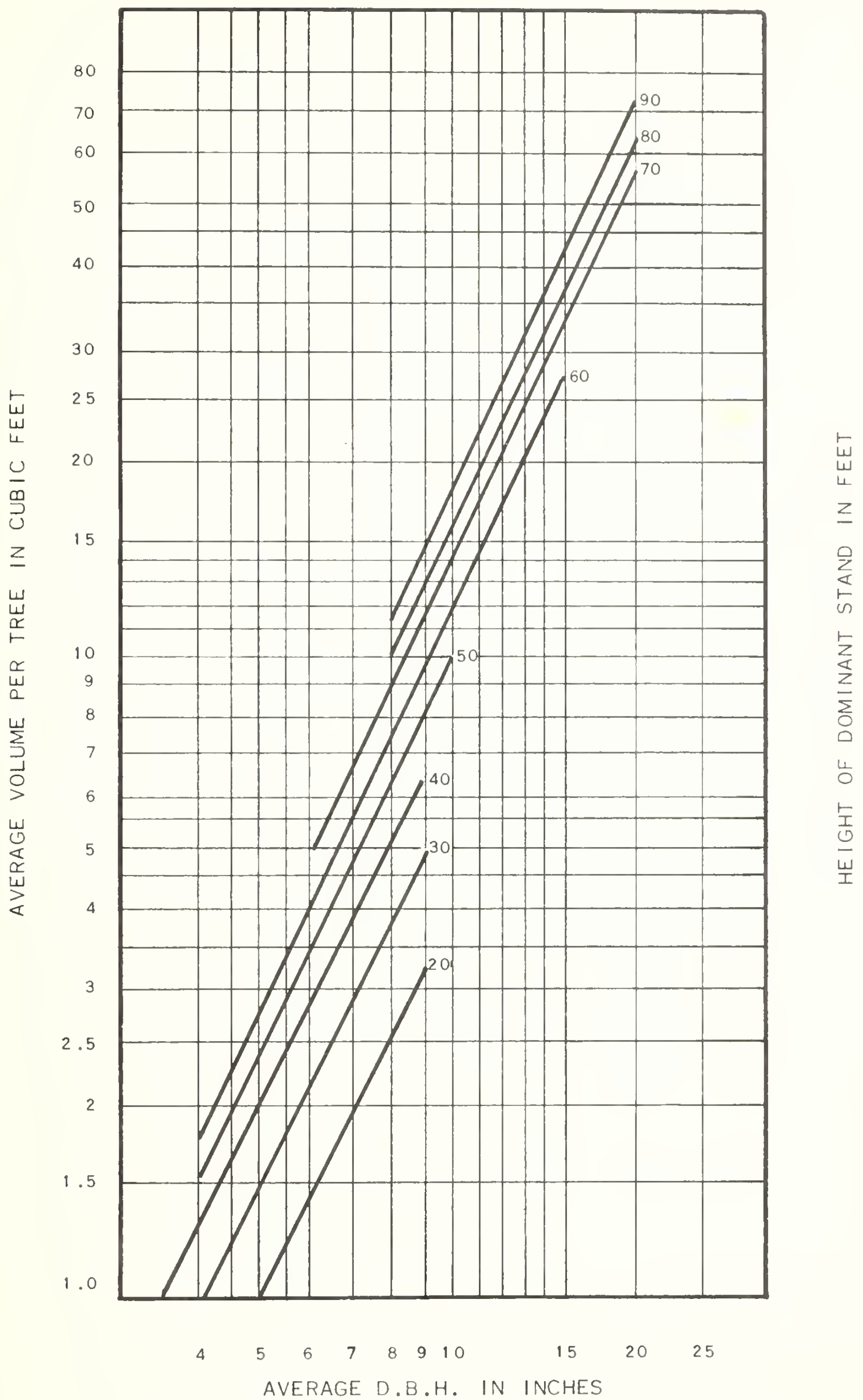


Figure 11.--Average volume per tree in cubic feet for various average stand diameters and dominant heights.

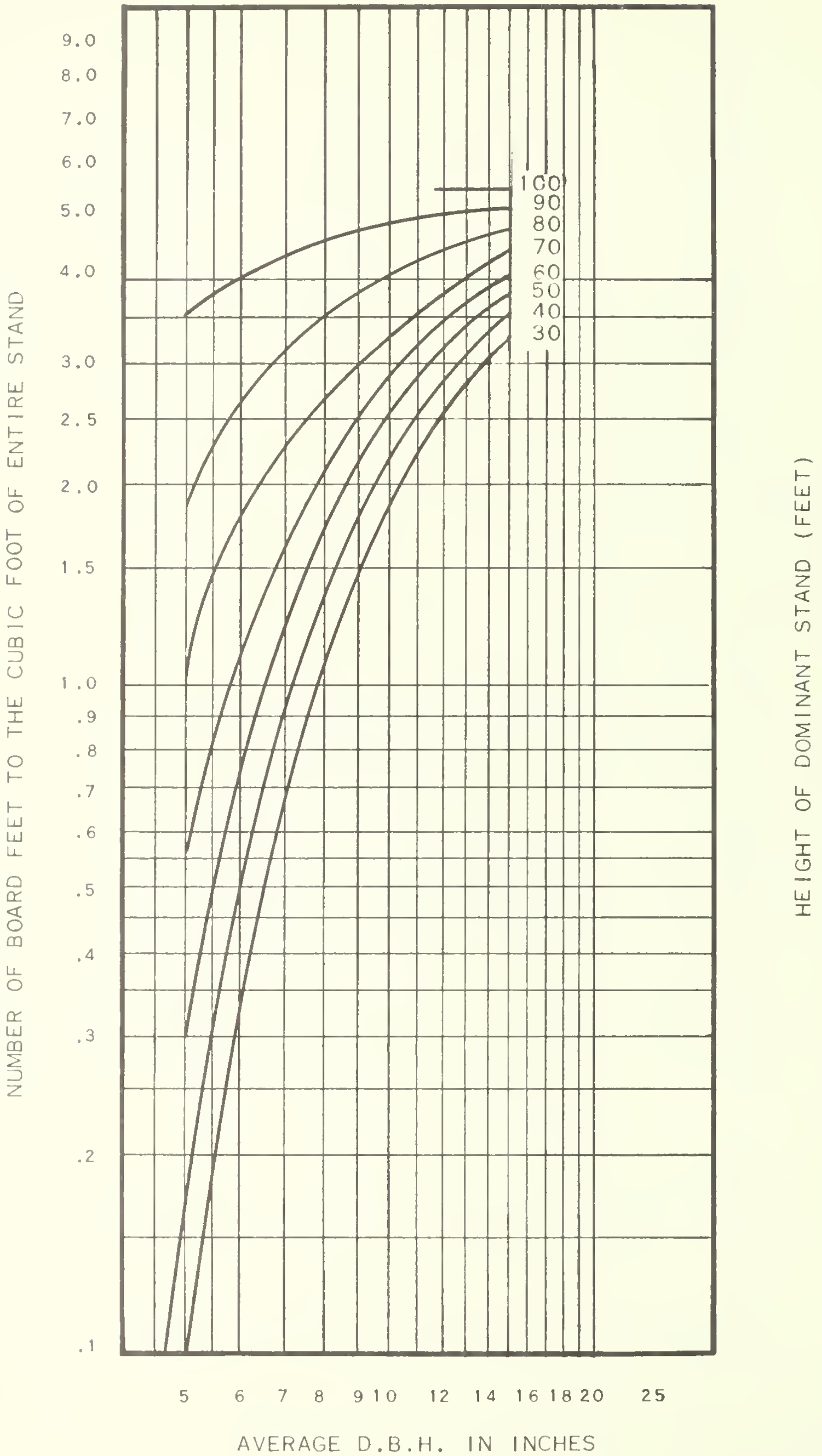


Figure 12.--Ratios of board feet in trees 10 inches d.b.h. and larger to total cubic feet in all trees 0.6 inch and larger for various average stand diameters and dominant heights.

Table 2.--Yields per acre of average-stocked second-growth ponderosa pine stands showing height, basal area, number of trees, average diameter, cubic-foot volume, and board-foot volume for ages 40 to 120 and site indices 50 to 110. All trees 0.6 inch d.b.h. and larger are included

Age (years)	Height of dominant stand	Basal area per acre	Trees per acre	Average d. b. h.	Total volume[1/]	Volume in trees 10 in. & over[2/]
	Feet	Sq. ft.	Number	Inches	Cu. ft.	Bd. ft.
			Site Index 50			
40	22	125	3,334	2.6	950	0
60	35	151	1,621	4.1	1,830	0
80	44	164	1,122	5.2	2,580	720
100	50	171	911	5.9	3,060	2,080
120	55	176	775	6.5	3,480	4,000
			Site Index 60			
40	29	132	1,756	3.7	1,340	0
60	43	160	1,031	5.3	2,350	700
80	53	173	747	6.5	3,240	2,400
100	60	180	611	7.3	3,790	6,800
120	65	183	531	7.9	4,180	10,100
			Site Index 70			
40	35	141	1,184	4.7	1,770	0
60	52	170	686	6.7	3,110	3,600
80	63	183	517	8.1	4,150	9,960
100	70	189	439	8.9	4,740	14,900
120	76	191	376	9.6	5,120	18,900
			Site Index 80			
40	42	151	814	5.8	2,230	1,000
60	60	182	522	8.0	3,900	8,580
80	72	195	400	9.5	5,420	18,860
100	80	199	334	10.4	6,030	25,300
120	86	200	291	11.2	6,560	30,370
			Site Index 90			
40	50	164	582	7.2	2,940	3,800
60	69	197	407	9.4	4,840	15,970
80	82	209	315	11.0	6,100	26,840
100	90	211	267	12.0	6,760	33,660
120	96	210	234	12.8	7,200	38,160
			Site Index 100			
40	58	180	453	8.5	3,700	10,540
60	78	214	333	10.9	6,030	25,330
80	91	223	264	12.4	7,230	36,300
100	100	223	220	13.6	7,970	43,840
120	106	220	194	14.4	8,360	48,070
			Site Index 110			
40	66	200	377	9.9	4,770	15,740
60	88	235	279	12.4	7,390	36,200
80	101	241	225	14.0	8,730	48,000
100	110	238	189	15.2	9,420	55,600
120	116	232	166	16.0	9,670	59,000

1/ Total cubic-foot volume inside bark in trees 0.6 inch d.b.h. and larger. Volumes per tree taken from Meyer's (1938) bulletin.

2/ Board-foot volumes in trees 10 inches d.b.h. and larger by the International 1/4-inch rule to a variable top.

The number of trees per acre is lower in table 2 for young ages but higher in old ages than in Meyer's tables. These relationships of basal area and number of trees result in average diameters being slightly higher in table 2 for young stands and lower for old stands than those shown in the normal yield table. Cubic-foot volumes are generally somewhat lower for comparable ages and sites than in the normal yield tables. This could be expected because the 100 percent stocking used in this study is still understocked according to the normal yield tables, as table 1 shows.

Values in table 2 have only limited use in growth prediction, but they are of interest because they show a comparison of Inland Empire stands with the so-called normal stands of the ponderosa pine type covered in Meyer's interregional study.

