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LOGGING SLASH FLAMMABILITY

By

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G. R. F.

Most of the experimental work reported in this paper was performed while the author was in the division of Forest Fire Research of the Intermountain Forest and Range Experiment Station. He is now a member of the staff of Forest Fire Research, Southern Forest Experiment Station, Alexandria, Louisiana.

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INTRODUCTION

Some of the most disastrous forest fires in North American history burned in slash left from logging and land clearing. In the era before organized fire control, the names Miramichi, Peshtigo, Hinckley, and Cloquet stand for millions of acres blackened and thousands of lives snuffed out (*17*).[1] More recently the Half Moon Fire in Montana, the Tillamook Fire in Oregon, the Forks Fire in Washington, and the Dudley Lake Fire in Arizona, to name only a few, owed their irresistibility to the slash fuels that fed them. Over much of the West logging slash is now the most hazardous forest fuel, and it threatens to remain so for an indefinite period.

Slash is the residue left in the woods after timber has been harvested. It consists of foliage, twigs, branchwood, bark, rotten wood, and cull or otherwise unusable material. Most of this debris once comprised parts of the harvested crop trees, but sizable quantities are sometimes broken from the residual stand in logging. Leaving slash after the harvest of forest products is as inevitable as leaving the core after eating an apple. An apple core must be picked up because garbage is an eyesore and a public nuisance. Slash also is unsightly, but it requires treatment primarily because it is highly flammable.

To reduce or compensate for flammability, slash and cutover areas are treated in various ways, all of them expensive. In Montana, Idaho, and northeastern Washington, forestry and protection agencies annually spend about $3.75 million for slash disposal and extra fire protection on cutover lands. Effective expenditure of these funds has been difficult because means for measuring the fire hazard of slash have been inadequate. In 1948 the College of Forestry of the University of Idaho started comprehensive research on the slash problem in the northern Rocky Mountains. Since 1952 the University and the Intermountain Forest and Range Experiment Station have cooperated to study intensively the physical characteristics and flammability of slash fuels. Technical guidance and physical assistance in carrying on experiments have been generously provided by several cooperators. A description of the entire slash research program, including some information on early results, was published in 1955 (*31*).

The present publication reports more technically and in greater detail the results of the first 5 years of research on slash flammability. It states explicitly how various factors affect flammability and describes new methods for more accurate evaluation of the hazard of varied slash situations than has been possible hitherto.

SPECIES STUDIED

Forests in the northern Rocky Mountains are rich in coniferous species. Opinion about their relative flammability varies widely, and unquestionably important differences between species do exist. To identify and measure meaningful differences, slash of the nine species that are most important commercially was used in the flammability investigations reported here. These species are: western white pine (*Pinus monticola* Dougl.), lodgepole pine (*P. contorta* Dougl.), ponderosa pine (*P. ponderosa* Laws.), western redcedar (*Thuja plicata* Donn), Douglas-fir (*Psuedotsuga menziesii* var. *glauca* (Beissn.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Engelmann spruce (*Picea engelmannii* Parry), grand fir (*Abies grandis* (Dougl.) Lindl.), and western larch (*Larix occidentalis* Nutt.).

KIND AND LOCATION OF STUDIES

Research on slash flammability thus far has involved three major types of operations: (1) experimental burning to measure rate of fire spread and fire intensity; (2) continuous study of moisture content of slash from the time of cutting until the end of the current fire season; and (3) crown analysis to determine the relationship of tree crown weight and other characteristics to species, d.b.h., and crown length. Various sidelines to these three main lines of endeavor were pursued as possibilities of obtaining additional worthwhile information appeared.

All the experimental research reported herein was done on the Priest River Experimental Forest in northern Idaho. Most of the complete crown analyses were made there also. Crown length measurements, to permit extension of the basic crown weight relation to forest stands,

[1] Italicized numbers in parentheses refer to items in the Bibliography.

Figure 1. **Upper,** extreme slash condition after cutting sawlogs and cedar poles in the western white pine type; **lower,** result of fire in heavy slash.

were made on permanent sample plots in northern Idaho and northeastern Washington. Additional determinations of crown weight and crown length in the lodgepole pine type east of the Continental Divide were made in central Montana. The main research installation was the so-called "outdoor slash laboratory" for experimental burning (fig. 2).

SUMMARY OF RESULTS

The generally accepted definition of flammability is "the relative ease with which fuels ignite and burn regardless of the quantity of the fuels" (*43*). In the research described here, flammability means burning rate and fire intensity as affected by all qualitative and quantitative characteristics of the fuel. Ease of ignition is not discussed in this study since effective fire-starting agencies may be assumed to exist.

General Characteristics of Slash

All kinds of conifer slash are so similar chemically that physical characteristics appear to determine how slash burns. The general appearance of tree crowns — length, width, density, diameter, and length of branches — is a good rough indication of relative flammability. In general, tolerant species have more needles and fine twigs than intolerant species. The relative amount of this fine material decreases with age. *Loss of needles is the most important change in slash during the first few years after cutting.* Some splitting of bark and checking of wood also occur, but decay is not noticeable under northern Rocky Mountain conditions. Continuity of fine material within the fuel bed varies with distribution of foliage and twigs on branches and retention or loss of needles as slash ages. Compaction of the fuel bed usually reduces flammability, but much less so than reduction in amount of fine slash components.

Drying Rate

Moisture content of freshly cut slash varies from less than 100 percent to more than 350 percent. Time required for moisture content of fine material to reach 10 percent varies from 2 weeks to several months, depending on treatment and exposure to sun and wind. *Sometimes the slow drying rate of unlopped tops may obviate the need for early disposal, but usually enough quick-*

drying, lopped or broken material is present to cause high hazard. Slash in exposed locations — in heavily cut areas, especially those on southerly aspects — requires treatment soon after cutting during the fire season. During the first summer after cutting, moisture in wood more than 4 inches in diameter becomes evenly distributed and declines to about 30 to 40 percent.

Measurement

The quantity of slash that will result from cutting a given stand can be estimated with acceptable accuracy from measurements of the standing trees. Crown weight is proportional to the product of d.b.h. and crown length. Tables of crown weight by d.b.h. classes have been prepared using average crown length values. Although these tables are subject to considerable error if used to estimate the crown weight of an individual tree, they can be used in conjunction with stand tables to obtain satisfactory estimates of slash weight per acre. Greater accuracy can be attained by measuring representative crown lengths in each stand to be estimated. Weight of slash per thousand board feet cut varies widely with species and size of timber. Factors are provided for use in estimating the relative quantities of slash on different areas; these estimates, in turn, indicate the relative size of the disposal job and form a basis for estimating what should be charged for disposal.

Rate of Fire Spread

During the year of cutting, quantity of slash is the main factor affecting rate of spread, but lesser effects of species characteristics are noticeable. Thereafter species becomes more important because of differences in rate of decomposition. For fresh and 1-year-old slash, experiments have developed relative flammability factors and rankings for the species studied on a pound-for-pound basis. These factors can be multiplied by quantity factors to calculate over-all relative flammability ratings. From these measurements it appears that rate of spread in slash has been underrated by the Region 1 fuel-type classification system.

Results of experimental burning indicate that increasing relative humidity proportionately reduces rate of fire spread. This effect is about twice as great in 1-year-old slash as in fresh.

Figure 2. Outdoor slash laboratory at Priest River Experimental Forest where experimental burning and study of slash characteristics were carried on.

Intensity of Slash Fires

Fire intensity, measured in terms of heat radiation, closely parallels rate of spread. Because large quantities of attached foliage are held above the ground and well aerated, fires are especially hot in heavy concentrations of fresh and 1-year-old western white pine and lodgepole pine slash and in fresh Douglas-fir and grand fir slash. When a large area is burning rapidly, flames reach high into the air and often pulsate rhythmically. Gases in the convection column above the main body of flames commonly ignite when heavy slash concentrations burn; this ignition of gases and the presence of dense black smoke indicate incomplete combustion. Maximum emissivity of experimental slash fires approximates 0.30.

Application of Research Findings

The study of slash flammability was designed to increase basic knowledge of slash as a forest fire fuel. Results of the experimental burnings have given specific information applicable to conditions in the northern Rocky Mountains, but possibly more important are indications of principles that may guide in selection of slash treatment anywhere it is needed. *By ap-*

plying factors for slash quantity, rate of fire spread, and fire intensity, relative hazard can be calculated as a basis for establishing priorities in slash treatment. Taken individually these factors have little meaning; for example, no species of slash can be called more flammable than another if the quantities of each are not specified. Information on drying rate indicates when treatment should be applied. Kind of treatment must be determined on the basis of such considerations as: (1) values to be protected, and their susceptibility to damage by fire; (2) ability to abate the hazard; (3) ability to protect the area if the hazard is not abated; (4) availability of manpower and equipment for hazard reduction and protection; (5) relative costs of hazard reduction and protection; and (6) effect of possible slash treatments on land management objectives.

From the standpoint of fire control alone, slash disposal seems to be necessary wherever heavy concentrations of slash retain needles for several years, especially when these concentrations are in exposed locations. Intensive protection in lieu of disposal has the best chance of success in slash that loses its foliage early, that is not abundant, and that is protected from extreme drying conditions. All gradations are found between extremes of each of these conditions.

Need for Further Research

Following is a list of needed research projects. Information gained from them would help to answer several basic questions and would facilitate application of what is already known.

1. Evaluation of effectiveness of various types of slash treatment as means for fire protection.
2. Evaluation of slash treatments according to cost and benefit.
3. Development of methods and machines that will reduce the slash problem to the minimum, especially through modification of logging practices.
4. Improvement of techniques of using fire for slash disposal; study of effects of slash-burning fires.
5. Investigation of possible uses for slash.

CHARACTERISTICS OF SLASH FUEL COMPONENTS

Knowledge of the characteristics of slash is a step toward better understanding of fuels generally found in forests of the inland Northwest. Tree crowns are the major source of fine forest fuels except in open stands having a ground cover of grass. Even in grassy forests fallen tree crown materials are the fuels that burn hottest and longest. Fons (*13*) has shown mathematical relationships between physical characteristics of idealized fuel beds and rate of fire spread. Probably fire behavior in forest fuels as they occur naturally never can be reduced to an equation, but better knowledge of fuels will lead to better understanding of fire behavior. This section treats logging slash as a fuel, and includes measurements of physical characteristics heretofore unavailable.

CHEMICAL CHARACTERISTICS

The chemistry of wood has been studied intensively in the development and improvement of forest products. *From the standpoint of forest fire control, the most important finding is that all species have essentially the same chemical components in approximately the same proportions.* Cellulose and lignin comprise 88 to 98 percent of wood by weight (*44*). The amount of extractives in ordinary forest fuels varies, but the quantity of highly flammable fats and volatile oils rarely exceeds 8 percent. Variants from ordinary wood fuels, such as pitchy stumps and knots, have higher percentages of these flammable materials; hence fires in such fuels are very hard to extinguish and pose special problems in fire control. However, the chemical composition of all wood species is so nearly the same that quantity, arrangement, and moisture content are the fuel characteristics that most directly affect the combustion of wood. This is equally true for foliage and bark. Although in exceptional cases highly flammable extractives may be important, physical rather than chemical characteristics of the fuel particles and the fuel bed chiefly determine flammability.

PHYSICAL CHARACTERISTICS

The components of logging slash come in a multitude of sizes and shapes. Fine fuel components exert greatest influence on rate of fire spread and fire intensity; hence consideration of their characteristics provides a background for appraisal of flammability. Large components increase fire persistence and resistance to extinguishment, and physically obstruct suppression measures.

General Consideration of Tree Crowns

Certain general characteristics of tree crowns indicate properties of the slash that will result when the trees are cut. Width of crown obviously is related to length of the branches; to a lesser degree it also indicates diameter of the branches, since long branches must be relatively thick. Width of crown also indicates distribution of fine material, especially foliage, which usually is concentrated near the ends of branches. Long branches are relatively bare of fine material over most of their length, whereas short branches may have needles and twigs throughout the length of the branch.

Amount of daylight that can be seen through a crown in silhouette or from below shows relative amount and distribution of fine material also. Crowns that appear generally thin, like those of western larch, have relatively little foliage and fine twigs. Little light passes through the crown of Engelmann spruce because it has a large amount of foliage on a rather dense network of fine twigs. When needles are borne in clumps, light can pass through in spots, as it does in ponderosa pine particularly. Figure 3 shows distinctive crown characteristics typical of four northern Rocky Mountain species.

Length, width, and density of crown affect the total amount of solid material present. Width is the best single indicator, but a dense, narrow crown can be rather heavy. Table 1 lists typical gross characteristics for the species included in this study. Crowns of open-grown trees of any species tend to diverge from the typical by becoming broader, longer, and usually denser than those in closed stands. Beyond a certain number, as yet unknown, variation in number of dominant trees per acre may not affect quantity of slash.

Observation of gross crown characteristics provides a basis for adjusting calculations of slash quantity to allow for abnormal conditions. Crowns of pole-blighted western white pine are short and thin and produce less slash than healthy trees. Douglas-fir heavily infected with mistletoe has much fine material concentrated

Figure 3. Crowns of some northern Rocky Mountain conifers, illustrating characteristics listed in table 1. **Upper left,** western larch; **upper right,** western white pine; **lower left,** ponderosa pine; **lower right,** Engelmann spruce.

Table 1.--Gross crown characteristics of nine northern Rocky Mountain timber species

Species	Typical characteristics				
	Length	Width	Density	Continuity	Special features
Western white pine	Medium to long	Narrow	Low to medium	Low to medium	Often thinned and shortened by pole blight
Lodgepole pine	Short	Narrow	Low	Low	None
Ponderosa pine	Short to medium	Wide	Medium	Low	None
Western redcedar	Long	Medium to wide	Medium to dense	Medium to high	Crowns of residual trees in heavily cut stands become thin
Douglas-fir	Short to medium	Medium	Medium	Medium to high	Subject to large witches'-brooms
Western hemlock	Long	Wide	Dense	High	None
Engelmann spruce	Very long	Narrow to medium	Very dense	High	None
Grand fir	Long	Narrow to wide	Dense	Low to high	Crown often narrows and lengthens in old trees
Western larch	Short to medium	Narrow	Low	Low to medium	Frequently has witches'-brooms

in witches'-brooms. Whether the total amount of fine slash is increased by mistletoe is not known, but distribution certainly is affected.

Size Distribution of Crown Components

Relatively little work has been attempted on classifying crown components according to size. Storey and associates (*38*) give total weights of foliage and branchwood in relation to trunk diameter and crown length. This publication supplements their findings by providing a further classification of branchwood by size. Table 2 summarizes findings thus far on proportional weights of fuel material in the different size classes for nine northern Rocky Mountain species. These figures are based on a composite crown sample taken from one tree of each species. The sample consisted of three healthy and apparently typical branches, one each from the top, middle, and bottom one-third of the crown. Most of the sample trees were young, merchantable, and 90 to 100 years old. Hemlock and spruce were older.

The most interesting feature shown in table 2 is that quantity of both foliage and very fine twigs is related to tolerance. In the samples, needles comprised only 11.7 percent of total crown weight in western larch, a very intolerant species, but 36.8 percent in the very tolerant grand fir. Other species between these two extremes are arranged in the table in approximate order from least to most tolerant. Western hemlock, a tolerant species, appears to be out of place, possibly because the sample tree was older and less vigorous than those of other species. If weights of needles and of twigs less than one-eighth inch in diameter are combined, the contrast between tolerant and intolerant species is accentuated.

Proportional amount of fine material increases with height in the crown. The greatest increases are in larch, ponderosa pine, and lodgepole pine, whose lower branches become large in diameter with increasing age.

Proportional weight of branchwood increases as d.b.h. increases. Rate of increase in percent of branchwood as d.b.h. increases does not differ significantly between western larch and Engelmann spruce, two very dissimilar species. Therefore, the relation may be the same for all species.

Surface Area and Solid Volume

Fuel burns only where it is in contact with air; the more extensive the contact, the faster and more efficient the combustion. Fresh slash has a high ratio of surface area to volume. Olson and Fahnestock (*31*) report that, on an average, 1 pound of fresh Douglas-fir slash has 25 square feet of surface area. At this rate 15 tons of slash on an acre of ground would have 750,000 square feet, or 17.2 acres, of contact with the air. Compressed into a solid having the specific gravity of Douglas-fir wood, the same amount of slash would occupy 1,120 cubic feet, about the equivalent of a sheet of ¼-inch plywood covering the acre. Such a sheet of plywood could hardly be considered a fire hazard; its weight equivalent of slash would be a serious hazard because of high surface-volume ratio.

Slash becomes a less dangerous fuel as it ages because its surface area is drastically reduced. In the Douglas-fir slash described above, needles made up only 35 percent of the weight but 80 percent of the surface area. When needles fall, surface exposed for active combustion is reduced 73 percent. (Needles lying on the ground are assumed to have an exposed surface area equal to the area of ground covered.) Absence of needles from slash does not necessarily indicate a safe level of flammability. The surface area of branchwood may be several times that of fuel that existed before addition of slash.

Change Due to Aging

Foliage.—Loss of foliage is the most significant change in slash during the first 3 years after cutting. Length of time needles are retained is a good index to flammability: the more needles on a limb or twig, the higher the flammability. Species fall into three distinct groups according to duration of foliage retention.

Western hemlock and Engelmann spruce needles fall as they dry. Actual time required varies with exposure to drying conditions and size of wood on which needles are growing, but neither species retains dry foliage after the season of cutting. Being small, needles fall through the network of branches and lose their identity as they become part of the forest floor.

Western larch, Douglas-fir, and grand fir generally lose their foliage the first winter after cutting, but exceptions occur. On cutover areas, 1-year-old Douglas-fir tops sometimes have their needles still attached. In 1956, on experimental plots, grand fir slash cut the preceding fall still retained at least 50 percent of its foliage, but slash cut in the fall of 1954 had lost nearly all its needles by August 1955. No instances have been observed of foliage persisting into the second summer after logging. Fallen needles sometimes form noticeable concentrations on the ground, especially where they are supported by twigs.

Foliage falls gradually from slash of the three pines and western redcedar. Most of it has dropped from very exposed small branches at the end of the first year, but the fallen needles and sprays, being large, are trapped and supported by branches and so remain high in the fuel bed. Three years after cutting, supported foliage is still an important fuel component, but it is nearer the ground than when it first fell. On experimental plots western redcedar showed more nearly complete loss of foliage and greater compactness of fallen fine material than the pines, although cedar slash is generally considered the most durable of all species.

Twigs and branches. — Most of the fine twigs and all larger branches are still intact at the end of 3 years. Pine branches, especially ponderosa, retain much of their arching habit. Hemlock branches curl conspicuously; some lift their twigs 4 feet above the ground. All other species lie increasingly flat with age.

Bark. — Bark disintegration is noticeable at the end of 2 to 3 years but has not progressed far. Early disintegration of bark is limited to branches larger than 3/8-inch in diameter. White pine loses the most bark in the first 3 years; ponderosa, the least. On plots, ponderosa was the only species appreciably attacked by bark beetles.

Table 2.--Proportional weights of foliage and branchwood of various diameters

Species	Percent of total crown weight						
	Foliage	Branchwood by diameter classes					
		< 1/8"	1/8"-1/4"	1/4"-1/2"	1/2"-1"	1"-2"	> 2"
Western larch	11.7	4.8	14.3	8.7	31.6	28.9	--
Lodgepole pine	15.3	.5	10.9	18.0	19.9	27.0	8.4
Ponderosa pine	21.2	--	1.0	12.8	16.5	37.0	11.5
Western white pine	25.3	2.0	14.6	8.6	16.5	33.0	--
Douglas-fir	26.8	7.2	4.7	6.0	22.9	32.4	--
Grand fir	36.8	8.4	6.2	4.7	17.6	26.3	--
Western hemlock	23.0	10.5	4.0	5.3	13.9	41.9	1.4
Engelmann spruce	29.6	9.0	5.8	5.2	12.1	27.9	10.4
Western redcedar	36.0	(1/)	5.3	3.9	25.6	29.2	--

1/ Included with foliage.

Wood. — Butt ends of branches tend to split in drying, and surface checks occur where bark is lost. No evidence of decay was seen on plots at age 3 years.

FUEL BED CHARACTERISTICS

As they occur in cutover forests, slash fuel beds are the products of many factors whose relative importance varies from logging job to logging job. Age, composition, and health of stand; type, size, and quantity of products cut; method of logging and care in its application — all these plus some minor considerations strongly influence the quantity, arrangement, and continuity of slash. Slash used in this study was not affected by the external factors that are at work on cutover areas. Therefore, experimental fuel beds reflected only species characteristics. Observation and measurement of slash on sample plots have provided information that leads to better understanding of slash flammability in the woods. The important observations and measurements are discussed here and are illustrated by figures 4 to 7 inclusive.

Continuity

The effect of fuel continuity on fire behavior is somewhat controversial. The basic question is, "How far apart can fuel particles or fuel concentrations be and still produce continuous fire spread?" The biggest obstacle to answering this question directly is that fire spread depends not only on quantity of available fuel but also on fuel arrangement and weather conditions, and hence fire intensity. Fire spreads rapidly through continuous fine fuels; because of spotting, perhaps spread would be as rapid if the same amount of fuel were arranged in separated piles. This possibility should be considered carefully where a large quantity of fuel per acre would cause slash piles to be close together. Extreme situations have been observed where fires spread from pile to pile by heat radiation alone, independent of spotting. Figure 8 shows contrasting continuities of slash in which fire might spread at about the same rate.

This study does not analyze the large-scale effects of fuel continuity on cutover areas, but it does provide information on small-scale variations in continuity within the fuel bed as affected by species and quantity of slash. Although even

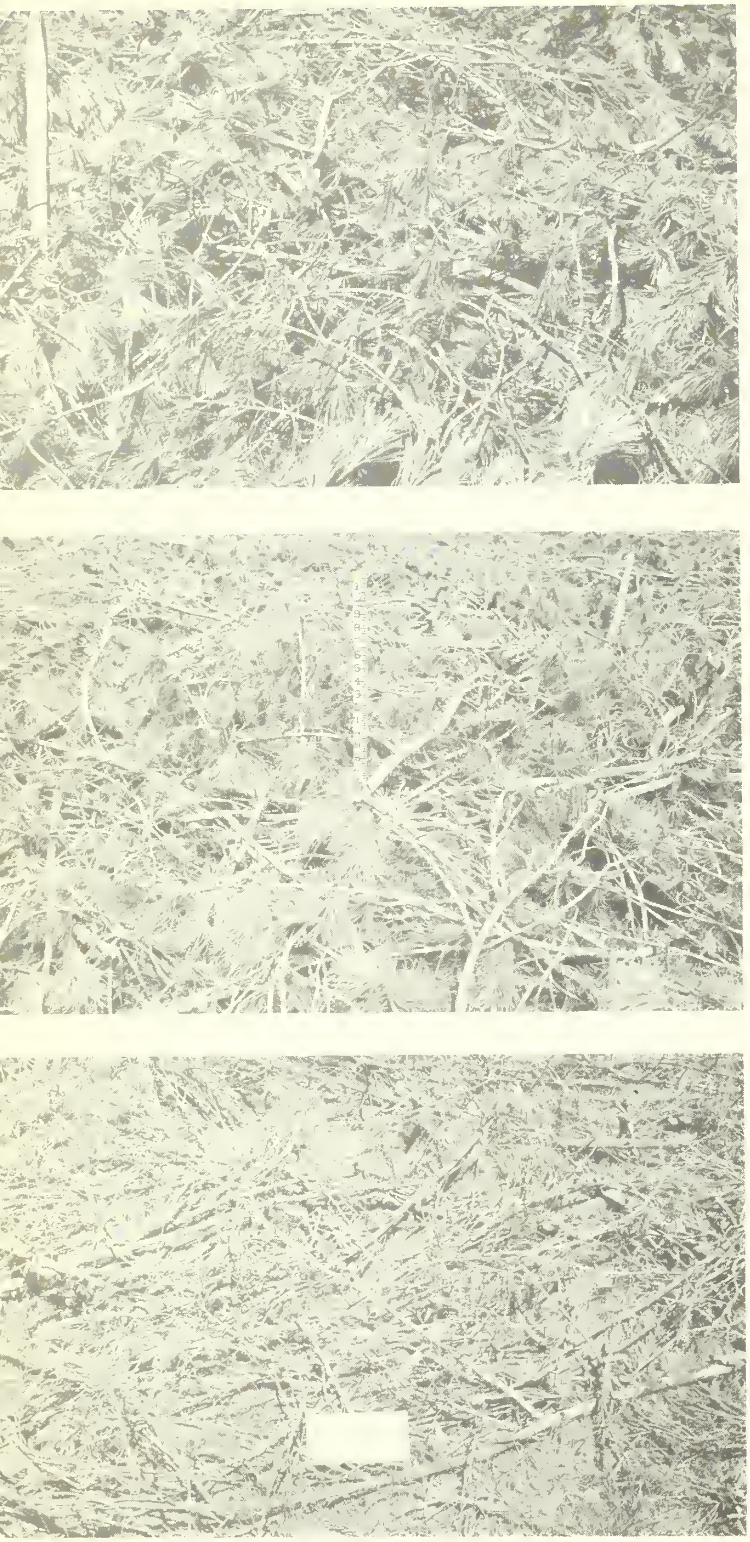


Figure 4. Slash of western white pine, which retains its needles 2 or more years after cutting (32.5 tons per acre). **Upper,** year of cutting; **middle,** 1 year after cutting; **lower,** 3 years after cutting.

these variations have not yet been measured, simply observing some of them gives a clue to expected fire behavior. Branching characteristics strongly affect continuity where quantity of slash is small. Short, uniformly leafy branches, as in western white pine, result in good continuity; the sparse branching habit and clumped needles of ponderosa pine, and the long, heavy branches of old hemlock cause fine components to be patchy. As quantity of slash increases, importance of branching habit decreases. On experimental plots fine fuel was continuous at 20 tons per acre in most slash with needles, but breaks large enough to affect fire spread occurred in ponderosa pine and species without needles. At 32.5 tons per acre, all kinds of slash were continuous. Figure 9 shows some of the variation in continuity that were observed.

Depth and Density

Density, or volume of solid fuel per unit of fuel bed volume, is a measure of oxygen availability and distance between particles across which heat must be radiated to ignite additional fuel. Where quantity of slash per acre is known, depth is a direct measure of density. Aging decreases depth of fuel, hence increases density. Depth was measured annually at four points on each plot of experimental slash to determine initial density and changes caused by aging (table 3).

Compaction of the fuel bed usually reduces flammability. Availability of oxygen is reduced, fuel moisture is increased by shading and proximity to the ground, and efficiency of interradiation is decreased. It was obvious from the first that decreased depth of experimental slash would indicate reduced flammability. In some situations on cutover areas, however, the reverse appears to be true. In large Douglas-fir, hemlock, and spruce tops without foliage, fine fuels are so sparse and widely separated that they burn only with the help of underlying or adjacent fuels. Where these tops are lopped or crushed, the fine material forms a dense enough fuel bed to burn vigorously without outside assistance.

Relation to Other Fuels

Some fuel is always present before slash is created. Superimposing even a small amount

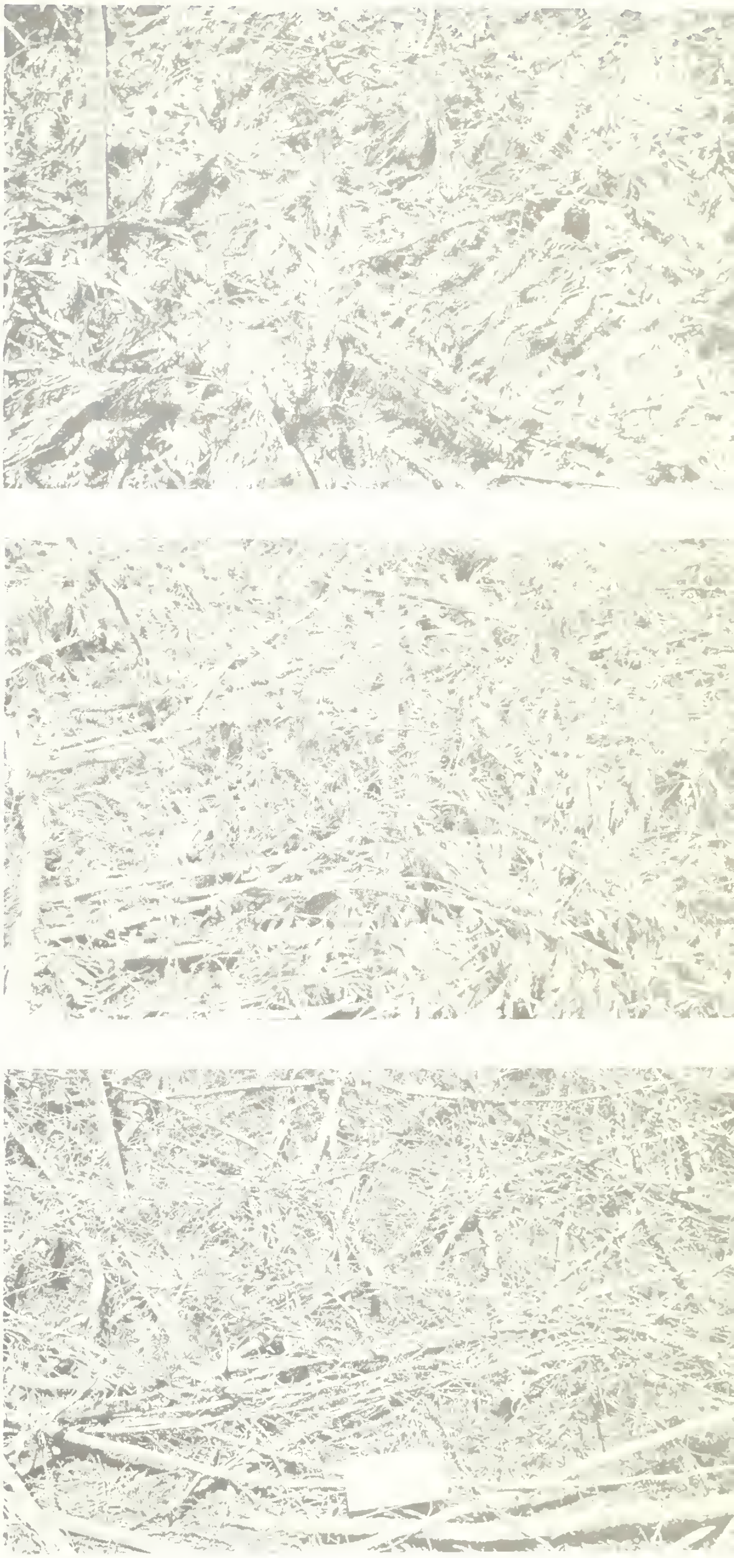
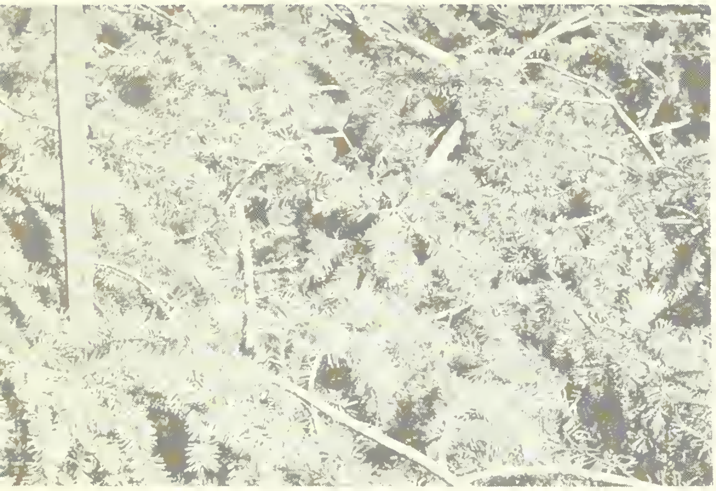


Figure 5. Slash of western redcedar, whose sprays disintegrate gradually in no set pattern (32.5 tons per acre). **Upper,** year of cutting **middle,** 1 year after cutting; **lower,** 3 years after cutting.



of slash on natural fuels may produce an intolerable hazard where neither the slash nor the natural fuels alone would be serious. Slash under dense, young stands and tolerant, long-crowned trees draped with lichens results in a vertically continuous fuel bed as deep as the trees are tall. The disastrous McVay Fire in the Black Hills of South Dakota fed on pruned branches and thinnings in the young ponderosa pine. The same amount of slash under older trees would have been far less damaging. Where fires in light, flashy natural fuels, such as grass and ponderosa pine litter, would be fast, easy to control, and not very damaging, the presence of slash results in longer heat duration, greater resistance to control, and more damage to forest values. On the other hand, where natural fuels are predominantly coarse and slow-burning, slash may be just the kindling needed to produce a destructive, hard-to-handle fire.

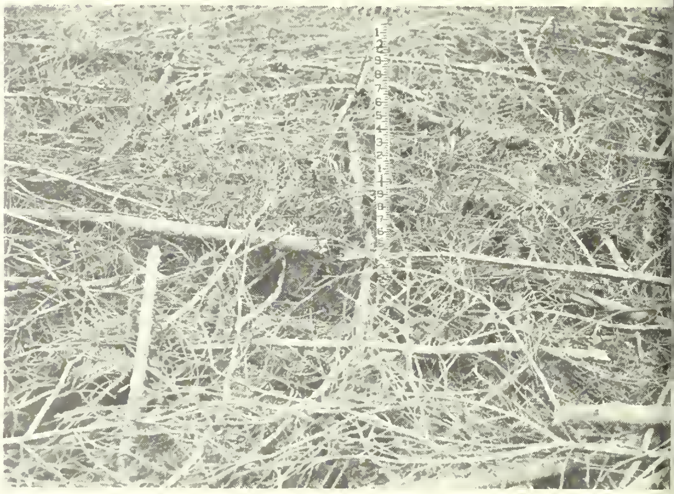


Figure 6. Slash of Douglas-fir, which usually loses its needles the winter after cutting (32.5 tons per acre). **Upper,** year of cutting; **middle,** 1 year after cutting; **lower,** 3 years after cutting.