SUMMARY

Dense stocking in second-growth ponderosa pine stands on poor sites in the Inland Empire causes stunting of heights sufficient to impair site index determination by the usual methods. The present study was conducted to measure the extent of this stagnation and to develop adjusted site index curves for use in overstocked stands. A second objective of the study was to present a method for growth prediction, especially suited to understocked stands, which accounts for changes in stocking with time.

The effects of stocking on heights, as reported by other investigators for several forest types, are reviewed; generally, height retardation due to stocking is correlated with site and with the inherent ability of the species to express dominance. In a few instances, dense stocking results in taller than average trees, particularly on good sites; but more commonly, if stocking has any effect at all, it retards height growth.

Data for this study were taken from 207 temporary plots well distributed geographically over the Inland Empire and covering a wide range of sites, stand densities, and ages up to 125 years.

Stocking was evaluated by an equation based on basal area, age, and height, giving a stocking percentage for each plot; a stocking of 100 percent represents the average for all plots of the study. This average stocking is somewhat lower than the normal yield table stocking shown in Meyer's (1938) bulletin.

Height retardation was found to increase as stocking increased above 100 percent and to increase as site indices decreased below site index 75. These effects were measured on paired plots where abrupt changes in stocking were associated with marked differences in stand heights on areas of uniform site insofar as soil, aspect, and surface vegetation could determine.

Adjusted site index curves are presented for stocking percentages 100 or less, 110, and 120. In addition to the differences resulting from the introduction of stocking, the curves differ from the normal yield site curves by being lower for younger and older ages, but higher in the central range of ages. They are believed to fit the conditions of the Inland Empire better than the interregional normal yield curves.

For purposes of predicting future yields of second-growth ponderosa pine stands, graphs are presented, for various site indices, showing basal area by age for different initial basal areas. Graphs showing the relationship of present and future numbers of trees for various initial basal areas are also presented for a range of site indices.

From an estimate of future basal area and number of trees, the forester can determine from appropriate graphs the future average-stand diameter, average volume per tree, and volume per acre. Finally, a method of converting total cubic-foot volume per acre to board-foot volume in trees 10 inches d.b.h. and larger, is presented graphically.

A table of yields for average-stocked stands shows heights, average diameters, basal areas, number of trees, cubic-foot volumes, and board-foot volumes.

The details of the analytical methods are described in the Appendix.

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A P P E N D I X

I. STOCKING PERCENTAGE

Tree-area ratio, as presented by Chisman and Schumacher (1940), expressed the ground area, Y, of a tree in the forest as a function of its d.b.h., d, such that

$$Y = b_0 + b_1 d + b_2 d^2.$$

The sum of the areas occupied by the n trees of a plot is, then,

$$\sum^{n}(Y) = b_0(n) + b_1\sum^{n}(d) + b_2\sum^{n}(d^2), \qquad (11)$$

where $\sum^{n}$ denotes sum of the n values. The observation equations for individual trees cannot be written, because a single tree occupies an unknown area in the forest. But the area that a group of trees occupies, on a one-fifth-acre plot, can be expressed as in equation (1) in terms of the number of trees, sum-of-diameters, and sum-of-diameters-squared. Thus, a group of plots supplies observations for computing the coefficients for the equation from which the area occupied by individual trees may be determined. If plot areas are constant and expressed as unity (or more conveniently as 100), the equation gives relative stocking for any particular set of plot data.

Experience of others with this equation has shown that sum-of-diameters usually is not significant. Basal area can, of course, be substituted for sum-of-diameters-squared because of the constant relationship,

$$B = \Sigma(d^2)0.005454.$$

Other stand variables also affect tree area to a considerable degree. Two important ones to consider are age and height, which can be included by beginning with the equation,

$$S = b_1 N + b_2 B,$$

where S is plot area (conveniently taken as 100), N is number of trees per plot, and B is basal area. The coefficient of B can be considered a function of height and the reciprocal of age; that is,

$$b_2 = a_0 + a_1(H) + a_2\left(\frac{H}{A}\right) + a_3\left(\frac{1}{A}\right).$$

Substituting this value of b_2 into the equation above gives

$$S = b_1 N + \left[a_0 + a_1(H) + a_2\left(\frac{H}{A}\right) + a_3\left(\frac{1}{A}\right)\right] B$$

or

$$S = b_1 N + b_2(B) + b_3(BH) + b_4\left(\frac{BH}{A}\right) + b_5\left(\frac{B}{A}\right). \qquad (12)$$

Solution of this equation by the method of least squares for a group of plot data of uniform area, 100, gives stocking directly in percent. It was solved in this study using data from 207 plots; the contribution of each of the variables is shown in table 3. The added effect of N, although significant, was least important of any of the variables. Because the presence of N in the stocking equation would rende it difficult to use in the growth prediction phase of the study, N was dropped, and the coefficients for the remaining variables computed independently. The completed equation appears on page 10.

Table 3.--Analysis of variance showing the contribution of each variable in the stocking equation,

$$S = b_1(N) + b_2(B) + b_3(BH) + b_4\left(\frac{BH}{A}\right) + b_5\left(\frac{B}{A}\right).$$

Source of variation	Degrees of freedom	Sum of squares	Mean square
Regression on B	1	1,805,664	1,805,664*
Added effect of BH	1	54,592	54,592*
Added effect of B/A	1	7,259	7,259*
Added effect of BH/A	1	31,039	31,039*
Added effect of N	1	5,848	845
Residuals	202	165,598	
Total	207	2,070,000	

* Significant beyond the 1-percent level.

In using the stocking equation to predict future basal area, where basal area becomes the dependent variable, it was necessary to drop BH from the equation. The presence of this variable gave unrealistic values of basal area for advanced ages. Dropping BH and recomputing the coefficients for the remaining variables gave a more satisfactory equation and at the same time made very little difference in the stocking percentages computed. The contributions of the variables in the altered equation are shown in table 4.

Eliminating the variable BH increased the residual mean square from 845 to 898, or increased the uncorrelated variance from 8.28 to 8.37 percent.

Table 4.--Analysis of variance showing the contribution of each variable in the stocking equation,

$$S = b_2B + b_4\left(\frac{BH}{A}\right) + b_5\left(\frac{B}{A}\right).$$

Source of variation	Degrees of freedom	Sum of squares	Mean square
Regression on B	1	1,805,664	1,805,664*
Added effect of BH/A	1	41,199	41,199*
Added effect of B/A	1	39,890	39,890*
Residuals	204	183,247	898
Total	207	2,070,000	

* Significant beyond the 1-percent level.

II. PAIRED PLOT ANALYSIS

The factor Z, i.e. (S-100)(75-Ip), is a variable that was used to measure the effect of site index discrepancies between paired plots; one plot had dense stocking, but the other (the control) had only average stocking. Negative values of (S-100) and of (75-Ip) were considered zero.

Since height and site indices plot as straight lines in the logarithmic transformation, the difference between the site indices of paired plots was written as

$$\log Ic - \log Ip = \log\left(\frac{Ic}{Ip}\right)$$

where Ic = site index of control
Ip = site index of plot.

Expressing the logarithm of the ratios in the first and second power of Z and fitting the equation to the data from the 24 sets of paired plots gave the following equation:

$$\log Ic/Ip = 0.000269(Z) - 0.000093\left(\frac{Z^2}{1000}\right) \tag{13}$$

The analysis of variance is shown in table 5, and the equation is plotted in figure 13.

Table 5.--Analysis of variance showing the contribution of the two variables in the equation

$$\log Ic/Ip = b_1 Z + b_2 Z^2.$$

Source of variation	Degrees of freedom	Sum of squares	Mean square
Regression on Z	1	0.127912	0.127912*
Added effect of Z^2	1	.006349	.006349**
Residuals	22	.029686	.001349
Total	24	0.163947	

* Significant beyond the 1-percent level.
** Significant at the 5-percent level.

III. THE SITE INDEX EQUATION

Starting with the basic equation, in which logarithm of height is a function of the reciprocal of age,

$$\log H = a + b\left(\frac{1}{A}\right). \tag{14}$$

Introducing log I as an independent variable to allow for differences in the growth curves from site to site, the coefficients from equation (14) become

$$a = a_0 + a_1 (\log I)$$

and

$$b = b_0 + b_1 (\log I).$$

Substituting:

$$\log H = a_0 + a_1(\log I) + \left[b_0 + b_1(\log I)\right] \left(\frac{1}{A}\right). \tag{15}$$

Imposing the site index concept, in which log H equals log I at index age 100, gives

$$\log I = a_0 + a_1(\log I) + \left[b_0 + b_1(\log I)\right] \frac{1}{100}$$

or

$$a_0 = \log I - a_1(\log I) - \frac{b_0}{100} - b_1\frac{\log I}{100}.$$

Substituting this value of a_0 in equation (15) gives

$$\log H = \log I - a_1(\log I) - \frac{b_0}{100} - b_1\frac{\log I}{100}$$

$$+ a_1(\log I) + \frac{b_0}{A} + b_1\frac{\log I}{A} .$$

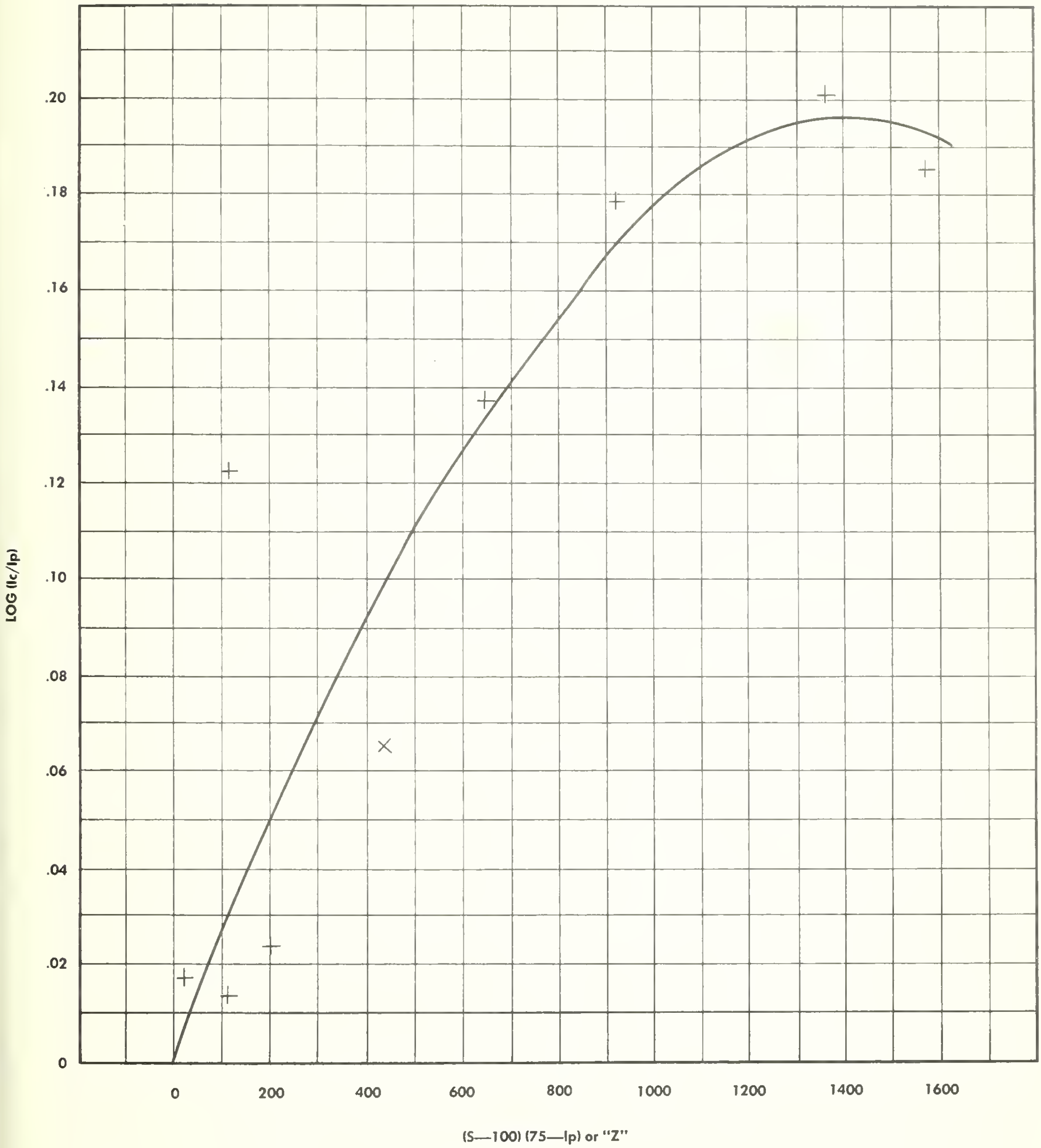

Figure 13.--Graph of the logarithm of the ratio of control site index to plot site index over the factor Z.