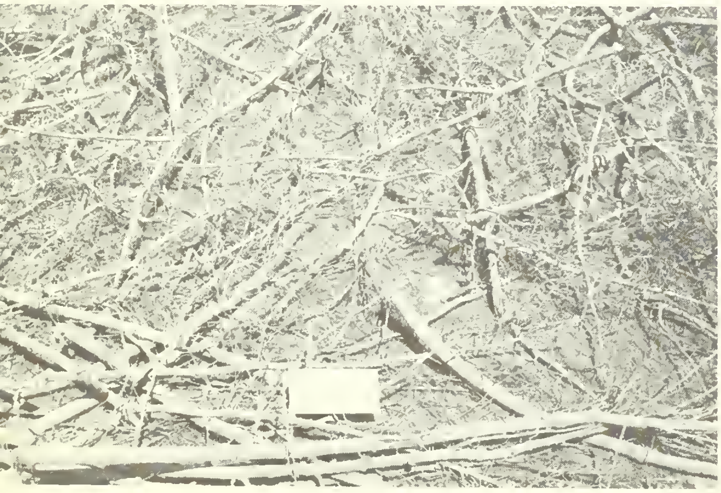


Figure 7. Slash of western hemlock, which loses its needles while drying (32.5 tons per acre). **Upper,** year of cutting; **middle,** 1 year after cutting; **lower,** 3 years after cutting.

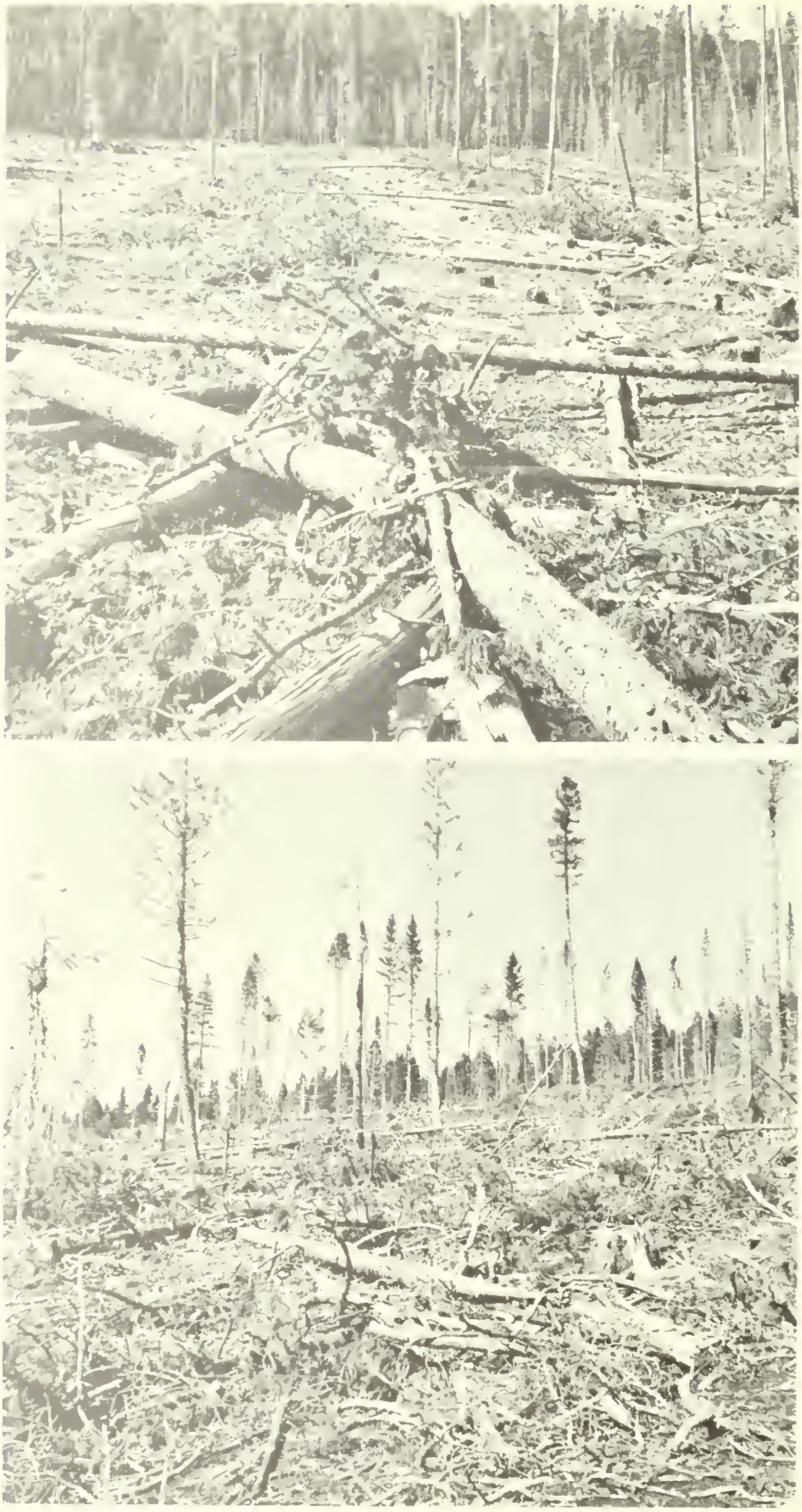


Figure 8. Slash fuel bed continuity as affected by method of logging. **Upper,** slash in windrows separated by nearly bare ground; **lower,** slash continuous over entire logged area.

Figure 9. Variation in continuity within the fuel bed. **Upper,** continuous fine fuel in western white pine slash due to moderately fine branching and even distribution of needles; **middle,** discontinuity in western hemlock slash due primarily to loss of needles; **lower,** discontinutiy in ponderosa pine slash due to coarse branching and tufted foliage (all species 7.5 tons per acre).

Table 3.-- Depth (in feet) of evenly distributed, lopped slash in relation to species, age, and weight

Species	Years of cutting			1 year old			3 years old		
	Tons per acre								
	7.5	20.0	32.5	7.5	20.0	32.5	7.5	20.0	32.5
Western white pine	0.51	0.80	1.00	0.32	0.54	0.78	0.35	0.55	0.72
Lodgepole pine	.51	1.04	1.29	.38	.66	.90	--	--	--
Ponderosa pine	.34	.97	1.36	.44	.69	.96	--	--	--
Western redcedar	.35	.53	.84	.24	.66	.76	.35	.62	.92
Douglas-fir	.23	.63	.83	.23	.67	.72	.22	.78	.65
Western hemlock	.30	.62	.92	.31	.71	.88	--	.65	1.68
Engelmann spruce	.49	.92	.96	.40	.58	.88	--	--	--
Grand fir	.46	.76	.94	.26	.52	.74	--	--	--
Western larch	.30	.78	.97	.26	.52	.70	--	--	--

HOW SLASH DRIES

The rate at which slash dries determines how soon cutover areas become special forest fire hazards. Opening up the stand increases fire danger, and even green slash will burn under the right conditions. However, the full potential for fire occurrence, rate of spread, and intensity is attained only when moisture content, of fine fuels especially, has declined to a dangerous level. In the northern Rocky Mountains an average fine-fuel moisture content of 10 percent is dangerous, and 5 percent or below is critical. Coarse fuels contribute significantly to fire spread, intensity, and duration when moisture content of the peripheral inch approaches 10 percent.

Initial drying of slash involves change from the living to the dead state. It is not logical to expect freshly cut slash with a moisture content near 100 percent to dry to 10 percent as quickly as equally moist dead material of the same size. Initial moisture content and size of fuel particle are the important characteristics that affect rate of drying in slash just as they do in dead fuels. However, the influence of both these factors is modified by the presence of unbroken bark, especially on large slash components, and by the ability of fine twigs and needles to obtain moisture from the larger material to which they are attached. To get some idea of how soon slash becomes a serious fire hazard, initial moisture content of nine timber species has been investigated, and experiments have shown how rapidly slash of one species (Douglas-fir) dries in relation to size under three degrees of shade.

MOISTURE CONTENT OF GREEN SLASH

Moisture content of freshly cut slash was measured for two purposes: (1) to find out how much drying would be required to cause high flammability and (2) to provide a basis for calculating the amount of green slash equivalent to a desired ovendry weight of experimental material. Some additional determinations were made in conjunction with crown dissection and classification. Material used included: needles, branchwood, mixed chips of needles and branchwood, and entire branches. Moisture content was determined by ovendrying and was expressed as percent of ovendry weight.

Table 4 shows that moisture content varies widely with species and with size of material. Differences greater than 50 percent were found between needle samples from the same tree. Obviously, many samples would be required to provide reliable average moisture content figures for material collected at any one time. Such intensive sampling would be desirable for studying flammability of living vegetation in relation to season and site, but it has no practical value for the present investigation. Severity of drying conditions to which fuel material is exposed after cutting soon obscures effects of initial moisture content.

LOSS OF MOISTURE

Loss of moisture begins as soon as a tree is cut. Change in moisture content is noticeable almost immediately in fine, detached material. Western larch needles stripped from their branches lost 6 percent in less than 30 minutes despite being shaded. Small detached branches in full sun turn brown and brittle in a few days. On the other hand, unlopped tops may remain green several weeks after cutting, especially on north slopes and in shade. An experiment in 1953 with Douglas-fir slash has provided a better understanding of how slash of different sizes dries in relation to its environment.

Experimental Procedure

Loss of moisture was followed in the unlopped tops of 15 young merchantable Douglas-fir trees, cut especially for the purpose, and in three beds of branches lopped from the same trees. Nine tops were located in a clear-cut area receiving 96 percent of full sunlight, one in a partially cut area receiving 69 percent, and five in an uncut stand receiving only 22 percent. A bed of lopped branches was located in each degree of shade. The study area was on a southeasterly exposure at 3,000 feet elevation.

The study continued from July 9 to October 9, 1953. Rainfall during the period was 19 percent below average; July and September were

Table 4.--Moisture content of four types of fuel materials in freshly cut slash, by percentage

Species	Needles		Branchwood		Mixed chips		Whole branch	
	Samples	Moisture content	Samples	Moisture content	Samples	Moisture content	Samples	Moisture content
		Percent		*Percent*		*Percent*		*Percent*
Western white pine	14	117.0	11	81.1	4	104.2	9	117.3
Lodgepole pine	1	178.6	1	95.5	18	90.0	9	82.2
Ponderosa pine	4	124.7	1	85.3	5	90.9	--	--
Western redcedar	14	113.7	11	87.1	4	74.6	6	101.8
Douglas-fir	13	95.3	10	79.1	4	81.0	9	90.1
Western hemlock	11	115.8	11	72.4	4	88.5	--	--
Engelmann spruce	8	117.6	5	70.1	--	--	9	98.0
Grand fir	2	148.1	1	83.9	4	87.3	--	--
Western larch	1	360.0	1	66.1	9	93.2	--	--

dry, but August was relatively wet. Departures from normal precipitation were not unusual for the region. Temperature and relative humidity were about average. Records from three weather stations on the study area were compared with each other and with records from a fire-danger station 1 mile away. Factors of fire danger varied in response to topographic location and degree of shade as had been indicated by earlier research (*16, 21, 22*).

Moisture content of fine twigs and needles attached to tops of unlopped branches and of trunkwood one-fourth and seven-eighths inch inside the bark was measured at intervals suited to detection of significant changes. Samples of fine material were collected and ovendried. Readings of trunk moisture content were made with a commercial lumber moisture meter (*6*) at points where the trunks of experimental tops were 2, 4, 6, and 8 inches in diameter. At the start and end of the experiment, moisture content of wood was checked by ovendrying disks sawed from the tops.

Drying Rate of Fine Material

Needles and twigs on lopped branches dried faster than any other material. In full sun, moisture content dropped to 10 percent in 13 days and to 6.5 percent in 18 days. Thereafter it fluctuated between 5 and 13 percent, just as it did in dead fuels during the same period. In partial shade, moisture content dropped to 10 percent in 24 days; after that, it stayed 1 to 5 percent higher than in unshaded material. Heavily shaded fine slash attained a minimum moisture content of 12 percent after 25 days, and then stayed 7 to 20 percent more moist than unshaded slash. Figure 11 (upper) shows the rate of drying of lopped slash.

The initial drying rate of lopped slash was less than one-third that of dead fuels. After a 1.59-inch rain, ½-inch sticks at the nearby fire-danger stations dried from 43 to 8 percent moisture in 3 days. The same change required 11 days in the fastest drying experimental slash.

Needles and twigs on branches attached to the trunk dried slowly (fig. 11 lower). In full sun, moisture content dropped steadily, with minor interruptions, to 11 percent at the end of 42 days. Three weeks later, on September 11, a minimum of 8 percent was reached. The last

Figure 10. Conditions under which rate of drying was studied: **upper**, clear-cut area, with heavy partial cut in the background; **lower**, lightly cut area. Arrows point to weather stations and tops studied.

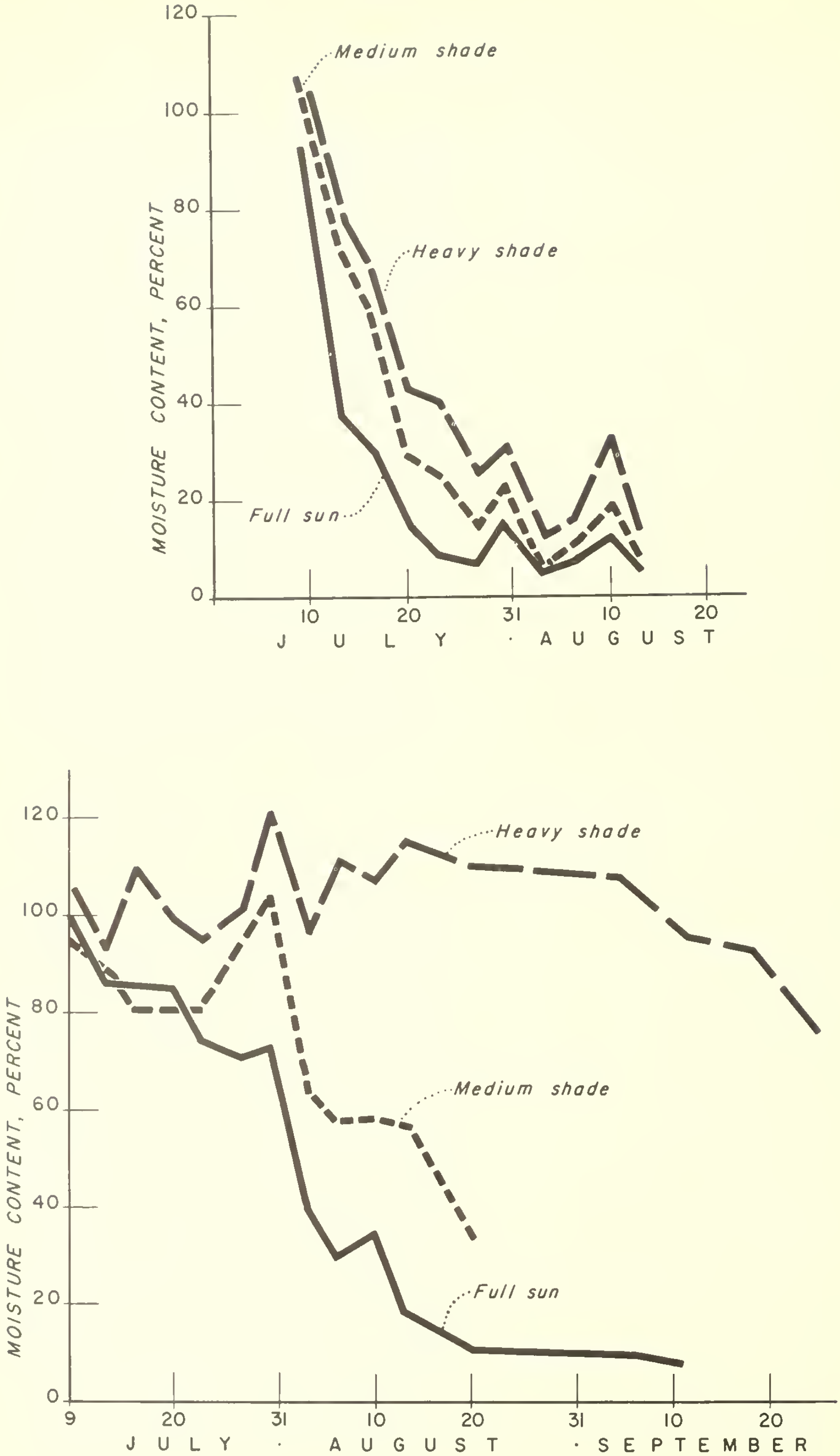


Figure 11. Drying rate of foliage and fine twigs: **upper**, on lopped branches; **lower**, on unlopped branches.

Table 5.--Moisture meter values at end of study for all trees in full sun and heavy shade

Tree No.	Average meter reading							
	1/4-inch depth				7/8-inch depth			
	Trunk diameter at point of reading (inches)							
	8	6	4	2	8	6	4	2
	Tops in full sun							
1	27.0	20.0	16.9	11.0	22.0	19.7	17.3	13.0
2	21.0	21.3	20.3	17.0	20.3	21.0	22.0	22.0
3	24.3	23.2	22.3	(1/)	22.3	22.0	21.0	(1/)
4	22.3	23.0	14.7	(1/)	20.7	21.7	15.3	(1/)
5	21.7	21.7	18.7	17.0	21.0	20.7	19.7	18.0
7	19.3	22.3	16.7	12.0	19.3	21.3	17.3	16.0
8	27.7	26.7	19.7	21.0	25.3	24.7	19.7	22.0
9	23.7	19.3	21.0	17.0	23.0	20.3	20.7	22.0
10	21.0	19.0	19.7	14.0	21.7	20.3	19.7	16.0
Mean	23.1	21.8	18.9	15.6	21.7	21.3	19.2	18.4
	Tops in heavy shade							
11	37.7	34.7	33.0	31.0	27.0	29.3	30.7	31.0
12	39.7	34.7	(1/)	(1/)	28.3	30.0	(1/)	(1/)
13	34.3	32.3	33.3	36.0	28.7	29.7	31.3	34.0
14	33.3	36.0	(1/)	(1/)	31.3	36.3	(1/)	(1/)
15	35.3	31.0	33.3	28.0	27.7	27.3	28.3	27.0
Mean	36.1	33.7	33.2	31.7	28.6	30.5	30.1	30.7

1/ All missing values resulted from felling breakage of tops.

figure obtained for the one tree in partial shade was 33.5 percent on August 20.[2] The shape of the curve suggests that a moisture content below 15 percent might have been reached between September 5 and 10. After reaching its low point, slash moisture content in unshaded and partially shaded areas would be expected to fluctuate like that in other similarly situated dead fuels.

In heavily shaded tops, fine material did not dry to high flammability during the first summer. Average moisture content remained above 100 percent until shortly after a steady decline began on September 4. The minimum value, 76 percent, was recorded on September 25, when measurement was terminated.

Needles tended to drop off in approximately inverse proportion to the drying rate. Virtually all needles remained firmly attached to lopped slash exposed in full sun and partial shade, while needles on the tops in full shade had thinned noticeably by the end of the experiment. Probably selective loss of needles characterizes only Douglas-fir, and possibly grand fir; both species usually retain all of their foliage through the summer of the year in which they are cut, then lose their needles the following winter. Other species either lose all of their foliage in drying or retain all of it for a year or more regardless of the rate of drying.

2/This tree was moved and damaged when logs were skidded near it.

Drying Rate of Wood

Moisture content of trunk wood samples, cut from the disks mentioned earlier and ovendried, averaged 140 percent in the outermost ½ inch, 102 percent in the ¾- to 1¼-inch layer, and 30 percent at a depth of 2 to 3 inches. As would be expected, nearly all the initial moisture meter readings at the ¼-inch depth were 65+, the maximum shown by the meter. Since most of the initial readings at the ⅞-inch depth were between 35 and 45, apparently a reasonably representative sample of heartwood moisture content was obtained.

Drying curves for shaded and unshaded material followed essentially the same pattern but differed strongly in response to depth of measurement. Figure 12 illustrates the drying process for 6-inch trunkwood. Apparently the initial rapid drying of the outer sapwood was accomplished largely through diffusion of moisture into the heartwood. At the end of the summer the moisture content of the experimental tops was still much greater than that of older, barkless logs at nearby flammability stations.

At the end of the study, average moisture meter reading at ¼-inch depth at all diameters was 19.8 for tops in full sun and 33.7 for tops in heavy shade. Ovendried samples gave corresponding figures of 29.5 and 41.0 percent. At the ⅞-inch depth, terminal meter readings were 20.2 and 30.0 percent in full sun and heavy shade, respectively, as compared with ovendried sample values of 31.0 and 41.4 percent. Table 5 gives moisture meter readings on October 9, when the study of trunk moisture content was concluded. In spite of their final 7- to 11-percent minus error, the meter readings apparently gave an acceptable representation of the drying curves. A more accurate measure would be required for large fuel that might become dry enough to burn.

The final moisture content of about 30 percent for topwood in full sun indicates that only free water from the cell cavities is lost by the end of the first summer (2). Moisture content becomes essentially uniform throughout the peripheral inch and probably to the center of the trunk, presumably because the unbroken bark prevents rapid evaporation from the surface. Flammability of large slash with unbroken bark remains low throughout the first summer in comparison with that of older, barkless logs whose surface can be almost as dry as fine fuels late in the fire season.

USES OF INFORMATION ON HOW SLASH DRIES

The time required for different kinds of slash material to reach high flammability under various types of cutting may be summarized as follows:

	Type of cutting		
Material	Clear cut	Moderate partial	Light
Lopped branches	2 weeks	3 weeks	4 weeks
Unlopped branches	6 weeks	9 weeks	3 months
Trunk wood	2 summers	2 summers	2 summers

This information has several practical uses. Although only one tree species (Douglas-fir) was investigated, results should be applicable to most other northern Rocky Mountain species. Parker (*33, 34*) has reported that ponderosa pine needles and twigs dry more slowly than those from Douglas-fir, but that needles and twigs of grand fir and western redcedar dry at the same rate. Observations made during other phases of the present study showed that ponderosa pine dried slowest of the nine species and that all the other eight species dried at about the same rate.

Rating Fire Hazard on Cutover Areas

The information listed in the tabulation above applies directly to slopes and flats that are fully exposed to summer sun. Drying rate in clear-cut areas on protected sites, such as north slopes, approximates that tabulated for the partial cut. Moderate cutting in such locations results in a drying rate near that shown for the very light cut. On the lowest third of steep, north-facing slopes and in canyon bottoms, fuels dry more slowly than in any of the three types of drying area used in this study. Probably 5 to 7 weeks would be a realistic time allowance for lopped slash in these locations to dry, depending on the exact topographic situation and severity of cutting. Unlopped tops lying on north slopes are unlikely to dry significantly even when

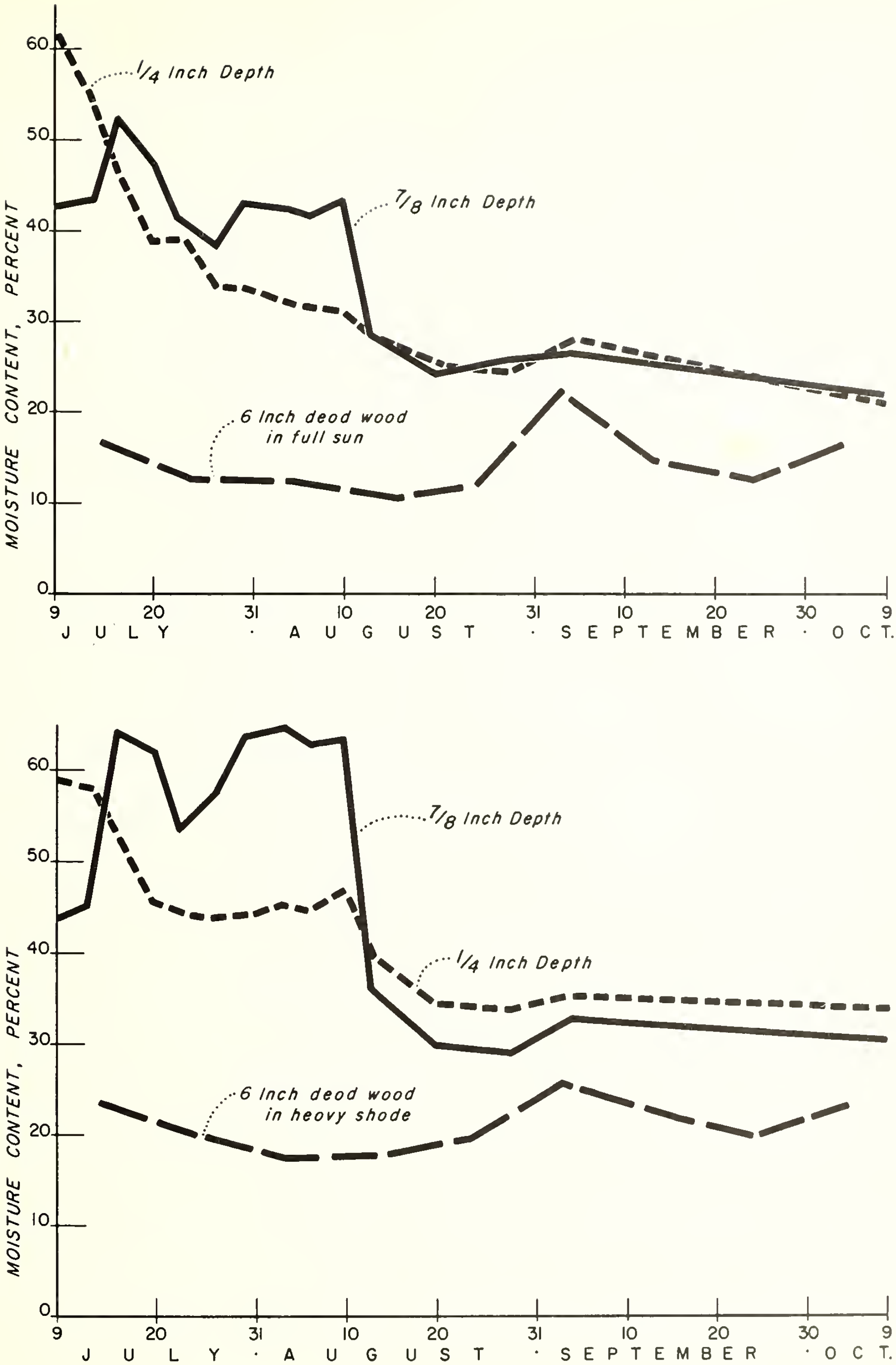


Figure 12. Drying rate af 6-inch waod of freshly cut taps, and comparison with alder waad: **upper**, in full sun; **lower**, in shade.

exposed for the whole summer. However, moisture content of lopped and broken branches is the factor that controls flammability, since green tops burn if associated dry fuels supply enough heat; and concentrations of tops usually are accompanied by varying quantities of small, detached material.

Setting Slash Disposal Priorities

Usually only slash cut the previous summer or fall in exposed locations is dry enough to require attention before about June 15. Since only dry, open sites are ordinarily accessible early in the season, spring slash disposal operations tend to be automatically directed against the worst hazard.

Current slash cut as late as August 10 in exposed areas may become dangerous before the end of the fire season. If the fall is dry, even slash cut in September can become a hazardous fuel. In sheltered situations, on the other hand, slash cut after the third week of July is unlikely to become highly flammable before the following summer. Data on slash drying indicate that disposal operations will be most effective if commenced as follows:

Before June 15:

Slash cut in the previous fall and winter in exposed locations

June 15 to September 1:

Current season's slash in exposed locations and slash cut before July 20 in sheltered locations

After September 1:

Current season's slash in areas likely to be least accessible next spring.

These suggestions are intended to be used in conjunction with the usual considerations of slash quantity and kind, fire risk, and values to be protected. Dates must be adjusted locally according to disappearance of snow and the start of fall rains.

Preparation for Prescribed Burning

Since large tops require at least 6 weeks to dry, extensive felling in preparation for a prescribed burn the same year should be completed by about July 15. If this is impossible, partial lopping of felled trees will provide dry fuel if done while 2 to 4 weeks of drying weather can be expected. The suggested action is particularly important around planned ignition points and wherever dead ground fuels are sparse.

MEASURING SLASH

To predict how any fire will burn, one must know the quantity, chemical composition, and arrangement of the fuel. Most of the solid and liquid fuels man uses are homogeneous and easily measured, and their characteristics can be adjusted to suit the purpose at hand. But forest fuels, including slash, are heterogeneous and very difficult to measure. Little progress has been made toward understanding forest fuels more than superficially. This section explains methods of measuring slash that will reduce the guesswork in estimating both the degree of fire hazard on cutover areas and the amount of work required to reduce this hazard to a tolerable level.

BACKGROUND OF FUEL MEASUREMENT

Fuel Type Classification

In the United States the need to measure forest fuels in order to make forest fire control more scientific was recognized by Gisborne and Hornby about 30 years ago. Their efforts produced the "fuel type" concept (*18*) and fuel type classification has been undertaken since then in all parts of the country. Probably the fuel type concept has been used most intensively in the northern Rocky Mountain region, primarily for fire control planning. Fuel type standards have been developed, and fuel types have been mapped on some 30 million acres of national forests.

Fuel types as now developed are an impressionistic, essentially qualitative measure of fuel quantity and arrangement. They do not actually measure fuel at all, but evaluate expected fire behavior in the various fuel complexes. Fuel type classification and mapping have been valuable tools for fire-control planning but have contributed little to the basic understanding of how fuel characteristics affect combustion. Moreover, keeping fuel type maps up-to-date has proved too expensive and complicated to be justified by the benefits they provide.

Experience has shown that the northern Rocky Mountain fuel type classification system had seriously underrated slash (*42*). Increasing area of recently cutover land, extending logging into zones of frequent lightning fire occurrence, and skyrocketing cost of slash disposal make a reevaluation of slash imperative. Learning to measure the fuel is one essential step toward reevaluation. Since slash is created by the one severe act of logging rather than by gradual accumulation, this fuel can be identified readily and measured directly.

Measurement of Tree Crowns

In slash most of the fine fuel particles that burn rapidly are components of tree crowns — leaves, twigs, and branchwood. Coarse fuels — cull logs, broken chunks, long butts, etc. — can be tolerated in the absence of fine material that dries rapidly and acts as kindling. *Therefore, measurement of tree crowns is the most appropriate means of measuring slash.*

Weight and surface area of tree foliage have long interested students of tree physiology and forest influences. Several workers (*23, 25, 38*) have described methods of estimating leaf weight and area. Their work deserves close scrutiny by students of forest fuels, for both methodology and factual content. Kittredge's method, relating foliage weight to trunk diameter (*23*), has provided the basis for measuring slash described on the following pages.

In 1950, Olson, at the University of Idaho, attempted to measure volume of slash in place. But slash, as it lay after logging, varied so greatly in species composition, horizontal distribution, and compactness that meaningful measurement in place was impossible. Accordingly Olson concluded that the best procedure was to measure individual trees. After compiling and analyzing measurements of slash from crowns of felled trees before lopping, after lopping, and after piling, he could estimate the volume of slash per thousand board feet cut by species and d.b.h. (*29*). The weakness inherent in using volume as a measure of an unconsolidated fuel was partly overcome by determining the ratio of solids to voids in various slash fuel beds having a known volume per acre (*30, 39*).

At the same time, a group in California investigated the possibility of determining the dry weights of tree crowns by modifying Kittredge's method. Storey, Fons, and Sauer have since reported (*38*) estimates of total crown weight, and of the weight of needles and branchwood separated for 13 coniferous species.

They found a linear relation between the logarithms of crown length × weight and trunk diameter at the base of the crown. Although significant differences among species and species groups did occur, the general relation was surprisingly similar in all species. The Californians' method gives accurate results, but it has the serious drawback for practical application of using as a premise diameter at base of crown, a measurement that is difficult to obtain on standing trees. A further inconvenience is that weight × crown length rather than weight alone is presented as the dependent variable. The California method is desirable because it uses weight rather than volume as a direct measure of solid fuel quantity.

CROWN WEIGHTS OF NORTHERN ROCKY MOUNTAIN TREES

In appraising the potential fire hazard of slash, one needs to predict what fuel situation will result from cutting given trees or stands. Any usable method of estimating must be reasonably simple and, if possible, based on measurements obtained in cruising or marking the timber. Such a method has been developed by modifying the California method to show crown weight (ovendry) as a function of the product of d.b.h. and crown length.

Basic Crown Weight Relationship

During the 5-year period 1952 through 1956 crown weight relations were studied on 225 trees of nine species. Trunk diameter at breast height and base of live crown and length of live crown were measured, and all of the live crown exclusive of the trunk was weighed. Ovendry weight of crown was calculated by assuming average moisture content of green material to be 100 percent. Use of this assumption eliminated need for determining moisture content of every tree and, as shown by a check on two species, did not affect accuracy of subsequent calculations appreciably.

Analysis followed the form used by Storey, *et al.* (*38*), but for greater convenience of application the data were rearranged to make crown weight alone the dependent variable. A linear relation was found to exist between the logarithm of crown dry weight and the logarithm of the product of d.b.h. and crown length. Correlation coefficients were insignificantly smaller than those found when length × weight of crown was made dependent on d.i.b. at base of crown.