Collecting terms,

$$\log H = \log I + b_0\left(\frac{1}{A} - .01\right) + b_1 \log I\left(\frac{1}{A} - .01\right)$$

In the same manner, Z can be introduced to give the equation:

$$\log H = \log I + b_0\left(\frac{1}{A} - .01\right) + b_1 \log I\left(\frac{1}{A} - .01\right)$$

$$+ b_2Z\left(\frac{1}{A} - .01\right) + b_3Z \log I\left(\frac{1}{A} - .01\right) + b_4Z + b_5Z^2.$$

The separate independent variables Z and Z^2 were added to allow site indices less than 75 to fall below the site index points for age 100.

In calculating coefficients for this equation, the variables in which Z appears with the others were nonsignificant, and the equation took the form shown on page 13. The contributions of the variables in the regression analysis are shown in table 6.

Table 6.--Analysis of variance showing the contribution of each variable in the equation,

$$\log H - \log I = b_0\left(\frac{1}{A} - .01\right) + b_1 \log I\left(\frac{1}{A} - .01\right) + b_4Z + b_5Z^2.$$

Source of variation	Degrees of freedom	Sum of squares	Mean squares
Regression on $\left(\frac{1}{A} - .01\right)$	1	14.0512	14.0512*
Added effect of Z	1	.7520	.7520*
Added effect of log $I\left(\frac{1}{A} - .01\right)$	1	.2261	.2261*
Added effect of Z^2	1	.0353	.0353*
Residuals	203	.1965	.0010
Total	207	15.2611	

* Significant beyond the 1-percent level.

IV. AN EQUATION FOR FUTURE STOCKING

Figure 14, A shows the change in stocking with advancing age, the understocked plots increasing in density and the overstocked plots decreasing. In figure 14, B the two outside curves of figure 14, A are shown as straight lines when stocking is transformed to logarithms and age to its reciprocal. In this figure, S is stocking percentage and A is age; with subscripts 0 for present and 1 for future, then,

$$\text{length } PQ = \frac{1}{A_0}$$

and

$$\text{length } QP_2 = \log S_0 - 2$$

$$\text{slope of line } PP_2 = \left(\frac{\log S_0 - 2}{\frac{1}{A_0}}\right)$$

$$\text{length } P_1Q_2 = \frac{1}{A_0} - \frac{1}{A_1}$$

$$Q_2P_2 = \left(\frac{\log S_0 - 2}{\frac{1}{A_0}}\right)\left(\frac{1}{A_0} - \frac{1}{A_1}\right) = (\log S_0 - 2)\left(1 - \frac{A_0}{A_1}\right).$$

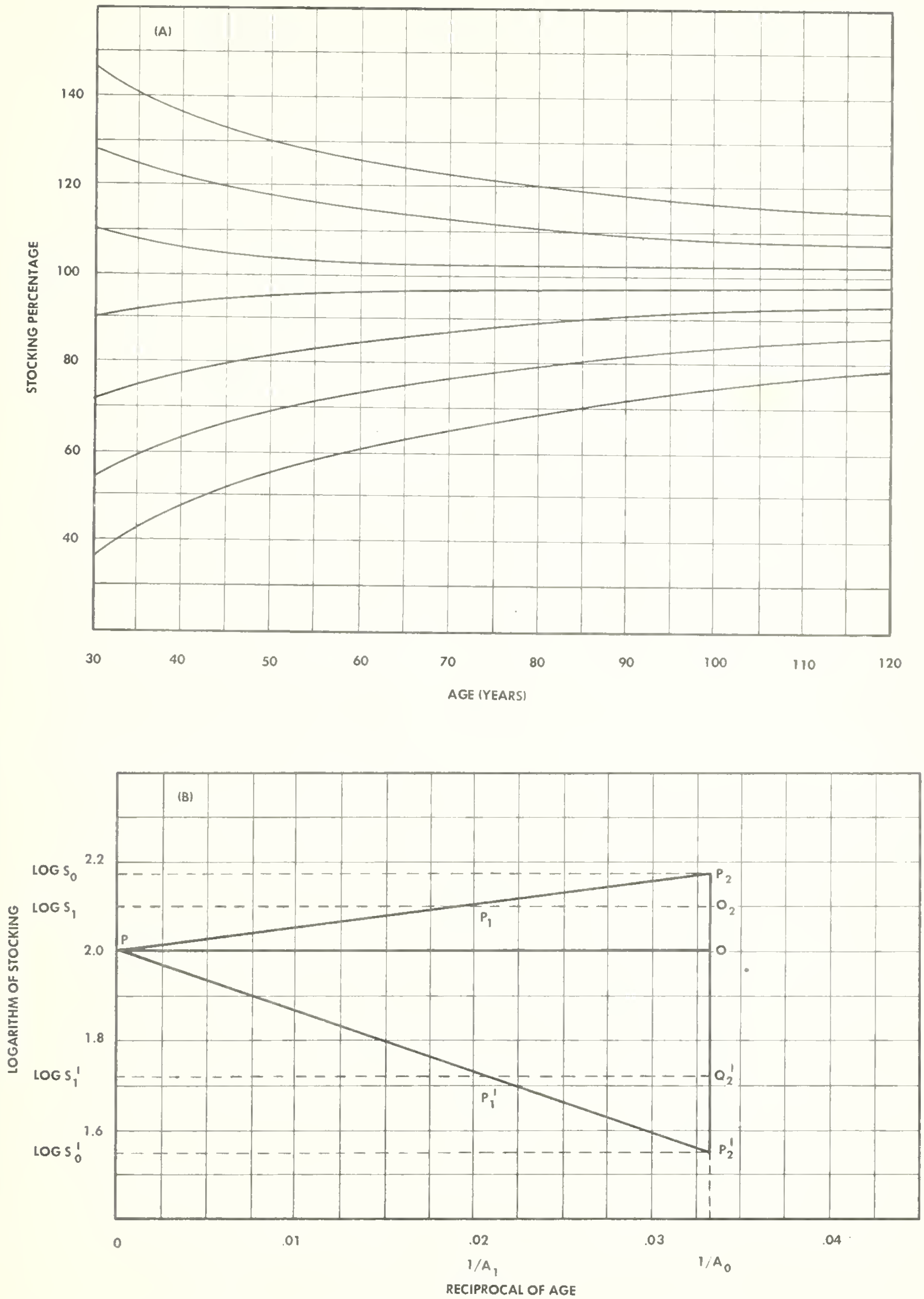

Figure 14.--A, Change in stocking (approach to normal) is shown for ages 30 to 120 and for various initial densities. B, A graphic explanation of the change in stocking equation

$$\log S_1 = 2 + (\log S_0 - 2)\left(\frac{A_0}{A_1}\right).$$

Then $$QQ_2 = (\log S_1 - 2) = (\log S_0 - 2) - (\log S_0 - 2)\left(1 - \frac{A_0}{A_1}\right)$$

or $$(\log S_1 - 2) = (\log S_0 - 2)\left(\frac{A_0}{A_1}\right)$$

and $$\log S_1 = (\log S_0 - 2)\left(\frac{A_0}{A_1}\right) + 2 . \qquad (16)$$

Similarly,

$$\text{length } QP'_2 = (2 - \log S'_0) ;$$

$$\text{slope of line } PP'_2 = \frac{(2 - \log S'_0)}{\frac{1}{A_0}} .$$

$$Q'_2P'_2 = \frac{(2 - \log S'_0)}{\frac{1}{A_0}}\left(\frac{1}{A_0} - \frac{1}{A_1}\right) = (2 - \log S'_0)\left(1 - \frac{A_0}{A_1}\right).$$

$$QQ'_2 = (2 - \log S'_1) = (2 - \log S'_0) - (2 - \log S'_0)\left(1 - \frac{A_0}{A_1}\right) .$$

Then $$(2 - \log S'_1) = (2 - \log S'_0)\left(\frac{A_0}{A_1}\right)$$

or $$- \log S'_1 = -2 + (2 - \log S'_0)\left(\frac{A_0}{A_1}\right)$$

and $$\log S'_1 = (\log S'_0 - 2)\left(\frac{A_0}{A_1}\right) + 2. \qquad (17)$$

Equations 16 and 17 are appropriate for determining future stocking for both overstocked and understocked stands.

V. NUMBER OF TREES

Number of trees per acre can be expressed linearly by the logarithmic transformation of the variables, number of trees (N), dominant height (H), and basal area (B), and by the reciprocal of age $\left(\frac{1}{A}\right)$, in the form

$$\log N = b_0 + b_1 (\log H) + b_2\left(\frac{100}{A}\right) + b_3 (\log B) . \qquad (18)$$

The computed coefficients for this equation appear on page 17. Its analysis of variance is shown in table 7.

Equation (18) can, of course, be used for present number of trees as well as future number by substituting appropriate values. If subscript 0 indicates present and subscript 1 indicates future values of the variables, the difference between future and present log N is

$$\log N_1 - \log N_0 = b_0 - b_0 + b_1(\log H_1 - \log H_0)$$
$$+ b_2\left(\frac{100}{A_1} - \frac{100}{A_0}\right) + b_3(\log B_1 - \log B_0)$$

or $$\log\left(\frac{N_1}{N_0}\right) = b_1 \log\left(\frac{H_1}{H_0}\right) + b_2\left(\frac{100}{A_1} - \frac{100}{A_0}\right) + b_3 \log\left(\frac{B_1}{B_0}\right). \qquad (19)$$

Thus, the ratio of future to present number of trees can be computed.

Table 7.--Analysis of variance showing the contribution of each variable in the equation,

$$\log N = b_0 + b_1 (\log H) + b_2 \left(\frac{100}{A}\right) + b_3 (\log B).$$

Source of variation	Degrees of freedom	Sum of squares	Mean square
Constant	1	1,745.5131	
Added effect of (log H)	1	32.5501	32.5501*
Added effect of (log B)	1	11.2550	11.2550*
Added effect of (100/A)	1	.7380	.7380*
Residuals	203	7.0718	.0348
Total	207	1,797.1280	

* Significant beyond the 1-percent level.