Species were classified into three groups on the basis of similarity of regression coefficients. Lodgepole pine alone formed one group, having considerably the largest regression coefficient, which was shown to differ significantly from those of all other species. Western redcedar and grand fir had closely similar coefficients at the opposite end of the scale; the other six species were intermediate. Statistical analysis showed that each of the latter two groups was homogeneous as to the regression coefficients of the species included. Statistical comparisons of individual species across group lines frequently failed to show significance; but classifications other than those used appear illogical, reduce within-group homogeneity, and increase errors of estimate.

Figures 13, 14, and 15 show the regressions for the several species and species groups. A single regression adequately represents both grand fir and western redcedar, since their adjusted mean crown weights do not differ significantly. Similarly one regression represents western hemlock, Douglas-fir, and Engelmann spruce in the intermediate group. Separate but parallel regressions are shown for the other three species, which have a common regression coefficient but significantly different means. Prediction equations are as follows:

lodgepole pine: $W = \frac{(hd)^{1.3789}}{34.507}$

western white pine: $W = \frac{(hd)^{1.0108}}{8.541}$

ponderosa pine: $W = \frac{(hd)^{1.0108}}{2.525}$

western larch: $W = \frac{(hd)^{1.0108}}{5.828}$

Douglas-fir, western hemlock, and Engelmann spruce: $W = \frac{(hd)^{1.0108}}{3.811}$

western redcedar and grand fir: $W = \frac{(hd)^{0.8301}}{1.278}$

W is ovendry weight of the live crown in pounds, h is length of live crown in feet, and d is d.b.h. in inches.

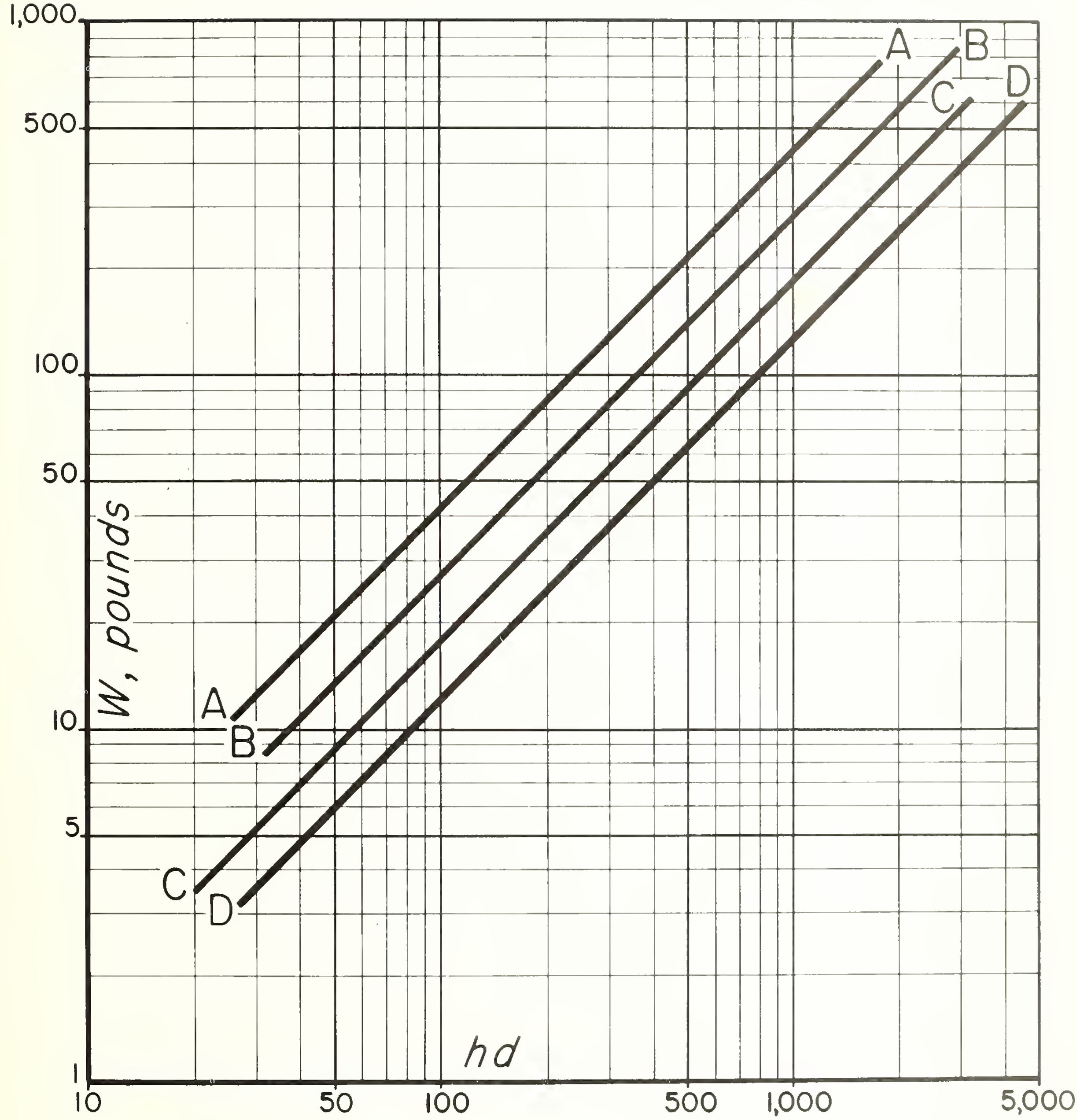


Figure 13. Crown weight, W, in relation to the product of d.b.h. and crown length, hd, for ponderosa pine (AA); Douglas-fir, western hemlock, and Engelmann spruce (BB); western larch (CC); and western white pine (DD).

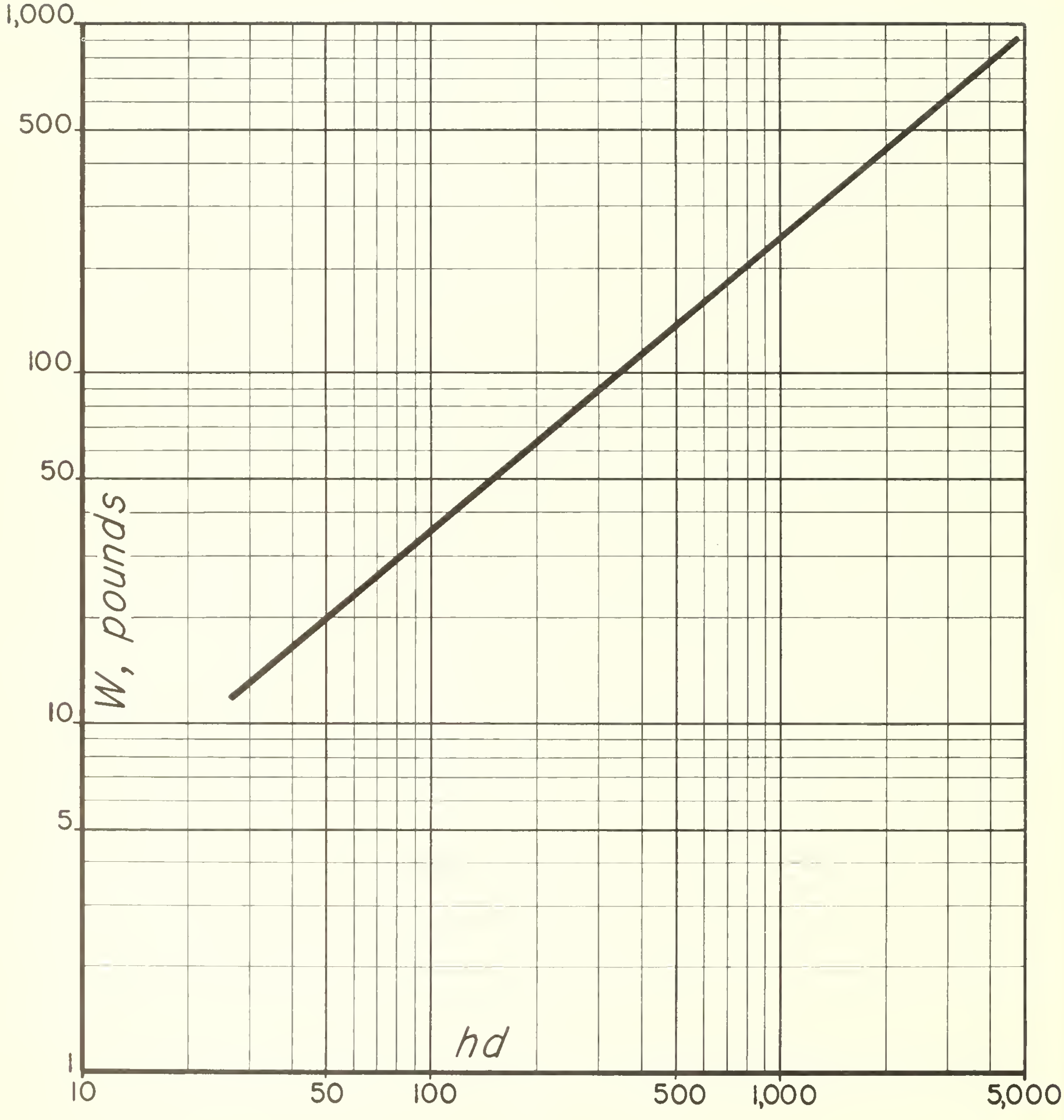


Figure 14. Crown weight, W, in relotion to the product of d.b.h. ond crown length, hd, for grond fir and western redcedor.

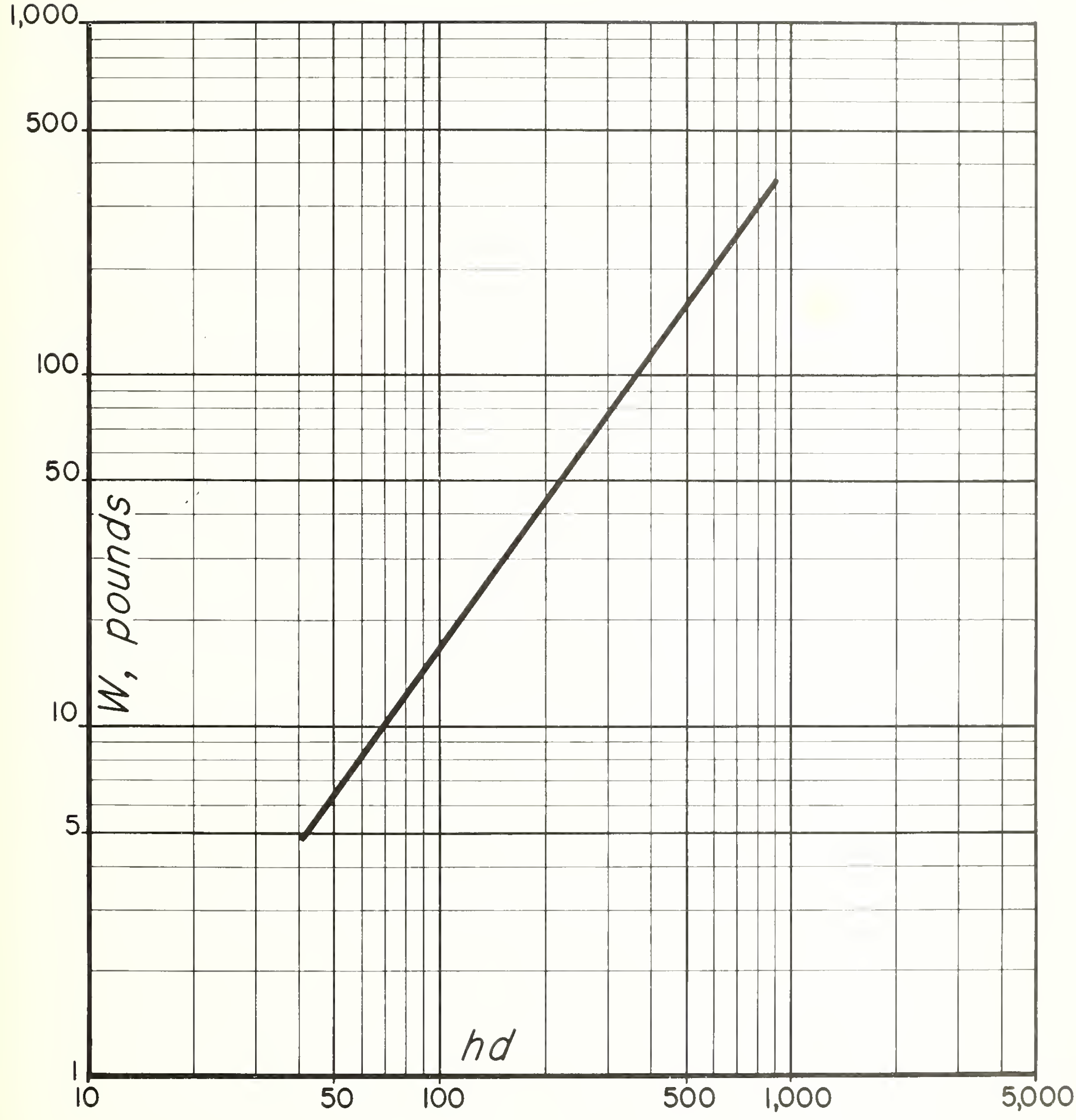


Figure 15. Crown weight, W, in relation to the product of d.b.h. and crown length, hd, for lodgepole pine.

Table 6 gives fiducial limits of the regression values for each species. The probability is only 1 in 20 that calculations based on another sample comprising an equal number of trees would yield predicted values outside these limits. Thus average or total crown weight for a moderate-to-large number of trees can be estimated with reasonable accuracy. For an individual tree, however, actual crown weight may differ greatly from the regression value.

Crown Length

To estimate crown weight by the method just described, d.b.h. and crown length must be known. D.b.h. is regularly measured in cruising and sometimes in marking, but crown length is not commonly measured and is difficult to obtain. Therefore, an effort was made to learn what general relations might exist between crown length and species, site index, crown class, and stand density. Crown length data were available for the 225 trees used in weight determination. To supplement this information, 1,945 crowns were measured on 40 sample plots in the western white pine, ponderosa pine, and western larch--Douglas-fir types.

Crown length for trees up to 30 inches in diameter bore a linear relationship to d.b.h. Differences among species were unexpectedly small. Statistical comparisons showed that for dominant and codominant trees species could be divided into two groups. Western white pine and the four very tolerant species had significantly longer crowns than the rest; also, their crown length increased more per inch of increase in diameter. For intermediate and suppressed trees the groupings were not so clear cut on purely statistical grounds. Western white pine definitely joined the other intolerant species, however, and hemlock was retained in the tolerant group on the basis of judgment, although it was between the two main groups. Actually small variations in crown length make little difference in crown weight at the small diameters representative of intermediate and suppressed trees. Figure 16 shows the relation of crown length to d.b.h. for all crown classes. For curve A, $h = 7.5 + 3.12d$; for B, $h = 4.0 + 2.60d$, in which h is crown length in feet and d is d.b.h. in inches.

Crown length was expected to vary widely by site index and stand density. The 31 plots in the western white pine type afforded good opportunity to test this hypothesis. Site index at age 50 ranged from 20 to 76, and percent of normal basal area ranged from 38 to 143. Very large differences in site index caused differences in average crown length of western white pine that were statistically significant but too small to affect crown weight appreciably. No significant effect of stand density on crown length was found. The relation of crown characteristics to site and stocking is an interesting subject for further study, but more intensive consideration here would not significantly improve the technique of measuring slash.

Crown Weight Tables

Figures 13 to 16 inclusive are the basis for constructing a table of crown weight by d.b.h. class and species. Multiplying d.b.h. by the corresponding crown length in figure 16 gives the value hd with which to enter the appropriate graph to obtain crown weight. For example, the entering value for a 24-inch western white pine is $24 \times 82.2 = 1{,}973$, and the corresponding crown weight, from figure 13, is 302 pounds. This process was used to arrive at the crown weight values shown in table 7. Each value is the probable weight of crown for a tree having average crown length for the specified diameter. Though the tabulated value may differ greatly from the actual weight of any given crown, the total weight of a large number of tree crowns should be estimated within reasonable limits by this procedure.

Data collected were inadequate for construction of a reliable crown weight table for intermediate and suppressed trees. Applying figures for dominants and codominants to all trees is not likely to introduce serious overestimates in most instances, since relatively few intermediate and suppressed individuals are harvested. Incidental slash, i.e., that broken from residual trees, which cannot be estimated accurately, probably will more than compensate for overestimates.

A Warning

Use of estimated average crown length in estimating crown weight is not defensible statistically. A second error of estimate is superimposed on the first (table 6), and the total error

Table 6.--Fiducial limits of regressions of crown weight on the product of crown length and d.b.h.

Species	No. trees sampled	Fiducial limits, percentage of regression value	
		10-inch trees	30-inch trees
Western white pine	31	+13.5 to -11.0	+13.9 to -12.2
Lodgepole pine[1/]	51	+13.9 to -12.3	+20.0 to -16.4
Ponderosa pine	14	+20.2 to -16.9	+21.5 to -17.6
Western redcedar	17	+18.6 to -15.6	+21.6 to -17.8
Douglas-fir	23	+9.9 to -9.1	+11.3 to -10.1
Western hemlock	15	+9.2 to -8.4	+12.0 to -10.8
Engelman spruce	20	+9.2 to -8.4	+12.0 to -10.8
Grand fir	18	+18.6 to -15.6	+21.6 to -17.8
Western larch	36	+12.6 to -11.3	+13.0 to -11.5

1/For lodgepole only, the limits are for 8- and 18-inch trees.

of estimate is not known. Since crown length varies with site index and stand health, and probably other factors as well, application of average figures to any given stand may result in large errors. To estimate crown weights with reasonable accuracy, enough crown lengths should be measured to determine whether the averages given here apply, and to construct a new curve of crown length on diameter if they do not. The next step is to calculate new values of crown length X d.b.h. for each d.b.h. class, enter figures 13 to 15 with these values, and find corresponding crown weights.

The curves of crown length on d.b.h. and the mean crown weights estimated by use of these curves provide bases for comparison. They also can be used as they are when crown length data are not available for a stand, a deficiency that is likely to be common until the value of calculating slash quantity within measurable limits of accuracy is generally realized. *Any objective method of calculating slash quantity is vastly superior to the guesswork used heretofore.* However, the goal should be to obtain measurements of crown length for individual stands during cruising or marking.

PREDICTION OF SLASH QUANTITY

Inability to measure slash quantity has been the main hindrance to realistic appraisal of flammability on cutover forest areas. The preceding discussion provides means for removing this obstacle. Similar methods can be used to predict slash weight that is expected to result from cutting certain specified trees or total crown weight per acre of stands of given age, site index, and density. Both types of calculations are described below.

Slash Weight from a Prescribed Cut

Accurate prediction of slash weight per acre is possible when a record is made of each tree marked. A summary tabulation is made by listing the number of trees in each species by d.b.h. classes and reducing tree numbers to a per-acre basis. Then the number of trees in each class is multiplied by the appropriate value from table 7. Table 8 shows such a calculation for a hypothetical 160-year-old western white pine stand on an excellent site in which a re-

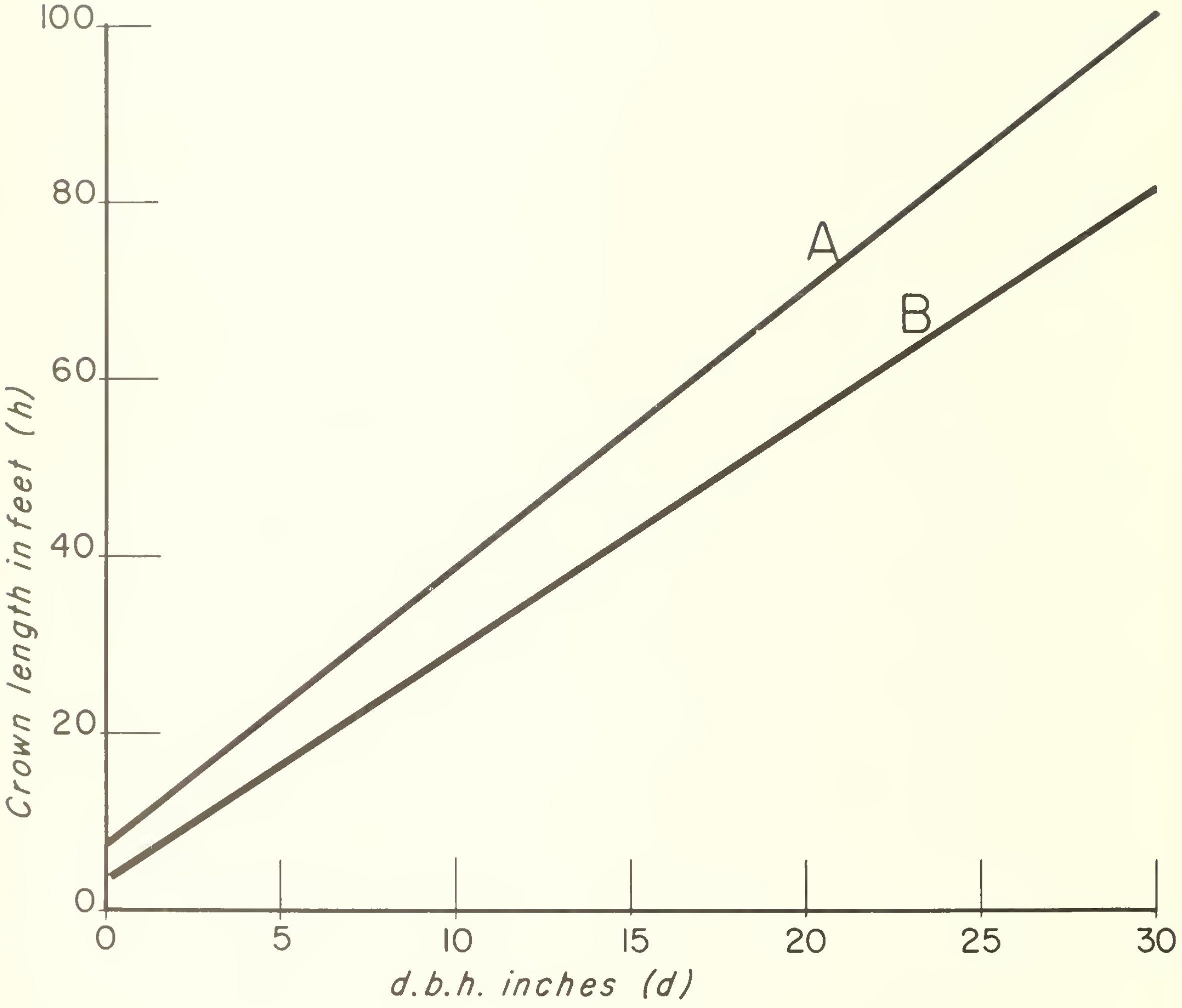


Figure 16. Crown length in relation to d.b.h. for nine species of northern Rocky Mountain trees. Curve A represents western white pine, western redcedar, western hemlock, Engelmann spruce, and grand fir; curve B represents lodgepole pine, ponderosa pine, Douglas-fir, and western larch.

Table 7. Crown weights of dominant and codominant trees by species and d.b.h. class

D.b.h. class (*inches*)	Weight of live crown (*pounds*)						
	Western white pine	Lodgepole pine	Ponderosa pine	Douglas-fir	W. hemlock E. spruce	W. redcedar Grand fir	Western larch
2	3	2	7	5	7	13	3
4	10	7	23	15	22	28	10
6	19	20	48	31	43	52	21
8	32	42	82	54	72	79	36
10	48	75	126	84	108	110	55
12	68	120	178	118	152	145	77
14	91	178	237	157	203	184	103
16	116	256	310	205	260	226	134
18	144	353	391	259	324	270	170
20	177	464	478	317	397	320	207
22	212	596	574	381	475	371	249
24	251	776	684	454	564	427	297
26	293	--	804	533	656	483	348
28	339	--	927	615	760	545	402
30	387	--	1,060	702	867	607	459
32	426	--	1,187	786	955	658	514
34	470	--	1,307	866	1,053	712	566
36	507	--	1,416	938	1,136	759	613
38	540	--	1,520	1,007	1,211	800	659
40	574	--	1,619	1,073	1,287	840	702

Note: Values below heavy line are outside the range of data used in calculations.

Table 8.--Sample prediction of slash weight per acre in a 160-year-old western white pine stand

D.b.h. class (*inches*)	Western white pine		Western redcedar		Grand fir		Western larch		All species	
	Number trees	Total weight	Number trees	Total weight	Number trees	Total weight	Number trees	Total weight	Total trees	Total weight
		Pounds		*Pounds*		*Pounds*		*Pounds*		*Pounds*
8	5	160	--	--	3	237	--	--	8	397
10	6	288	5	550	3	330	--	--	14	1,168
12	8	544	8	1,160	2	290	3	231	21	2,225
14	9	819	11	2,024	2	368	4	412	26	3,623
16	8	928	6	1,356	2	452	4	536	20	3,272
18	6	864	3	810	2	540	4	680	15	2,894
20	5	885	2	640	2	640	2	414	11	2,579
22	4	848	--	--	2	742	2	498	8	2,088
24	3	753	--	--	2	854	--	--	5	1,607
26	2	586	--	--	--	--	1	348	3	934
28	1	339	--	--	1	545	--	--	2	884
30	1	387	--	--	1	607	1	459	3	1,453
Total	58	7,401	35	6,540	22	5,605	21	3,578	136	23,124

generation cut is to be made favoring pine. Approximately 60 percent of the pine volume in trees 14 inches d.b.h. and over is to be removed plus nearly all merchantable trees of other species. The dominant residual stand per acre will consist of 25 white pine, two redcedar, and two larch more than 14 inches in diameter. It is assumed that all trees 8 inches and larger can be utilized either for pulpwood or poles, but 18 cedar 8 to 11 inches d.b.h. are left for value increment. Total calculated weight of slash per acre is 11.6 tons. This amount of slash produces very high flammability.

Most oldgrowth stands contain numerous trees larger than 30 inches in diameter. Too few of these large trees were measured to permit determination of a crown length—d.b.h. relation. For the present, on-the-spot measurement of a representative number of crowns must be made to provide the necessary information. This can be accomplished when heights are checked by Abney level during cruising or marking. Then diameter can be used in conjunction with the appropriate curve from figure 13, 14, or 15 to obtain crown weight.

Approximate slash weight per acre can be calculated if number of trees of each species to be cut and their average diameters are known. Crown weight for the tree of average d.b.h. in each species is multiplied by the number of trees per acre that will be cut. The accuracy of this method is unknown; it probably varies considerably with species and tree size. For the example given in table 8, use of average d.b.h. and number lowers the estimate of slash weight per acre by 9 percent. By species, the underestimate varies from only 1 percent for western redcedar to 16 percent for western white pine.

Expected distribution of slash on large areas can be mapped approximately in the office if tallies are kept separate by timber type or other appropriate land subdivision. Slash distribution maps show where slash disposal is needed to reduce hazard to a favorable level. Map presentation of slash concentrations with respect to improvements, roads and natural firebreaks, high risk areas, and topographic features can help in determining the location, method, intensity, and cost of slash disposal and extra protection.

Total Crown Weight Per Acre

In clear cuttings to a low diameter limit (e.g., lodgepole pine pulpwood cuts), virtually the total crown weight per acre becomes slash. Even where lighter cuts are to be made, advance consideration of the potential maximum slash tonnage has some value. The relation of crown weight to forest type, site, age, and stand density may also be interesting to tree physiologists and students of forest influences. To get an indication of these relations, total crown weight per acre was calculated for the 40 plots used in crown length determinations, for four additional plots in older age classes, and for a lodgepole pine stand in central Montana. Some of these findings are summarized in table 9.

Information from many more plots is needed before a clear relation can be shown for the response of crown weight per acre to the various factors affecting it. At present, enough data pertaining to 60- to 80-year-old western white pine stands are available to indicate what may be expected. Statistical tests on these data showed that total crown weight was correlated significantly with number of tolerant stems larger than 3 inches d.b.h. and with stand density expressed as percent of normal basal area, but not with site index. The absence of correlation with site index was surprising and will bear further investigation. Apparently the most useful relation is found with stand density, which can be expressed by the equation $W=0.143\ A$, where W is crown weight in tons per acre and A is basal area expressed as percent of normal. Thus a given increase in basal area results in a proportional increase in crown weight. Departures from this rule appear to result primarily from variation in the number of tolerant stems large enough to contribute significantly to total crown weight. The number and size of these stems vary with age and average diameter of the stand; hence the relation is rather difficult to interpret.

Some idea of the effect of age was obtained by a theoretical calculation based on Haig's and Meyer's stand tables for western white pine and ponderosa pine, respectively (*14, 26*). Crown weights per acre were calculated for pure stands at 20-year intervals up to 160 years.

The calculated weights were not very consistent, especially for younger stands, probably

Table 9.--Total crown weights per acre for five major species on sample plots in Idaho, Montana, and northeastern Washington

Forest type	Location	Age	Site	Density (percent of normal)	Weight
	County	*Years*			*Tons/acre*
Western white pine	Shoshone (Idaho)	62	43	134	24.4
	Shoshone	67	40	101	9.6
	Bonner	67	54	38	5.3
	Bonner	95	62	136	18.3
	Shoshone	107	59	111	18.8
	Shoshone	107	55	82	11.7
	Clearwater	130	60+	83	13.5
	Clearwater	150	70	71	15.3
	Kootenai	170	65	65	14.0
Western redcedar	Bonner	87	--	--	26.0
Douglas-fir	Bonner	90	--	--	18.7
Ponderosa pine	Pend Oreille (Wash.)	90	III	52	12.0
		110-125	IV	50	11.0
Lodgepole pine	Meagher (Mont.)	200+	--	--	9.7

because no method was available to account for the lighter crowns of intermediate and suppressed trees. However, total crown weight per acre appeared to become constant at 60 to 80 years for both species. Total weight for site 100 (100 years) ponderosa pine was calculated to be approximately 25 tons per acre. The corresponding value for site 60 (50 years) western white pine is 17 tons per acre. The occurrence of heavy-crowned, tolerant species in mixture with white pine conceivably could result in almost doubling the above figure, which is for pure white pine.

Slash Weight Per M Bd. Ft.

In lieu of a more satisfactory method of measurement, slash is usually appraised in terms of timber volume cut per acre. Olson and Fahnestock have shown, however, that quantity of slash varies with species and size of tree (*29, 31*). Olson's figures were based on slash volume. This section shows the relationship of slash weight per M bd. ft., Scribner rule, to size of tree for trees from 8 to 30 inches in diameter.

A total-height-on-diameter curve was constructed for each species or group of similar species, based on heights of the same trees for which crown lengths were measured. Tree volume at each d.b.h. was determined by use of the height curve and Haig's volume tables (*14*). Crown weight per M bd. ft. was determined by dividing crown weight by $\frac{\text{tree volume}}{1,000}$, as shown in figure 17.

Crown weight, hence slash weight, per M bd. ft. at any d.b.h. depends on tree height and form class, crown characteristics, and utilization. Since western white pine usually is tallest for its diameter, tapers very gradually, is most completely utilized, and has the lightest crown of any species, slash weight per M bd. ft. is low--only 250 to 300 pounds for trees 18 inches d.b.h. and larger. Western larch, though similar to white pine in height and form, has thick bark and is utilized less fully. Therefore, slash weight per M bd. ft. is relatively high in the smaller diameters but approximates that for white pine in trees 24 inches d.b.h. and larger. The high and nearly constant weight per M bd. ft. found for lodgepole pine is surprising for a tree commonly considered to have a small crown. It appears to be caused by (1) the very heavy crown of lodgepole in relation to d.b.h. and crown length and (2) the slight variation in height among trees of merchantable size.

Figure 17 emphasizes clearly the effect of large numbers of tolerant trees on slash quantity. Western redcedar, western hemlock, grand fir, and Douglas-fir all produce from two to five times as much slash per M bd. ft. as the western white pine, with which they are commonly associated. The ratio is lowest for big, sound trees; it increases greatly when cull is heavy, as usually occurs in old-growth tolerant stands. Obviously weight of slash per M bd. ft. also is multiplied when tolerant understory trees are harvested or are broken in logging the overstory. Thus, cutting 2,000 feet of cedar poles per acre having an average d.b.h. of 12 inches would produce the same amount of slash as cutting 10,000 feet of western white pine 16 inches and larger.

CALCULATING RELATIVE SLASH DISPOSAL COSTS

Once the decision is made that slash disposal is needed, quantity of slash is the chief measure of the physical job to be done and hence the cost if hand methods are to be employed. Collections for slash disposal per M bd. ft., therefore, should reflect the quantity of slash anticipated. Usually, however, little change in collections is made from one species and average tree size to another. The chief reason, perhaps, has been lack of the information incorporated in figure 17. Table 10 expresses this information as multiples of a standard quantity of slash, or of the cost of treating this quantity. The standard used is slash weight per M bd. ft. of western white pine 16 inches and larger.