VI. AVERAGE VOLUME PER TREE

The volume per acre of a stand of timber can be expressed linearly in the logarithmic transformation in terms of $\log D^2$, log H, and log N, as

$$\log V = b_0 + b_1 (\log D^2) + b_2 (\log H) + b_3 (\log N).$$

Computing the coefficients on the basis of data from 207 plots gives

$$\log V = -2.6950 + 1.0203 (\log D^2) + 0.9704 (\log H) + 0.9996 (\log N). \quad (20)$$

It would be expected that the volume per acre of a stand would vary directly with number of trees, for constant average diameters and heights, in which case the coefficient of log N should be 1. The difference between 0.9996 and one is 0.0004, which is not significant when compared with 0.02248, the standard error of 0.9996. Consequently, the coefficient of log N can be taken as 1 and then,

$$\log V - \log N = \log \left(\frac{V}{N}\right) = \log v$$

in which V is volume of the stand and v is the average volume of the N trees in the stand. Hence,

$$\log v = -2.6950 + 1.0203 (\log D^2) + 0.9704 (\log H). \quad (21)$$

The analysis of variance for equation (20) is shown in table 8.

Table 8.--Analysis of variance showing the contribution of each variable in the equation,

$$\log V = b_0 + b_1 (\log D^2) + b_2 (\log H) + b_3 (\log N).$$

Source of variation	Degrees of freedom	Sum of squares	Mean square
Constant	1	2,276.6595	
Added effect of (log H)	1	18.4229	18.4229*
Added effect of (log N)	1	3.7540	3.7540*
Added effect of (log D^2)	1	1.5913	1.5913*
Residuals	203	.4154	.00205
Total	207	2,300.8431	

* Significant beyond the 1-percent level.

VII. BOARD-FOOT/CUBIC-FOOT RATIO

The logarithm of the ratio of board-foot volume in merchantable trees (10 inches and larger) to the total cubic-foot volume of a stand is related linearly to the reciprocal of average diameter, such that

$$\log R = b_0 + b_1 \left(\frac{1}{D}\right) + b_2\left(\frac{1}{D^2}\right) .$$

Tree form can be introduced by making the coefficients of $\frac{1}{D}$ and $\frac{1}{D^2}$ functions of height:

$$b_1 = a_0 + a_1 H$$

$$b_2 = c_0 + c_1 H .$$

Substituting,

$$\log R = b_0 + (a_0 + a_1 H)\left(\frac{1}{D}\right) + (c_0 + c_1 H)\left(\frac{1}{D^2}\right)$$

or

$$\log R = b_0 + a_0 \left(\frac{1}{D}\right) + a_1 \left(\frac{H}{D}\right) + c_0 \left(\frac{1}{D^2}\right) + c_1 \left(\frac{H}{D^2}\right) . \qquad (22)$$

Equation (22) was fitted to the data of 121 plots; the only significant variables were $\left(\frac{1}{D^2}\right)$ and $\left(\frac{H}{D^2}\right)$. The equation appears on page 20, and the contributions of the significant variables in the regression analysis are shown in table 9. For convenience, the variables were transformed as follows:

$$\log (R \times 100) = b_0 + b_1 \left(\frac{100}{D^2}\right) + b_2 \left(\frac{H}{D^2}\right) . \qquad (23)$$

Table 9.--Analysis of variance showing the contribution of each variable in the equation

$$\log (R \times 100) = b_0 + b_1 \left(\frac{100}{D^2}\right) + b_2 \left(\frac{H}{D^2}\right).$$

Source of variation	Degrees of freedom	Sum of squares	Mean square
Constant	1	608.8781	
Added effect of $100/D^2$	1	22.0571	22.0571*
Added effect of H/D^2	1	1.4955	1.4955*
Residuals	118	4.7598	.0403
Total	121	637.1905	

* Significant beyond the 1-percent level.

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WATERSHED MANAGEMENT PROBLEMS IN THE NORTHERN ROCKY MOUNTAIN REGION

By

Paul E. Packer
Forester

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE
OGDEN, UTAH

REED W. BAILEY, DIRECTOR

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WATERSHED MANAGEMENT PROBLEMS IN THE NORTHERN ROCKY MOUNTAIN REGION

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INTRODUCTION

Water that falls as snow and rain on mountain slopes of the Continental Divide is one of the most important natural resources in the drainage basins of the Columbia and Missouri Rivers. As this water moves down these two great river systems, considerable effort is directed toward regulating its flow to serve the numerous uses that depend upon it. Those who live in these basins have become aware, often painfully so, that the amount and condition of water flowing in these rivers exert tremendous influence upon personal, economic, social, and recreational affairs. Power plants have been erected to generate electricity for the demands of a rapidly increasing population and expanding economy. Large dams have been built to protect people and property against floods and to impound water for irrigation. Lakes formed by these impoundments have become scenes of intensified recreational developments for boating, fishing, and swimming.

Most of the interest displayed over water in the Columbia and Missouri River Basins is related to development of facilities to control it and put it to use after it enters larger tributaries and main streams. Unfortunately, there has been much less concern about controlling water where it first falls on the land in greatest abundance and where it is susceptible to management for control; namely, on upstream forest and range watersheds. Experience in many places has shown that a change in the disposition by the soil mantle of only a small portion of the water received may greatly affect the manner in which it is delivered as streamflow. The behavior of water and whether it is beneficial or harmful depends, in great measure, upon the condition and the uses of the lands from which it drains.

The Northern Region[1/] administered by the U.S. Forest Service occupies a strategic position with respect to the water resources of the entire Columbia and Missouri River Basins. Straddling the Continental Divide, this region lies almost entirely within the headwaters of these rivers. It contains extensive coniferous forests that are being harvested and converted

1/ The term "Northern Region" refers specifically to the six counties in the northeastern corner of Washington, that part of Idaho north of the Salmon River, all of Montana, the northwestern corner of South Dakota, and the northwestern corner of Wyoming (most of Yellowstone National Park). Likewise, when the terms "Columbia Basin" and "Missouri Basin" are used, it is to be understood that they refer only to that portion of either basin that lies within the Northern Region unless otherwise specified.

from a decadent old-growth condition to vigorously growing young forests. It also contains large areas of range land where many livestock and big game animals graze. The method of managing these forests and ranges can have far-reaching effects upon the condition of the vegetation and soil, and, hence, upon the quality, amount, and rate of water delivered to creeks and rivers.

Since 1905, when the national forest system was created, methods of managing the timber and forage resources have been improved. Most of these improvements were developed mainly in the interest of better production of timber and forage. Few were directed specifically at betterment of watershed conditions although some have effected improvement incidentally. Management problems concerning the influence of various resource use activities on water and soil continue to arise. Some of these problems involve methods of maintaining effective control of water and soil movement under continued timber harvesting, grazing, and recreational uses. Others are concerned with restoring control over water and soil on watersheds where it has been lost through overuse, abuse, or some catastrophe such as wildfire. Still others involve the management of timber and forage resources to improve water-yielding characteristics of watersheds, especially the amount and quality of water and the time of year when it appears as streamflow.

Satisfactory solutions for most of these problems require watershed management research, a need long recognized but only recently implemented in this region. Accurate knowledge is needed of climatic elements; of inter-relations between climate, vegetation, and soil; and of quantitative effects of vegetation and soil on amount, rate, time, and quality of streamflow. Management practices designed specifically to provide desired conditions of streamflow and control of soil must be developed and evaluated.

This report delineates the high priority problems of watershed management on forest and range lands of the upper Columbia and Missouri River drainages. To evaluate the relative importance of these problems it is necessary to understand their scope and the nature of the factors that influence them. This requires a thorough knowledge of: (1) pertinent facts about the existing water situation; (2) the nature of water problems in these two basins; and (3) the manner by which the physical features and resource uses of the region bear on these water problems. This report is not intended to be an exhaustive analysis of general watershed problems and research needs. Rather, it is a condensed summary of a more detailed watershed management research problem analysis recently developed for this area. It should engender interest in watershed management problems and should stimulate research efforts toward their solution.

THE WATER SITUATION

COLUMBIA RIVER BASIN

At its mouth the Columbia River discharges an average annual runoff of nearly 180 million acre feet from about 166 million acres. Of this amount about 41 million acre feet are produced on 35 million acres within the boundaries of the Northern Region (5).

The Columbia River Basin has great potentialities for development. About 4 million acres of land are already irrigated. Comprehensive basin development plans include irrigation of 3.8 million more acres and provision of supplemental water for about 1.5 million acres now irrigated (13).

Installed hydroelectric power capacity is about 5.9 million kilowatts. Potentially, the Columbia River is the greatest power-producing stream in America and one of the greatest in the world. Existing plans, if carried out, would create approximately 11.4 million kilowatts' installed capacity. Potential capacity is estimated at nearly 34 million kilowatts or 40 percent of the Nation's total estimated potential (11).

Existing storage capacity of irrigation, power, and flood control structures on the Columbia River is about 9.5 million acre feet. These structures plus those under construction, authorized, and recommended, would provide about 27 million acre feet of storage. Of this, about 19 million acre feet are considered necessary for control of major floods on the lower Columbia River. The potential developable storage capacity of the entire basin is estimated to be about 100 million acre feet (11).

The total investment to date for irrigation, power, and flood control developments in the entire Columbia Basin is approximately 2 billion dollars. Installation of authorized and recommended developments would bring this investment to about 7.6 billion dollars (12).

MISSOURI RIVER BASIN

At its confluence with the Mississippi River the Missouri River discharges an average of about 59 million acre feet annually from an area of 339 million acres. Of this amount, approximately 17 million acre feet originate on about 82 million acres of Northern Region land. Thus, the Missouri River discharges approximately one-third as much water from about twice as great an area as the Columbia does.

The chief potential of the Missouri River Basin lies in its development for irrigation agriculture. About 5 million acres of this basin are now irrigated. Proposed plans would provide irrigation for about 2.5 million additional acres plus provision of supplemental water for about 250,000 acres now irrigated. Irrigable land in the Missouri Basin, if fully developed, would total nearly 13 million acres (14).

Installed hydroelectric power capacity is only about 928,000 kilowatts, or one-sixth that of the Columbia Basin. Authorized and approved developments would increase this to 3.1 million kilowatts. The potential for development--nearly 6.6 million kilowatts--is still only about one-fifth that of the Columbia Basin (9).

Live storage capacity of existing reservoirs on the Missouri is more than 16 million acre feet. This storage plus that under construction will provide nearly 49 million acre feet of water (10).

The total investment to date for irrigation, power, and flood control facilities in the Missouri River Basin is about 1.9 billion dollars. Completion of projects under construction plus those authorized and recommended would raise this investment to nearly 8.5 billion dollars (8).

Thus, the total cost of water handling facilities in the two basins that depend heavily upon clean, usable water from the forest and range lands of the Northern Region is now about 3.9 billion dollars. Developments that would eventually increase this value to more than 15 billion dollars have already been proposed. Many more billions are already invested in agriculture and industry whose very existence depends upon water and power controlled and distributed by these facilities. Hence, the reliance placed upon water from this region is an integral part of the national, regional, and local economy.

WATER PROBLEMS OF THE COLUMBIA AND MISSOURI RIVER BASINS

Of primary and recurring concern to people living in the Columbia and Missouri River Basins are five important water problems:

1. How to control snowmelt floods, especially on main tributary streams.

2. How to prevent sediment from entering stream channels where it can be carried into power and irrigation reservoirs, water supply systems, and even onto irrigated farm lands.