Table 10 can be used in two ways. Direct use would simply assign slash disposal rates per thousand in proportion to the appropriate slash weight factor. Thus if $1.00 per M were considered adequate for disposal of slash from mature western white pine, the rate for cedar poles averaging 14 inches d.b.h. would be $3.30. On the other hand, if different rates are considered undesirable, a justifiable average rate for an area can be arrived at by prorating the slash weight factor according to relative volume cut. For example, assume that the year's cut in the western white pine type is expected to include:

	D.b.h. (inches)	Percent
Western white pine	16+	30
Cedar poles	12	10
Tolerant species	22	40
Lodgepole pine	12	5
Western larch	20	15

Then the average, or over-all, slash weight factor would be calculated as follows:

Western white pine	1.0	X	0.30	=	0.30
Cedar poles	5.6	X	.10	=	.56
Miscellaneous species	2.5	X	.40	=	1.00
Lodgepole pine	3.4	X	.05	=	.17
Western larch	1.5	X	.15	=	.22
Mean					2.25

Thus if $1.00 per M would provide for satisfactory disposal of white pine slash, the flat rate for all species would need to be $2.25.

Actually the problem is more difficult than these illustrations show: the cost of hand disposal is affected by terrain, travel, time, and other factors. Nevertheless, the slash weight factors appear to be the best available indicators of the cost of treating slash by hand methods.

Machine treatment of slash depends much less on slash quantity than does hand treatment. Slope steepness, number of residual stems per acre, and quantity of brush and down timber may be more important than slash weight. Consequently, estimates of needed slash disposal collections are based on average cost per acre for similar jobs. Perhaps the accuracy of these estimates can be improved if approximate slash weight per acre is known. As yet, there has been no opportunity to find out.

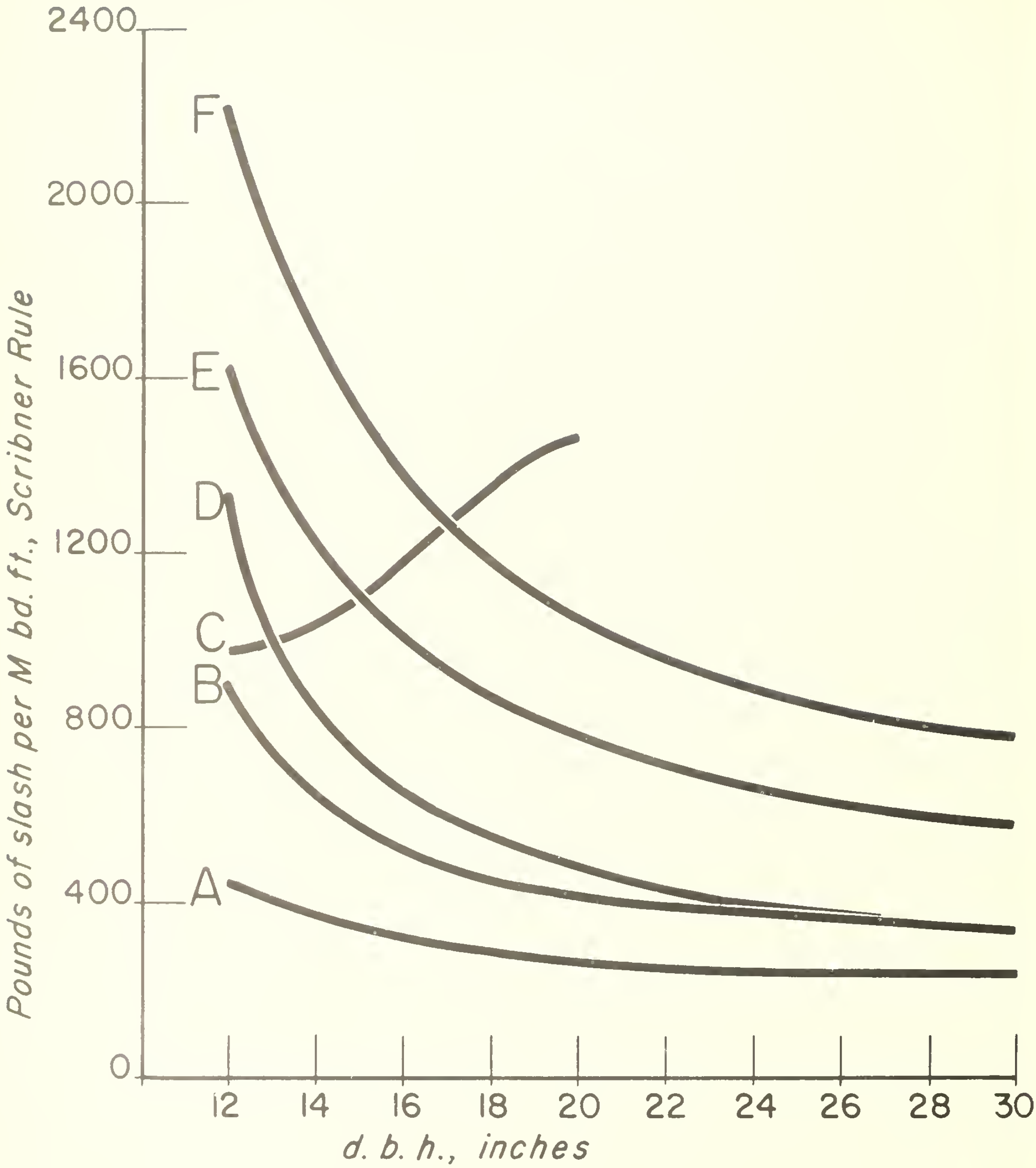


Figure 17. Relotion of crown weight to gross boord-foot volume by d.b.h. classes. (A) western white pine; (B) western lorch, (C) lodgepole pine, (D) grond fir, (E) Engelmonn spruce, (F) ponderoso pine. Douglos-fir, western redcedor, ond western hemlock foll between (D) ond (E).

Table 10. Relative quantities of slash per M. bd.ft. resulting from cutting stands of different species and average sizes

Species	Slash weight factor, by d.b.h. classes									
	12	14	16	18	20	22	24	26	28	30
Western white pine	1.5	1.3	1.2	1.1	1.0	0.9	0.9	0.9	0.8	0.8
Lodgepole pine	3.4	3.6	4.2	4.7	5.1	--	--	--	--	--
Ponderosa pine	7.7	5.8	4.9	4.1	3.7	3.4	3.1	2.9	2.8	2.7
Western redcedar, Douglas-fir, Western hemlock, Engelmann spruce	5.6	4.2	3.5	3.0	2.8	2.5	2.3	2.2	2.1	2.0
Grand fir	4.7	2.8	2.3	1.9	1.7	1.5	1.4	1.3	1.2	1.2
Western larch	3.2	2.2	1.8	1.6	1.5	1.4	1.3	1.3	1.2	1.2

FIRE SPREAD IN SLASH

A direct measure of flammability was obtained by burning slash experimentally. Fuel bed characteristics were controlled, and weather was selected to give maximum uniformity in burning conditions. Even so, results varied sufficiently to make analysis difficult and the drawing of fine distinctions somewhat hazardous. The major effects of species, quantity, and age of slash could be evaluated, however, and the experimental burnings gave some interesting information about the influence of rising relative humidity on rate of fire spread.

RESEARCH METHODS

Experimental Design

Experimental slash burning was done in the open on a flat area cleared of all other fuels (figs. 2 and 18). Slash of all nine species previously mentioned was cut especially and placed on square, 0.01-acre plots. Three weights per acre, 7.5, 20.0, and 32.5 tons, were selected as representative of what could be expected to result from light, medium, and heavy cutting, respectively, in heavy stands. The slash was scheduled to be burned (1) during the year of cutting, (2) 1 year after cutting, and (3) 5 years after cutting. Four replications were attempted in burning slash of each age, but unfavorable weather reduced the number to two in some instances.

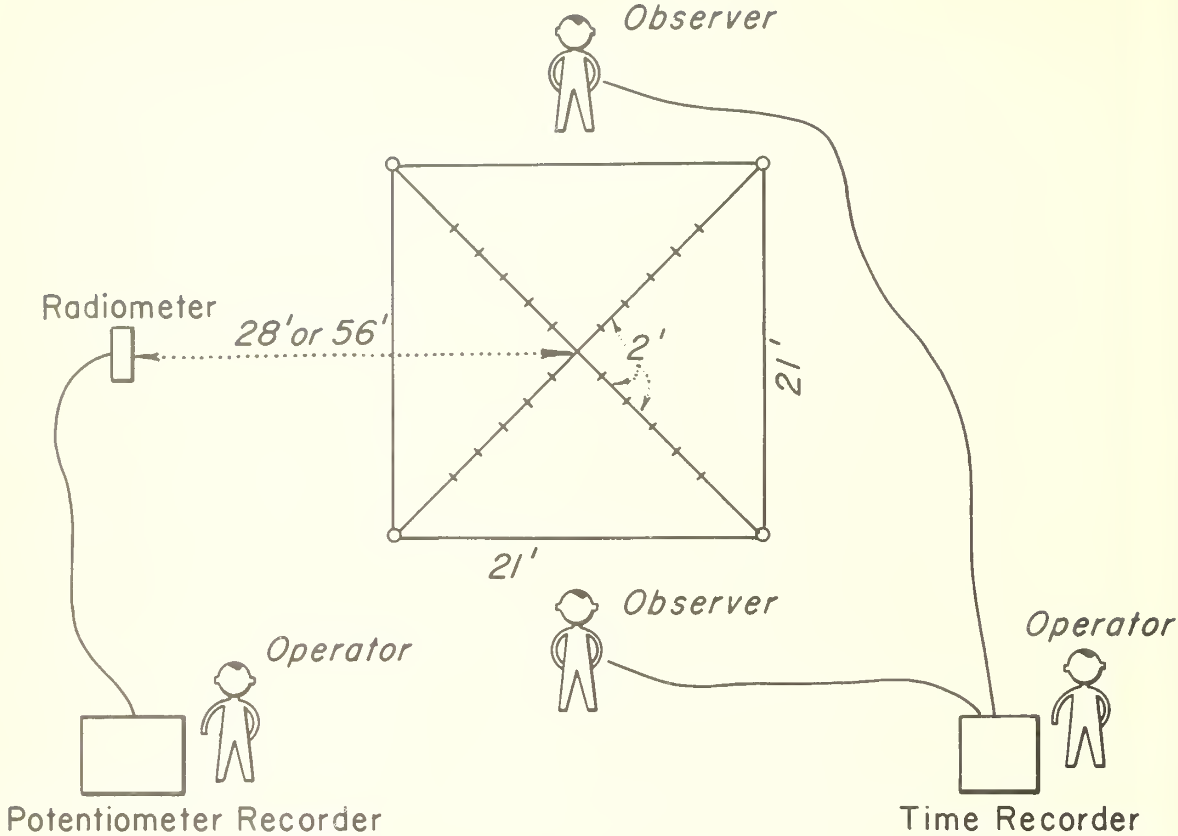
Experimental Material

Thrifty dominant and codominant trees were cut to provide slash for experimental burning. Most were 90 to 100 years old. Some western hemlock, Engelmann spruce, grand fir, and western larch trees were older; but, except in ponderosa pine, few limbs were more than 2 inches in diameter. Entire branches were used whenever possible, but some breakage and cutting to facilitate handling were unavoidable. Slash was thoroughly mixed so that each plot received representative amounts of all size classes. Fuel was spread on plots for as complete and uniform coverage as possible. Differences in arrangement and continuity reflected characteristics of the slash itself.

Conditions for Burning

Plots were burned in August on days that met the following specifications:

1. Less than 0.2 inch of rain during preceding 5 days
2. No rain in preceding 2 days



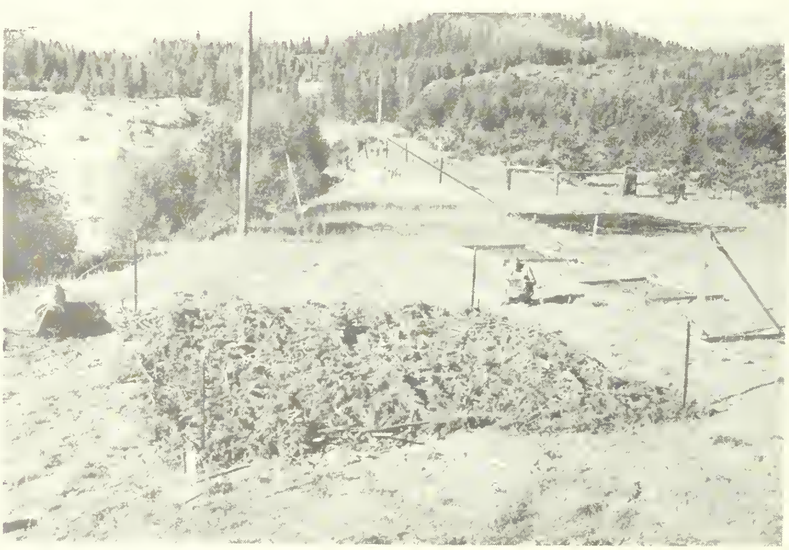


Figure 18. A sample plot ready for burning: **upper,** diagrammatic sketch of plot, personnel, and equipment; **lower,** plot No. 1, with 20 tons per acre of fresh Douglas-fir slash, prepared for ignition.

3. Midafternoon air temperature 70°F. or higher
4. Minimum 1/2-inch fuel-stick moisture content 8 percent or less
5. Minimum relative humidity 40 percent or less
6. Mean wind velocity at time of burning not more than 2 m.p.h.

Most of the slash was burned in the early evening. The rapid increase of relative humidity as temperature declined late in the day was accepted as a lesser evil than the stronger and capricious breezes in midafternoon. Fresh slash with needles attached was burned over a fairly representative range of relative humidity. Because they burned poorly or not at all at high relative humidities, most 7.5-ton plots and some 20.0-ton plots of slash that had lost its needles were burned at low humidities. This resulted in most 32.5-ton plots being burned at higher humidities, since only a few days each year were suitable for burning.

Burning Procedure

One or two plots of slash were burned at the same time. Plots burned simultaneously or consecutively were separated by at least one cool plot--one that had burned long previously or was yet to be burned. Each plot was ignited at its exact center. Time elapsed following ignition was recorded when the fire edge passed successive markers at 2-foot intervals on four equally spaced radii extending from the plot center. Figure 18 shows a plot ready for burning.

Temperature and relative humidity were recorded twice: when each plot was ignited, and when recording of rate of spread ceased. Total air movement during the same period was measured with a portable, vane anemometer 4 feet above the ground surface about 50 feet from the plot being burned. Supplementary measurements included 1/2-inch fuel-stick moisture at the start and end of each day's burning, and slash moisture content as determined by oven-drying one or two samples from each plot.

The basic records from experimental fires were reduced to terms of seconds required for the fire edge to spread 1 foot radially. An average value was calculated for each plot, and these averages were used in subsequent analyses. The averages were based on from three to 16 time observations for 2-foot segments of plot radii. The six averages based on five or fewer observations were viewed somewhat doubtfully, but they were the best estimates available and appeared sufficiently consistent to be retained and used in analysis. Table 11 summarizes the basic data.

Analysis

Preliminary exploration of the data disclosed an apparent linear relation between the logarithm of burning time in seconds per foot of radial spread and both relative humidity and tons of fuel per acre (*8, 10*). Furthermore, humidity and weight appeared to affect all species the same. Therefore, the data were subjected to multiple covariance analysis in which the two independent variables were relative humidity and weight per acre, and the dependent variable was the logarithm of burning time.

Separate analyses were made for fresh and 1-year-old slash. In both age groups the effects of both relative humidity and weight were found to be highly significant. The prediction equations are:

$$Y_0 = 1.7742 + 0.004931X_1 - 0.022293X_2,$$
for fresh slash, and
$$Y_1 = 1.8561 + 0.008677X_1 - 0.022522X_2,$$
for 1-year-old slash,

in which Y is the common logarithm of burning time, X_1 is relative humidity, and X_2 is weight.