3. How to increase water supplies for late summer irrigation where sufficient storage facilities cannot be developed.

4. How to improve winter streamflow to insure power generation during low flow periods.

5. How to prevent local "flash" floods that are caused by high-intensity summer rainstorms.

Floods have occurred periodically in the Columbia River drainage--more frequently in the Missouri. Average annual flood damage on the Columbia has been approximately 35 million dollars (11). On the Missouri it has averaged nearly 148 million dollars (14). A variety of climatic conditions can cause major floods in both drainages. Most common, however, is rapid snowmelt often accompanied by heavy rain. In the plains region of the Missouri Basin, snowmelt and/or rainfall on frozen soil have also caused floods.

Annually the Columbia River carries a sediment load estimated at about 19 million tons. This is considerably less than the 200 million tons estimated for the Missouri, but still enough to create substantial damage to downstream water-handling structures. About three-fourths of the sediment movement into these streams occurs during snowmelt runoff periods.

Some sections of both basins have suffered recurring crop failures aggregating millions of dollars of loss because of inadequate water supplies for late summer irrigation. This situation has been most prevalent in the Missouri Basin. Low winter flows have occasionally caused curtailment of power production resulting in "brown-outs" at various highly industrialized locations in the Pacific Northwest.

Major floods and water shortages occur because of untimely streamflow distribution. Sometimes there is too much; at other times, too little. Both of these problems have been alleviated somewhat on the Columbia and Missouri Rivers by construction of storage dams to regulate downstream flow. Projects proposed for both rivers should aid materially in solving the problems of flood control and water shortages.

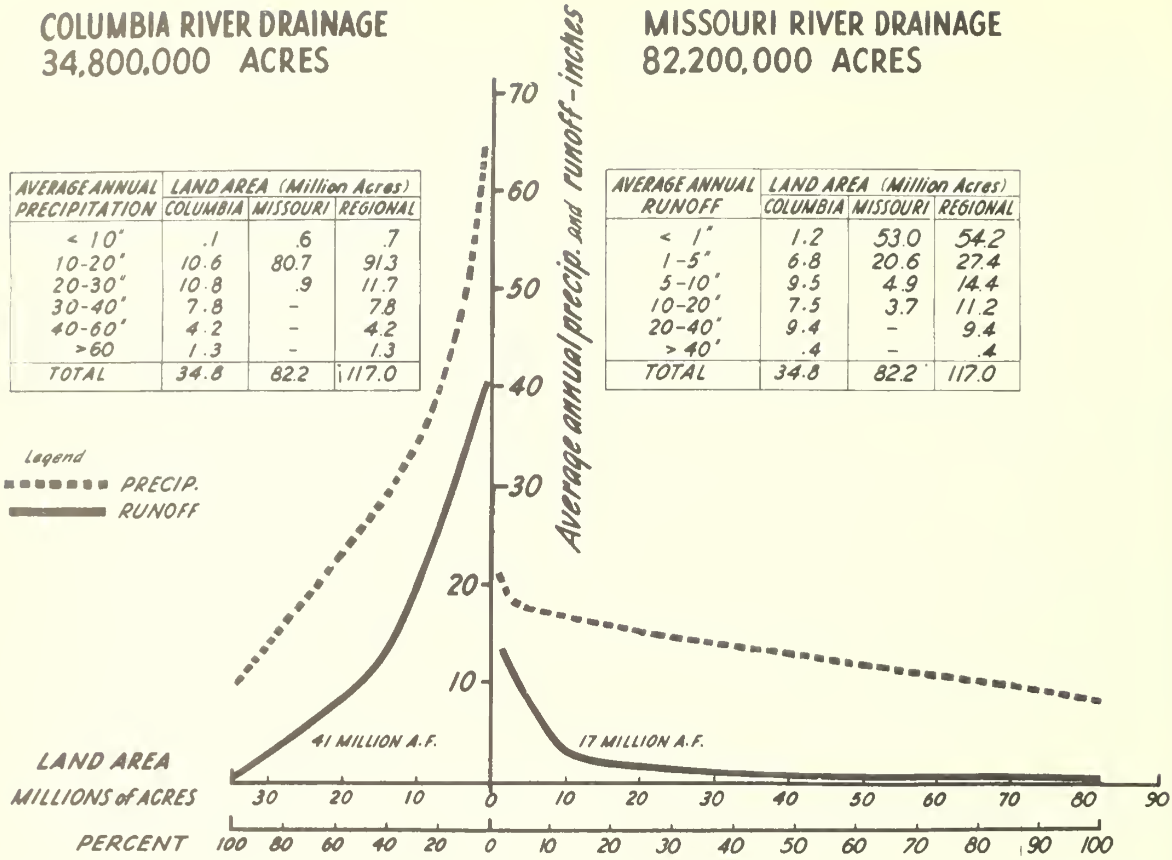
Despite this, two problems remain that storage and streamflow regulation by big dams will not solve. One of these is continuing sedimentation, with its attendant depletion of storage capacity and its high maintenance costs. The other is inability of large dams to prevent flood discharges and water shortages upstream, where sizable investments exist in both rural and urban developments. Methods of managing forest and range lands to regulate effectively streamflow quality, quantity, and timing must be found if the useful life of expensive downstream structures is to be protected and if important upstream areas are to be spared from floods and water shortages.

WATERSHED CHARACTERISTICS OF THE NORTHERN REGION

Hydrologically the upper Columbia and Missouri River drainages differ greatly (fig. 1).

PRECIPITATION

About 70 percent of the upper Columbia River drainage receives more than 20 inches of precipitation annually (15); 40 percent receives more than 30 inches, and 4 percent more than 60 inches. On the Columbia side of the Continental Divide two types of precipitation climate are marked by the



AVERAGE ANNUAL PRECIPITATION	LAND AREA (Million Acres)		
	COLUMBIA	MISSOURI	REGIONAL
< 10"	.1	.6	.7
10-20"	10.6	80.7	91.3
20-30"	10.8	.9	11.7
30-40"	7.8	-	7.8
40-60"	4.2	-	4.2
>60	1.3	-	1.3
TOTAL	34.8	82.2	117.0

AVERAGE ANNUAL RUNOFF	LAND AREA (Million Acres)		
	COLUMBIA	MISSOURI	REGIONAL
< 1"	1.2	53.0	54.2
1-5"	6.8	20.6	27.4
5-10"	9.5	4.9	14.4
10-20"	7.5	3.7	11.2
20-40"	9.4	-	9.4
> 40"	.4	-	.4
TOTAL	34.8	82.2	117.0

Figure 1.--Distribution of average annual precipitation and runoff in the upper Columbia and Missouri River drainages.

Bitterroot-Coeur d'Alene-Selkirk Mountain crest along the Montana-Idaho border. Westerly winds drop much of their moisture in crossing this barrier, and greater precipitation falls at comparable elevations on the west side than on the east. Heaviest rainfall comes during April, May, and June, the months when snowmelt runoff is greatest. Summer rainstorms of moderately high intensity occur, but not as frequently as on the Missouri side of the Continental Divide.

About 70 percent of the land area in the upper Missouri River drainage receives less than 15 inches of precipitation annually. Only about 1 percent receives more than 20 inches (15). The most significant climatic feature of the upper Missouri Basin is the great variation in precipitation from year to year, especially on the plains of eastern Montana. Here, precipitation varies annually from less than 30 to more than 200 percent of normal. Well over one-half of the annual precipitation of 10 to 15 inches in this section comes as rain during early summer. Late summer precipitation is sporadic and comes chiefly as high-intensity thunderstorms. Much of this precipitation is lost by rapid overland runoff that carries large amounts of sediment. In the higher mountains and valleys of the western part of the basin, most of the annual precipitation is snow (15).

RUNOFF

Average annual runoff from nearly 35 million acres in the Columbia Basin is about 14 inches, and represents about 41 million acre feet of streamflow (5). Of this amount, about 27 million acre feet, or 66 percent, originate on 17.8 million acres of national forest land. Main streams and tributaries in this basin have steep gradients, and tributaries are numerous, generally short, and drain rather small individual areas.

In the Missouri Basin slightly more than 82 million acres yield an average of about 2.5 inches of runoff that amounts to about 17 million acre feet of streamflow (5). Of this, about 6.2 million acre feet, or 36 percent, originate on 10.1 million acres of national forests. The flow of the Missouri River differs markedly from that of the Columbia except in the small headwater tributaries which have steep gradients. Many tributaries are large and long and their flow, like that of the main Missouri, is slow and sluggish.

Depending upon the manner in which they produce runoff, watershed lands in the Northern Region are of three kinds (fig. 2):

1. Arid lands, which ordinarily contribute less than 1 inch of runoff annually mostly as overland flow. These lands occupy about 54 million acres, or 46 percent of the region. Ninety-eight percent of these lands are in the Missouri Basin and are chiefly grass and shrub range.

2. Subhumid or semiarid lands, which produce more than 1 inch but usually less than 10 inches of runoff annually. These lands contribute most of their runoff as seepage flow from snowmelt during a short period in spring and early summer and contribute chiefly overland flow during the remainder of the year. They occupy about 42 million acres or 36 percent of the region. About 60 percent of these lands are foothills and lower mountain elevations in the upper Missouri Basin and are covered by a mixture of grass-shrub range and ponderosa pine—Douglas-fir forest. The remaining 40 percent occupies substantial areas along the western fringe of the region and in the valleys and lower mountain elevations of the Clark Fork and Flathead River tributaries of the Columbia in western Montana. Here, as in the Missouri Basin, grass and shrub cover, together with ponderosa pine and Douglas-fir forest, comprise the principal vegetation.

3. Humid lands, which yield more than 10 inches of runoff annually, nearly all as yearlong seepage flow. These lands, aggregating some 21 million acres, or 18 percent of the region, are the major water-yielding areas. Eighty-two percent of these lands are in the Columbia Basin, and are covered mainly by white pine, larch, spruce-fir, and lodgepole pine forests. The remaining 18 percent of the humid lands in the Missouri Basin, occupies the higher mountain elevations in central Montana where the main plant cover is lodgepole pine forests and subalpine grass-forb ranges.

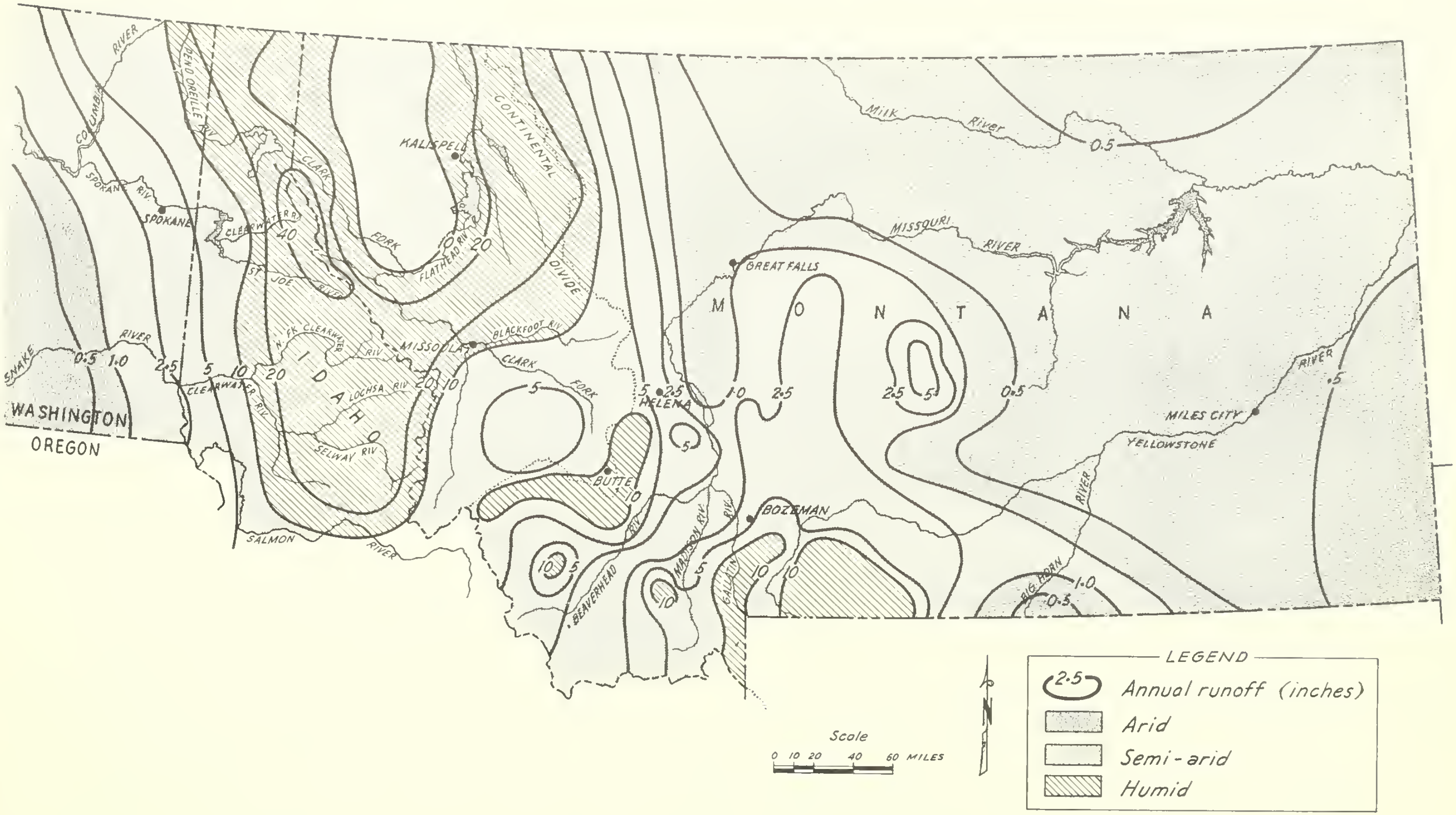


Figure 2.--Average annual runoff in the Northern Region.

When sufficient plant cover exists on these lands, only a small part of the annual precipitation becomes overland flow. Most of it contributes to seepage flow or is stored in the soil mantle and thus reduces soil moisture deficits created by evapotranspiration. When the protective plant cover is damaged and the soil is bared, each of these kinds of watershed lands can unleash undesirable and even destructive overland flow.

SOIL

Many kinds of soil are found in the Northern Region. Little is known about the location and extent of individual soils on the mountainous forest and range lands, and even less is known about their physical characteristics. In the summer of 1956, a cooperative soil survey was commenced by the Forest Service, Soil Conservation Service, and Washington State College on some national forests of this region. This survey should provide valuable information about the occurrence of different soils and important data about their physical characteristics. Hydrologists need more quantitative information about such soil characteristics as infiltration, storage, detachability, and transportability of soil particles, and how these characteristics are altered by different uses of the separate resources. Some important hydrologic features of the soil groups in this region can be related to their geologic origin and their behavior under use.

1. Soils derived from granite, because of their single-grain structure, are noncohesive and gully easily once they are cut by running water. These soils occur chiefly between the Salmon and St. Joe Rivers in northern Idaho on the Bitterroot Mountains, and in smaller areas scattered throughout western Montana.

2. Soils derived from glacial silt deposits, like the granitic soils, are single-grained, but they have finer texture and greater water-holding capacities. They are highly erodible when cut by running water and slip easily when saturated. These soils, deposited by glacial outwash, are scattered across the entire northern part of the region.

3. Loessial soils (windblown deposits from the Palouse prairie of eastern Washington) are fine-textured, productive soils and overlie residual soils at greatly varying depths. They have a high moisture storage capacity but are also highly erodible when cut by running water. These soils predominate along the western edge of the region.

4. Soils derived from basalt are fine-textured and more resistant to erosion than the other soils so far mentioned; they occur predominantly along the western edge of the region (as a result of the Columbia lava flows) and in and around Yellowstone Park.

5. Soils of andesitic and rhyolitic origin, associated with granitic soils, appear to be less permeable but also more stable when exposed to surface runoff. These soils are found chiefly in the mountains of western Montana along the Continental Divide.

6. Soils derived from hard sediments such as shales and sandstones, are silty, sandy, or gravelly loams. In the plains section and along the eastern side of the Lewis and Clark Mountains in Montana these soils are highly erodible and have been cut deeply by many streams. In parts of the upper Columbia Basin, soils from different hard sediments are quite stable, even under intensive forest operations.

7. Soft sediment and terrace soils, found mainly on benchlands and foothills of the upper Missouri Basin, are weakly consolidated alluvium. Two conditions make them heavy contributors of surface runoff and sediment: the sparseness of vegetation that often covers them, and the presence of clay layers that restrict percolation.

8. Soils derived from dolomite are fine-textured and have a tight subsoil. They have perhaps the most critical erosion potential in the region because they erode seriously even when the plant cover is only moderately disturbed. These soils cover extensive areas at intermediate and higher elevations throughout the Missouri Basin.

VEGETATION

Forests

A main concern in watershed management is the effect of forest cover and its treatment on streamflow and soil stability; hence, the extent and condition of forests in the Northern Region must be considered.

About 37 million acres of land in this region are classed as forests (18). Distribution of major forest types is shown in figure 3. Commercial forests in all ownerships total 27.2 million acres and is divided among the major forest types and geographic sections of the region as shown in table 1. Ninety-five percent of the forested area is in coniferous timber.

Table 1.--Area of commercial forest land by forest type and geographic location in the region[1/]

Forest type	Commercial forest area (millions of acres)			
	Northeastern Washington and northern Idaho	Western Montana	Eastern Montana	Totals
Lodgepole pine	1.5	2.3	2.4	6.2
Ponderosa pine	2.5	2.3	1.2	6.0
Douglas-fir	2.1	1.2	1.6	4.9
Larch	1.4	2.6	0	4.0
White pine	2.0	.4	0	2.4
Cedar-hemlock-fir	1.3	.1	0	1.4
Spruce	.2	.4	.3	.9
Woodland	.2	.1	1.1	1.4
Regional total	11.2	9.4	6.6	27.2

1/ Adapted from summary of forest survey statistics prepared for Region 1 as Task VI--Timber Resource Review.

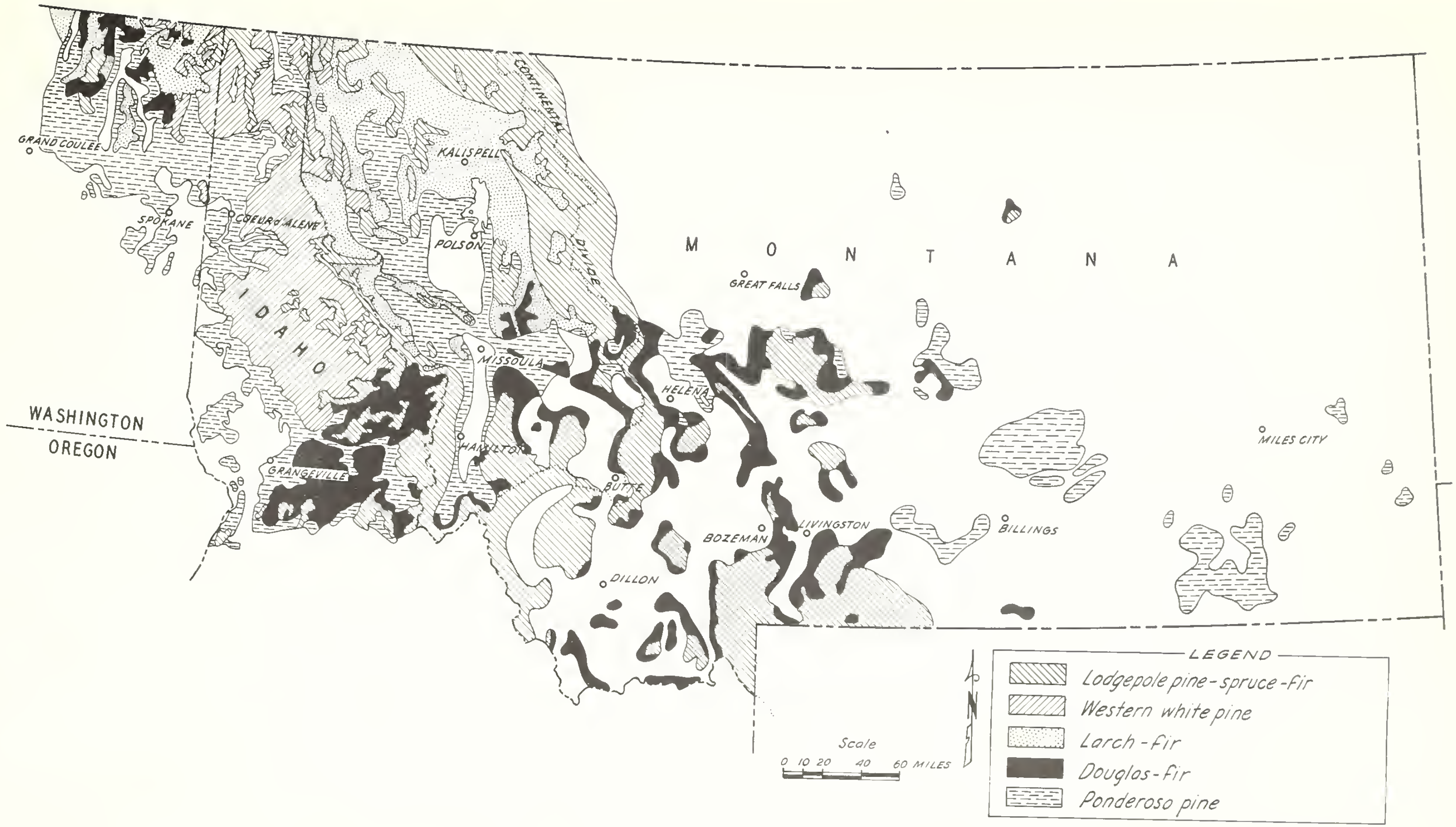


Figure 3.--Distribution of major forest types in the Northern Region.

The most extensive areas of forest land are on the west side of the Continental Divide in northeastern Washington, northern Idaho, and western Montana. Here, on abundant water-yielding areas, the most important forest types are white pine, larch, spruce, lodgepole pine, and cedar-hemlock-fir. On less humid sites Douglas-fir and ponderosa pine predominate.

On the east side of the Continental Divide the important water-yielding forest areas are mainly lodgepole pine with spruce-fir as a stringer type along streams and in higher elevation basins. At intermediate elevations a somewhat drier belt supports Douglas-fir forests; these are bounded at their lower extremities by range land or open ponderosa pine forests.

Some indication of the hydrologic condition of forests in the region is given by the percentages of forest area by stand-size classes shown in table 2. In each of the three major geographic divisions of the region, sawtimber

Table 2.--Percent of commercial forest area in different stand-size classes[1/]

Geographic section	Stand-size classes			
	Sawtimber	Poles	Seedlings saplings	Nonstocked
Northeastern Washington Northern Idaho	42	27	17	14
Western Montana	42	33	21	4
Eastern Montana	29	49	8	14

1/ Adapted from summary of forest survey statistics prepared for Region 1 as Task VI--Timber Resource Review.

and pole stands together occupy from two-thirds to three-fourths of the forested land. Most of these stands probably exert near their maximum effectiveness for controlling overland flow and soil movement and for maintaining moisture storage in the soil mantle. This high proportion of larger sized trees in commercial forests makes early timber harvest desirable to prevent excessive losses from insects and disease. This means that, as intensified timber harvesting progresses towards sustained yield, areas of forest land occupied by newly regenerated sapling and seedling stands will steadily increase. These stands of small young trees, growing on land recently disturbed by road building, log skidding, and other activities connected with timber harvesting, probably do not control overland flow and soil movement nor provide as much soil water storage capacity as do older and larger sized stands growing on long-undisturbed sites. Continued forest use in this region will increase the probability of accelerated overland flow and the threat of floods and sedimentation.

Ranges

The Northern Region contains about 60 million acres of nonforested range land. Most extensive is the sagebrush-grass and low shrub-shortgrass range in the semiarid and arid parts of eastern Montana, occupying about 47 million acres. Some portions of this range extend into badland areas, and probably have always had normally high rates of sediment production; but a far larger portion contributes sediment to the Missouri River system at highly accelerated rates. During the 14-month period from September 1929 to November 1930, sediment measurements disclosed that the Big Horn River drainage discharged about 16.5 million tons of soil (17). This is an annual sedimentation rate of 667 tons per square mile, of which 76 percent occurred during high-intensity rainstorms in June, July, and August. In the same period the Yellowstone River discharged nearly 32.5 million tons of sediment.

Approximately 1.5 million acres of subalpine grass-forb range occupy the higher elevation watersheds of the Northern Region. About 70 percent of this range lies on the Missouri side of the Continental Divide. Extensive summer grazing has seriously depleted much of it. As a result, control over summer storm runoff and soil movement has been lost, and many small streams rising on this range carry large sediment loads during high runoff periods.

Open ponderosa pine-bunchgrass range is dispersed widely over the region on about 3 million acres of semiarid lands. This important source of livestock forage furnishes considerable winter feed for deer and elk. Some areas, especially along the western fringe of the region and in the upper Clark Fork and Kootenai drainages in western Montana, have been overgrazed. Much of the native bunchgrass cover has been replaced by a sparse cover of annual weeds; this change has increased overland flow and soil erosion.

Most of the remaining 8.5 million acres of range is interspersed with forest. Only the mountain meadows and parklike openings in the timber are useful for livestock. Because of sparse forage and difficult accessibility through dense forest stands this range is used mostly by big game.

About 6.3 million acres of national forest range in this region currently provide approximately 689,000 animal unit months of livestock grazing annually, distributed as shown in table 3. Most of the concern about range watershed conditions and the influence of grazing management practices on these conditions is centered in Montana, where about 81 percent of the regional national forest grazing occurs on approximately 75 percent of the usable range. By far the larger part of this use is on the Missouri side of the Continental Divide.

Table 3.--Animal unit months of actual livestock grazing and area grazed annually on national forest ranges in the Northern Region[1/]

State	Actual grazing		Area used	
	Animal months	Percent of total regional use	Millions of acres	Percent of regional area
Montana	560,000	81	4.7	75
Idaho	77,000	11	1.2	19
Washington	30,000	5	.3	4
South Dakota	22,000	3	.1	2
Total	689,000	100	6.3	100

1/ From Annual Grazing Report, Region 1, 1955.

A 1949 estimate (2) of range condition on national forests in the Northern Region indicated 56 percent of the range to be in satisfactory condition, 30 percent to be fair, and 14 percent to be poor. More recent estimates indicate that a substantially higher proportion is in poor condition. On numerous areas signs of range deterioration have not been recognized. Two outstanding needs are: (1) more precise evaluation of range condition and trend on areas not yet obviously depleted, and (2) restoration of deteriorated ranges to such condition that they can control storm runoff and soil movement.

SUMMARY

This brief review of watershed characteristics reveals pertinent facts and relationships regarding watershed conditions in the Northern Region.

1. Average annual precipitation of about 29 inches on Columbia Basin lands is almost double the 15 inches received by lands in the Missouri Basin.

2. Three-fourths or more of the annual precipitation in the Columbia Basin falls as snow. In the Missouri Basin, snow accounts for only about one-half of the annual precipitation.

3. About one-half of the Columbia Basin's average annual precipitation, or approximately 14 area inches of water, runs off as streamflow. In contrast, only about one-sixth of the Missouri Basin's annual precipitation, or approximately 2.5 inches, appears as streamflow. From two-thirds to four-fifths of the annual discharge of both basins occurs between March and July.

4. Evapotranspiration causes loss of only about one-half of the precipitation in the Columbia Basin, but about five-sixths of the precipitation in the Missouri Basin. The greater loss is in the area that receives less total precipitation but more of it as intermittent summer rainstorms.

5. Nearly all the soils are highly erodible when bared by disturbance. They are shallow and have low storage capacity on the steep slopes. This condition emphasizes the necessity of maintaining protective plant cover to control overland flow and to maintain moisture storage capacity.

6. A high proportion of the forest cover is mature or near-mature and probably exerts close to its potential for flood control and consumptive water use. This hydrologic condition likely will be altered by timber harvest, which will convert these forests from an old to young growth condition.

7. A large percentage of range land is in unsatisfactory condition for controlling storm runoff and soil erosion.

WATERSHED MANAGEMENT PROBLEMS

The numerous problems of watershed management encountered in the Northern Region can be classified into three general groups.

First, and probably most pressing is the problem of maintaining the normal hydrologic functioning of watersheds under use without creating conditions that lead to a rapid and severe state of deterioration. Second, but of less magnitude is the problem of restoring damaged watersheds. Both of these problems are concerned with development and application of effective measures for controlling overland flow and soil erosion. Third, limited in extent, but growing in importance, is the problem of improving water yields by increasing streamflow or by altering its time of delivery to meet seasonal demands for water more satisfactorily.

Two general kinds of information about watershed management are needed to provide solutions to these problems. One is quick development of protection criteria or guides for such activities as road building, logging, and grazing. The other is development of quantitative relationships that express the hydrologic effects of management treatments on streamflow and soil stability characteristics of forest and range watersheds.

PREVENTION OF FOREST WATERSHED DAMAGE

Prevention of damaging increases in streamflow peaks and sediment from forests of the upper Columbia Basin is the most important watershed management problem for several reasons. These forests, especially those of the white pine, larch, spruce-fir, and cedar-hemlock types, receive heavy snowfall each year and accumulate extremely deep snowpacks. Snowpacks melt most rapidly during April, May, and June--the months of heaviest seasonal rainfall. Consequently, soil mantles must dispose of larger amounts of water here than in any other part of the region. These forests--about 20 million acres--are frequently a source of damaging floods on the Columbia River or its tributaries.

For the past several years the annual cut of timber in the Northern Region has been nearly 1 billion feet from national forests and more than 800 million feet from state and private forests. Ninety-five percent of this timber has come from Columbia Basin watersheds. This harvest removed all or part of the forest from about 112,000 acres annually. It also required building approximately 1,600 miles of truck and jammer roads and 1,000 miles of tractor trails, construction that removed nearly all protective plant cover from about 10,000 acres each year. It is estimated that the volume of merchantable sawtimber in the region (about 136 billion board feet (16)) can support a sustained allowable timber cut of nearly 2.7 billion feet annually, an increase of about 50 percent above the current cutting level. The area cut and occupied by roads and skidtrails can be expected to increase correspondingly.

Wherever timber is removed from such large areas, and especially when it is removed in clear-cut blocks as is commonly done in this region, the interception and shading effects of the forest may become negligible for a period of 10 to 20 years until new stands become established (fig. 4). During this interim period the soil mantle inevitably receives as precipitation more water requiring disposal. Following timber removal, transpiration of water and moisture storage opportunity in the soil mantle are reduced. This condition can lead to substantially aggravated flood discharges from forest lands. The normal storage capacity of forest soil is also reduced by removing litter and humus normally incorporated in the upper soil layers; this may be caused by road building, log skidding, fire, or erosion. The resulting increase in overland flow accentuates the potential for larger flood peaks.

These combined circumstances raise important specific questions about how much timber can be removed safely from a watershed, and in what manner, without aggravating flood peaks and sediment production:

1. How can logging roads be located and constructed to prevent or reduce soil movement into stream channels?

2. How can overland flow from road and skidtrail surfaces be controlled to prevent its entry into stream channels?

3. Where and in what patterns can timber be cut so that the rising stage of snowmelt streamflow begins earlier and the receding stage continues longer into the summer without increasing the height of peak discharge?

4. How can slash and other logging debris be disposed of without increasing overland flow and soil erosion?

Figure 4.--A clear-cut block of white pine timber on the Deception Creek Experimental Forest in northern Idaho.

White pine forests constitute those areas for which solutions to these problems are most urgently needed. The 2.4 million acres they occupy have the heaviest annual runoff in the region; it averages from 20 to more than 40 inches. These forests are infected with blister rust, control of which requires the harvesting of timber in relatively large blocks. The possibility of developing rust-resistant strains of white pine gives some hope for eventual greater flexibility in methods of cutting. The necessity for cutting white pine forests in large blocks creates the hazard of increasing peak streamflow from any given watershed in these forests. The granitic, glacial silt, and loessial soils, highly erosive when disturbed, are the most critical problem areas in white pine forest because of their potential for producing sediment.

These problems are almost as important in the larch and spruce-fir forests of western Montana and extreme northern Idaho, where snowpacks and water yields approach those in the white pine belt.

PREVENTION OF RANGE WATERSHED DAMAGE

Nonforested ranges occupy nearly 52 percent of this region. Except for those at high elevations, these ranges individually yield only small amounts of streamflow. Because collectively they occupy large areas, their total streamflow amounting to about 12 million acre feet annually is more than one-fifth of the regional water production. The most critical hydrologic problem on these ranges is the manner in which this water is yielded as streamflow and the accompanying sediment production. Nearly half of the rangeland in the region is not controlling storm runoff and erosion effectively. As a result, water from these ranges reaches stream channels as overland runoff laden with eroded soil. From two-thirds to three-fourths of the total sediment load carried by streams in this region is produced on deteriorated rangelands.

Three important physical processes contribute to range deterioration and loss of control over water and soil. One of these is reduction in surface area covered by plants and litter that follows the downhill soil sloughing caused by animals trampling on slopes. Another is soil compaction produced by this trampling, especially on gentle slopes and on dense or very wet soils. A third is reduction in the litter produced by range vegetation following repeated removal of excessive amounts of herbage as forage. Adequate information about litter production potentials of plant cover and tolerable limits of forage utilization and disturbance from trampling is lacking. Consequently, it is difficult to design effective methods for preventing depletion of plant cover and soil and loss of control over water and soil on the remaining undamaged ranges in the region. Specific quantitative knowledge is needed about:

1. How much and what kind of plant cover and what soil conditions are required to effectively cope with high-intensity summer rainfall?

2. To what extent and by what methods can ranges be grazed without destroying the plant cover and soil conditions that provide control of storm runoff and soil stability?

Figure 5.--The good cover of vegetation and litter controls storm runoff and erosion on this subalpine grass-forb range.

Solutions for these problems are needed most urgently on subalpine grass-forb, sagebrush-grass, and low shrub-shortgrass ranges in the upper Missouri Basin in Montana (fig. 5). Here, high-intensity summer rainstorms occur frequently on dolomitic and soft and hard sediment soils that are very unstable when protective plant cover is lacking.

RESTORATION OF DAMAGED FOREST WATERSHEDS

Wildfire and faulty road-building practices have been the two chief causes of forest watershed damage in the Northern Region. In the 40-year period from 1908 to 1947 more than 12 million acres burned, some areas two or three times (1). New stands of timber have regenerated on some burned areas, but more than 2 million acres that received multiple burns are either unstocked or are very poorly stocked with young timber. A large part of this multiple-burned area is in northern Idaho and western Montana. Active erosion continues over much of it (fig. 6). Tree planting programs are under way or planned for restoring forest cover to about 500,000 acres of the best timber-growing sites. On the remainder, improved plant cover is still needed to stabilize the soil.

Active erosion continues on numerous steep, poorly located and improperly constructed roads in logging areas. Major trouble spots are deep road cuts, long fill slopes, and poorly drained road surfaces, especially where they crowd stream channels (fig. 7). Repeated reseeding on many areas has failed to establish plant cover. Plausible causes for failure are unstable seedbeds, insufficient moisture available to seedlings near the soil surface, and lack of fertility in the raw, exposed subsoils.

If flood peak discharges and sediment are to be held in check, methods to control overland runoff and soil erosion on these damaged forest watersheds must be developed. To do this, we must learn:

Figure 6.--Protective forest litter and humus on this slope have been almost completely destroyed by fire.

1. What vegetation and what mechanical measures can be used effectively to control overland flow and stabilize soil on eroding burns, bared road surfaces, cuts, and fills?

2. How and in what degree do these measures affect streamflow and sediment production?

These problems are more closely associated with soils than with forest types. The loessial and granitic soils in north central Idaho, the glacial silt soils across the northern part of the region, and the dolomitic soils in the upper Missouri Basin are the most vulnerable to erosion in the absence of protective plant cover. Major forest types usually found on these soils, and in which these problems are of prime concern, are white pine, larch, spruce-fir, and lodgepole pine.

Figure 7.--This road was built too close to the stream channel. It reduced channel capacity and created a direct source of sediment for the stream.

RESTORATION OF DAMAGED RANGE WATERSHEDS

The need for more precise definition of present condition and trend on range areas that are in neither very good nor very poor condition has been pointed out. Despite some deterioration from overuse, many ranges still support abundant cover of native perennial vegetation. Some overland flow and soil movement may occur during heavy rainstorms, but most of the topsoil is still intact. Most such ranges could return naturally to a satisfactory condition by careful management that would include protection from excessive grazing.

On the other hand, on more than 200,000 acres of native range on the national forests and on more than 2 million acres of range outside these forests the perennial plant and soil cover has become so depleted that runoff has removed several inches of topsoil and carved pronounced gully systems (fig. 8). Streams rising on or flowing through these ranges carry large sediment loads during summer storms and periods of snowmelt runoff. Stream banks and channels have been torn by these sediment-laden discharges, and thus have contributed additional sediment. The quality of irrigation water from these streams has progressively deteriorated. If damaging peak discharges and the eroded soil they carry are to be controlled, methods of restoring plant cover and soil conditions that permit torrential rainfall to enter the soil mantle where it falls rather than to run off over the ground surface must be found. Studies are needed to determine:

1. What grazing management methods, artificial revegetation measures, and mechanical structures are required to restore runoff control and soil stability to badly damaged ranges?

2. How do restoration measures affect streamflow peaks, water yields, and sediment production?

Figure 8.--Loss of control of storm runoff on this deteriorated subalpine range has caused extensive sheet erosion and gully formation.

Critically depleted areas that cause most concern lie on the low shrub-shortgrass range in eastern Montana, on the subalpine grass-forb range in the higher mountains of the upper Missouri Basin, and on the sagebrush-grass range in the foothills of these mountains. On the low shrub-shortgrass range, abandoned dry-farm lands on hard sediment and glacial silt soils appear to be major sources of sediment and most in need of rehabilitation. Unstable dolomitic soils are major problem areas on subalpine grass-forb range. On sagebrush-grass range, which lies mainly on soft sediment and terrace soils, excessive winter use by game animals on south-facing slopes and wind-blown ridges has made these locations the main problem areas.

IMPROVEMENT OF WATER YIELDS ON FOREST LANDS

Water shortages occur throughout the Missouri Basin about 1 year in 10. Shortages also occur locally within the basin almost every year. Streams that have steep profiles and major tributaries provide little opportunity for surface storage of water. About 75 percent of the annual streamflow is discharged by early July; hence, upper basin irrigation depends upon variable and often inadequate streamflow in summer and fall. Increased water supplies and, even more important, improvement of streamflow timing are needed to meet irrigation demands.

The best opportunity for creating hydrologic conditions needed to improve summer water yields lies in the forested watersheds at high elevations in the upper Missouri Basin, where most of the precipitation is snow. Another opportunity exists in heavily vegetated streamside areas where much water is lost by transpiration. Cutting of forests and removal of riparian vegetation increase water yields, but the magnitude of increase in relation to the treatments required, the extent to which timing of streamflow can be altered, and the effects of treatment on peak discharges and sediment production are far from being known. It is important to know whether streamflow peaks increase in damaging amounts and whether streamflow can be delayed in terms of weeks or only days. Research is needed to determine:

1. Where and in what patterns timber can be cut so that any additional streamflow from snowmelt will be distributed more uniformly over the receding stage during the summer without increasing the height of peak streamflow?

2. How much timber can be removed safely from watersheds without creating flood and sediment hazards?

3. How, and to what extent, removal of riparian or other streamside vegetation affects water yields and peak streamflow?

Figure 9.--Clear-cut blocks in a lodgepole pine forest in Montana.

Solutions for these problems are urgently needed for those lands that support the lodgepole pine type. This forest type occupies about 2.5 million acres of the greatest water-yielding land east of the Continental Divide in Montana (fig. 9). Until recently, relatively little lodgepole pine timber was cut. Increased demands for lumber and improved techniques in wood utilization have combined to accelerate timber harvesting from these forests during the past few years. Silvicultural conditions favor clear cutting of lodgepole pine in large blocks. These forests are infected with dwarfmistletoe, a parasitic forest disease that develops most intensively within a distance of about one tree height from clear-cut borders. Large clear-cut blocks tend to reduce the perimeter exposed to infection, but they also tend to increase the hazards of higher runoff peaks and erosion. Dolomitic soils are the most critical areas in lodgepole pine forests because they are most extensive and can produce large quantities of sediment when disturbed. They also generally have deep soil mantles that afford more opportunity for increasing water yields by cutting timber.

IMPROVEMENT OF WATER YIELDS ON RANGE LANDS

Need for improved water yields in the Missouri Basin directs consideration to range lands as a possible source of additional water or as an area where timing of streamflow can be altered. Studies in Utah (7) and Colorado (19), as well as in the Siberian steppes (4), indicate that drifting snow can be piled into deep packs where melting may be delayed sufficiently to lower the peak streamflow and to prolong summer flow. The chief opportunity for snow management to accomplish these objectives exists on about 1 million acres of subalpine grass-forb range (fig. 10). In the Northern Region this range has received no attention as a possible source for water yield improvement. More knowledge is required about the following:

Figure 10.--Late summer remnants of snowbanks on a subalpine range in Montana.

1. How, and to what extent, such structures as drift fences and planted windrows can be employed to accumulate snow into deep packs and retard melting?

2. To what extent do such treatments affect the amount of streamflow and the time of its occurrence?

Considerable evidence indicates that increased yields of water may be obtained from some range lands by converting deep-rooted plant cover that consumes much water to a shallow-rooted cover that transpires less (3, 6, 9). Presumably, under these circumstances, less water would be required to recharge the soil mantle to capacity; hence, more water would be available for streamflow. Prerequisite to increased water yields obtained in this manner is the need to maintain high quality of water by keeping a protective plant cover on the ground to control overland runoff and prevent erosion. Studies are needed to learn:

1. How to convert a deep-rooted plant cover to a shallow-rooted one and maintain it?

2. How, and to what extent, such conversion affects the amount and rate of streamflow and sediment production?

Lying below and intermingled with the Douglas-fir forests of the upper Missouri Basin in Montana are about 2 million acres of sagebrush-grass range. Except for limited use by antelope and deer for winter forage, the sagebrush of this range is practically worthless. If most of this range could be converted to grassland, its value for cattle forage would be increased and, at the same time, water yields might be increased, especially on deep, soft sediment and terrace soils having high water storage capacities.

SUMMARY

Watershed management problems and the areas in this region where they need most attention are summarized in table 4. Three of these problems deserve immediate research.

Table 4.--Major watershed management problems and problem areas in the Northern Region

Problems	Areas: Drainage	Areas: Vegetation	Areas: Soil	Research priority
How to manage forests and ranges to prevent damaging increases in snowmelt runoff peaks and sediment	Columbia	White pine forest	Loessial-granitic-glacial silt	1
	Columbia	Larch-spruce-fir forest	Glacial silt	2
	Missouri	Subalpine range	Dolomitic	3
How to manage forests and ranges to improve summer water yields without increasing streamflow peaks and sediment production	Missouri	Lodgepole pine forest	Dolomitic	1
	Missouri	Subalpine range	Dolomitic	2
	Missouri	Spruce-fir forest	Dolomitic	3
How to manage damaged ranges to restore control of summer storm runoff and sediment	Missouri	Subalpine range	Dolomitic	1
	Missouri	Sagebrush-grass range	Soft sediment	2
	Missouri	Low shrub-shortgrass range	Hard sediment	3

First is the problem of managing white pine forests in the deep snowpack belt of northern Idaho and extreme western Montana to avoid aggravating snowmelt runoff peaks and sediment production. This problem should have highest priority because of the potential flood and sedimentation hazards contingent upon clear cutting timber from areas that normally produce near-flood peaks of snowmelt runoff.

The second major problem is the management of lodgepole pine forests in the snowpack zone of the upper Missouri Basin to increase the amount and improve the timing of summer streamflow without incurring damaging increases in peak runoff and sediment production. Solution of this problem is urgent for two reasons. One is the hazard of increasing flood and sediment production following clear cutting of timber from these areas that receive deep winter snowpacks and frequent torrential summer rainstorms. The other is the rapid expansion of timber harvesting, which may ease the increasing shortage of water in the upper Missouri Basin by improving summer water yields.

A third problem is restoration of plant cover and soil conditions capable of controlling summer storm runoff and erosion on damaged subalpine grass-forb ranges on the higher mountains of Montana. Solution of this problem should have high priority because large volumes of sediment now flow into downstream structures from these ranges.

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