Rate of fire spread is commonly given as chains of increase in perimeter per hour. If Y is expressed in these terms, the prediction equations become:

$$Y_0 = 0.7607 - 0.004931X_1 + 0.022293X_2,$$
and
$$Y_1 = 0.6788 - 0.008677X_1 + 0.022522X_2,$$

Statistical comparisons of rates of spread determined experimentally were calculated in terms of burning time but are expressed hereafter as chains per hour to be consistent with fire control usage. Because of the big differences in the effect of humidity, as indicated by the partial regression coefficients, separate prediction equations for the two ages of slash fitted the data significantly better than a single equation covering both ages. Therefore, com-

Table 11.--Results of experimental slash burning, by weight of slash per acre, age, and species, before analysis and adjustment

Age and species	Weight of slash (tons per acre)								
	7.5			20.0			32.5		
	Plots	Range of relative humidity	Mean rate of spread	Plots	Range of relative humidity	Mean rate of spread	Plots	Range of relative humidity	Mean rate of spread
Fresh slash:			*Seconds per foot*			*Seconds per foot*			*Seconds per foot*
Western white pine	3	58-62	80.3	3	34-86	32.3	3	30-65	18.0
Lodgepole pine	2	74-83	141.0	2	84-88	48.5	2	52-64	17.5
Ponderosa pine	(1/)	--	--	2	60-85	71.5	2	54-91	33.0
Western redcedar	3	28-56	73.3	3	36-81	52.7	3	42-73	24.3
Douglas-fir	3	33-50	64.3	3	39-72	41.3	3	52-70	20.7
Western hemlock	2	51-67	87.0	3	47-74	40.7	3	27-66	28.3
Engelmann spruce	-	--	--	3	38-74	50.0	3	68-82	35.0
Grand fir	2	54-70	77.5	2	60-80	51.5	3	50-94	28.7
Western larch	2	76-77	67.5	2	62-68	24.0	3	70-82	18.7
All species	17	28-83	82.3	23	34-88	45.2	25	27-94	25.7
1-year-old slash:									
Western white pine	3	26-90	81.7	3	80-91	62.3	3	71-90	26.3
Lodgepole pine	3	28-31	120.3	4	73-92	88.8	4	54-93	33.5
Ponderosa pine	2	28-30	153.5	4	66-85	129.0	4	71-83	83.8
Western redcedar	2	26-67	117.0	3	34-71	52.0	3	63-82	46.0
Douglas-fir	-	--	--	2	25-28	45.0	3	61-70	70.0
Western hemlock	2	28-30	43.5	3	44-81	58.7	3	64-82	74.0
Engelmann spruce	-	--	--	2	57-82	95.5	2	72-82	57.5
Grand fir	2	30-31	130.0	4	60-78	228.7	4	54-89	123.8
Western larch	1	30	109.0	4	64-86	215.2	4	55-87	97.5
All species	15	26-90	106.9	29	25-92	118.9	30	54-93	70.6

1/ Absence of data indicates that plots did not burn sufficiently to provide rate-of-spread measurements. In all, the following plots did not burn:

Fresh, 7.5-ton - - - - - - - 6

1-year-old, 7.5-ton - - - - 9

1-year-old, 20.0-ton - - - - 1

parisons among species were made within age groups. In order to test the effect of age within a species, however, the two groups were combined. The combined prediction equation is:

$$Y_{0+1} = 0.7859 - 0.007259X_1 + 0.021516X_2,$$

with Y_{0+1} expressed in chains per hour. Combining ages affected the adjusted mean rates of spread very little, since the mean relative humidities of the two age groups differed by only 2 percent.

Comparisons between species within ages and between ages within species were made by Scheffe's method (*32*). Results of the comparisons are discussed in subsequent sections.

EVALUATION OF FACTORS AFFECTING RATE OF SPREAD

Weight

Quantity of fuel was expected to affect rate of fire spread significantly, but the extent and nature of the effect were not known prior to the experimental burnings. Analysis of the first year's results for only four species indicated that in fresh slash, the effect of weight greatly overshadowed that of species (*8*). This preliminary analysis also indicated that the logarithm of rate of spread bore a straight-line relation to slash tonnage. However, relative humidity was not taken into account.

The present analysis, including all nine species at two ages, has confirmed the effect of weight found previously. The partial regression coefficients of rate of spread on weight, with relative humidity held constant, were 0.022293 and 0.022522 for fresh and 1-year-old slash, respectively. Thus, quantity of slash had the same effect in both ages of slash burned. The partial regression coefficients for weight are identical in the first three decimal places with the gross coefficient found in the earlier analysis.

Obviously fuel quantity consistently affects the rate at which fire spreads. Figure 19 shows that effect for all species of fresh and 1-year-old slash, with relative humidity at the respective means of 62.3 and 64.3 percent. Dashed lines are extrapolations that appear logical although they are outside the range of measured slash quantities burned. A rule of thumb for remembering the effect of slash quantity is that rate of spread increases approximately 6 percent for each ton increase in weight per acre.

Species

Slash flammability is commonly considered to vary widely by species; foresters' opinions on how to rank the species likewise vary widely. Analysis of the first year's burning records for western white pine, western redcedar, Douglas-fir, and western hemlock failed to show inter-species differences in rate of spread for equal quantities of slash. Wide variation among species in quantity of slash per unit of log scale, coupled with the strong effect of fuel weight on rate of spread, suggests that opinion about relative flammability is based largely on observation of slash quantity. Nevertheless, variation in relative quantity of fine fuel components, shape of branches, persistence of foliage, and durability is sufficiently large that some significant differences among species have been found by the latest analysis.

Table 12 lists adjusted mean rates of spread and interspecies differences in fresh and 1-year-old slash. Values correspond to the all-species averages of 62.3 percent relative humidity and 21.5 tons of fuel per acre in fresh slash, 64.3 percent relative humidity and 22.5 tons per acre in 1-year-old slash. Table 12 shows plainly that species had little influence on rate of spread in fresh slash but was responsible for important variation in 1-year-old slash. Sensitivity of statistical comparisons was low because of the small number of plots supporting each adjusted mean. Examination of the calculations indicates that if about double the actual number of observations had been made, all differences of 2 chains per hour or more would have been found significant. This line of reasoning suggests the following conclusions:

1. In fresh slash, larch supports faster spread, ponderosa pine and spruce slower spread, than the other six species.
2. In 1-year-old slash, white pine supports the fastest spread, followed in order by a lodgepole — redcedar — hemlock group, a ponderosa — Douglas-fir — spruce group, and a grand fir-larch group; these last two groups are quite close together.

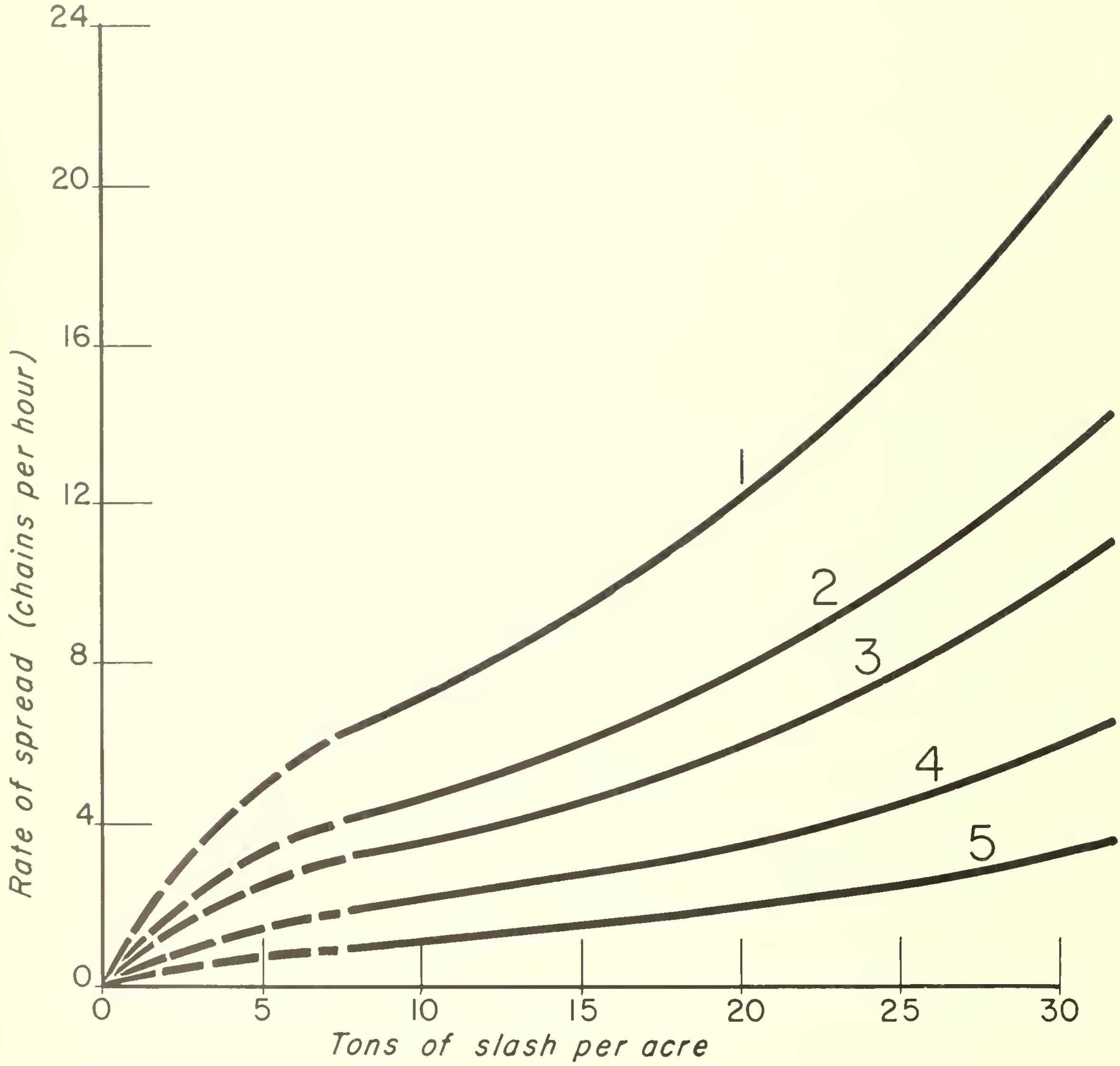


Figure 19. Rate of spread in relation to quantity of fuel by species and age groups. Curve numbers correspond with group numbers in the text.

Table 12.--Adjusted mean rates of spread and interspecies comparisons

Species	Adjusted mean rate of spread	Differences between adjusted means 1/									Adjusted mean rate of spread
		WL	GF	ES	WH	DF	WRC	PP	LPP	WWP	
		Chains per hour (Fresh slash above the diagonal; One-year-old slash below)									
WWP	9.6	3.6	1.2	3.0	1.6	0.7	1.7	3.2	1.5		9.7
LPP	8.1	5.1	.3	1.5	.1	.8	.2	1.7		3.9	5.8
PP	6.4	6.8*	2.0	.2	1.6	2.5	1.5		2.5*	6.4*	3.3
WRC	7.9	5.3	.5	1.3	.1	1.0		2.5	0	3.9	5.8
DF	8.9	4.3	.5	2.3	.9		2.4	.1	2.4	6.3*	3.4
WH	8.0	5.2	.4	1.4		2.0	.4	2.1	.4	4.3	5.4
ES	6.6	6.6*	1.8		1.0	1.0	1.4	1.1	1.4	5.3	4.4
GF	8.4	4.8		2.2*	3.2*	1.2	3.6*	1.1	3.6*	7.5*	2.2
WL	13.2		.1	2.1*	3.1*	1.1	3.5*	1.0	3.5*	7.4*	2.3

1/ (*) Designates differences that are statistically significant.

Observation of how slash burns in the field and comparisons of physical characteristics among species indicate that the above groupings, based entirely on experimental results, may be somewhat unrealistic. Therefore the following regrouping is suggested:

1. Fresh western larch.
2. Fresh western white pine, lodgepole pine, western redcedar, Douglas-fir, western hemlock, and grand fir.
3. Fresh ponderosa pine and Engelmann spruce; 1-year-old western white pine, lodgepole pine, and western redcedar.
4. One-year-old ponderosa pine, Douglas-fir, western hemlock, and Engelmann spruce.
5. One-year-old grand fir and western larch.

Rates of spread for these species groups are shown in figure 19.

A few discrepancies between experimental results and field experience warrant special mention. Although the fastest rates of spread were measured in fresh larch slash, this species is generally considered the least dangerous. High experimental rate of spread in larch probably resulted from (1) presence of much more slash per acre than ever occurs naturally, and (2) compact arrangement of experimental slash which brought fine, dead needles close together and prevented them from falling to the ground as they normally would on cutover areas. Western redcedar burned less spectacularly than would be expected from its usual rating as the worst slash of all. General opinion is influenced by (1) the large quantity of cedar slash per unit of timber volume, (2) the presence (commonly) of large tops, small deadwood, and bark in areas cut for cedar, and (3) the great durability of cedar logging residues. The rather compact arrangement of cedar slash on plots reduced rate of fire spread below what might be expected in wildfires. Ponderosa pine slash also burned slower than had been expected. Possibly the apparent high flammability of ponderosa pine slash on cutover areas is due more to its occurrence on very dry sites and to the fact that it is usually intermixed with grass than to the characteristics of the slash itself.

Age

Age, or time elapsed since cutting, causes a general reduction in flammability. The degree of reduction varies widely by species (table 13). This variation is an important factor in determining over-all species flammability ratings. A fuel that initially is highly flammable but becomes virtually nonhazardous after one winter obviously concerns foresters much less than one that deteriorates slowly.

Few of the tabulated reductions in flammability are very different from what was expected. Rate of spread in western white pine slash did not drop as much as was anticipated, but one such apparent inconsistency can be considered within the limit of experimental error. The close comparability of lodgepole pine and cedar indicates that the general great respect for cedar slash may be due as much to quantity and long-term durability as to inherently high flammability. Conversely, white pine slash may have been underrated somewhat because there is less of it per unit of timber volume. The big reduction in flammability of ponderosa pine slash is as surprising as the initial relatively low rate of spread in this species; this apparently low flammability may be offset by the long fire season and the very dry conditions typical of ponderosa pine sites.

As expected, rate of spread in Douglas-fir, grand fir, and larch slash dropped spectacularly after the first year because these species lost their needles over winter. The 90-percent reduction in flammability of larch placed this species at the bottom of the scale, where it had been thought to belong prior to the burning experiments. The change observed for Douglas-fir

Table 13.--Effect of aging 1 year on rate of fire spread in logging slash

Species	Adjusted mean rate of spread 1/		Reduction in rate of spread after 1 year 2/	
	Fresh	1 year old		
	Chains per hour		*Chains per hour*	*Percent*
Western white pine	9.2	9.3	- 0.1	-1.1
Lodgepole pine	8.7	5.6	3.1	35.6
Ponderosa pine	6.9	3.2	3.7	53.6
Western redcedar	7.7	5.8	1.9	24.7
Douglas-fir	8.5	3.6	4.9*	57.6
Western hemlock	7.8	5.5	2.3	29.5
Engelmann spruce	6.9	4.7	2.2	31.9
Grand fir	8.9	2.2	6.7*	75.3
Western larch	14.0	2.3	12.7*	90.1

1/ Based on analysis of data for the two ages combined; hence slightly different from values shown in table 12.

2/ (*) Indicates change that is statistically significant.

and grand fir does not always occur; occasionally these two species retain much of their foliage through the first winter.

Hemlock and spruce had lost their needles before the first burn; so they showed relatively little reduction in flammability after aging 1 year. One-year-old hemlock slash has been grouped with the other species without needles despite the fact that the rate of spread determined experimentally for it closely approximated rates for lodgepole pine and cedar. Its large quantity of closely spaced, very fine twigs makes 1-year-old hemlock appear more dangerous than other species that have lost their needles, but it is less flammable than species with foliage still attached.

One block of plots, containing four species, was burned after aging 3 years. Results showed the following percentages of reduction in rate of spread:

Western white pine	54
Western redcedar	71
Douglas-fir	86
Western hemlock	82

The data were too scanty for analysis and are listed as tentative indications only. Their main value, when taken in conjunction with observations of slash characteristics, is to suggest that:

1. The big reduction in flammability of white pine slash, and probably lodgepole pine as well, comes in the third year.
2. Flammability of cedar slash declines rather steadily during the first 3 years.
3. Flammability of slash that loses its foliage in the first year following cutting declines very slowly after the first year and is of little consequence by the end of 3 years.

Relative Humidity

Relative humidity was measured in order that its effect might be prevented from obscuring the effects of slash quantity, species, and age. Wind velocity and slash moisture content were recorded for the same reason; but wind velocity was held to a negligible quantity by careful selection of times for burning, and moisture content could not be determined reliably by the few samples obtained. Consequently the only extraneous factor included in the analysis was relative humidity. The values used were those corresponding to the midpoint of the time during which rate-of-spread records were being kept for each plot, as interpolated between psychrometric readings taken before and after each plot was burned.

Relative humidity had a highly significant effect on rate of fire spread. The apparent effect was much greater in 1-year-old slash than in fresh, as indicated by the respective partial regression coefficients, 0.008677 and 0.004931. Figure 20 illustrates this difference. Confounding of relative humidity with species and weight in 1-year-old slash may have caused part of the difference, but the major part appears to be a measure of the relative effect of atmospheric moisture on fire behavior in sparse as compared to abundant fine fuels.

The influence of relative humidity on rate of spread in experimentally burned slash is difficult to interpret. Since relative humidity increased rapidly while plots were being burned, fuel moisture could not reach equilibrium with atmospheric moisture. The behavior of a fire reflected the effect of the increase, over a period from a few minutes to nearly 2 hours, from the rather steady relative humidity of the afternoon to the transitory value determined for each plot.

From the data obtained, it is impossible to ascribe characteristic rates of spread to the various measured relative humidities. However, knowledge of how increasing humidity affected experimental slash fires provides some indication of what can be expected on wildfires and prescribed burns during the transition from afternoon to night. Figure 20 shows how rising humidity affected rate of spread in fresh slash and in 1-year-old slash. This relation prevailed regardless of quantity of fuel per acre. Given comparable weather and fuels, the behavior of any fire might be expected to conform to about the same rules. Wind would reduce the effect of increasing relative humidity and could nullify it completely. Topography would also have a modifying effect peculiar to each locality and existing weather pattern.

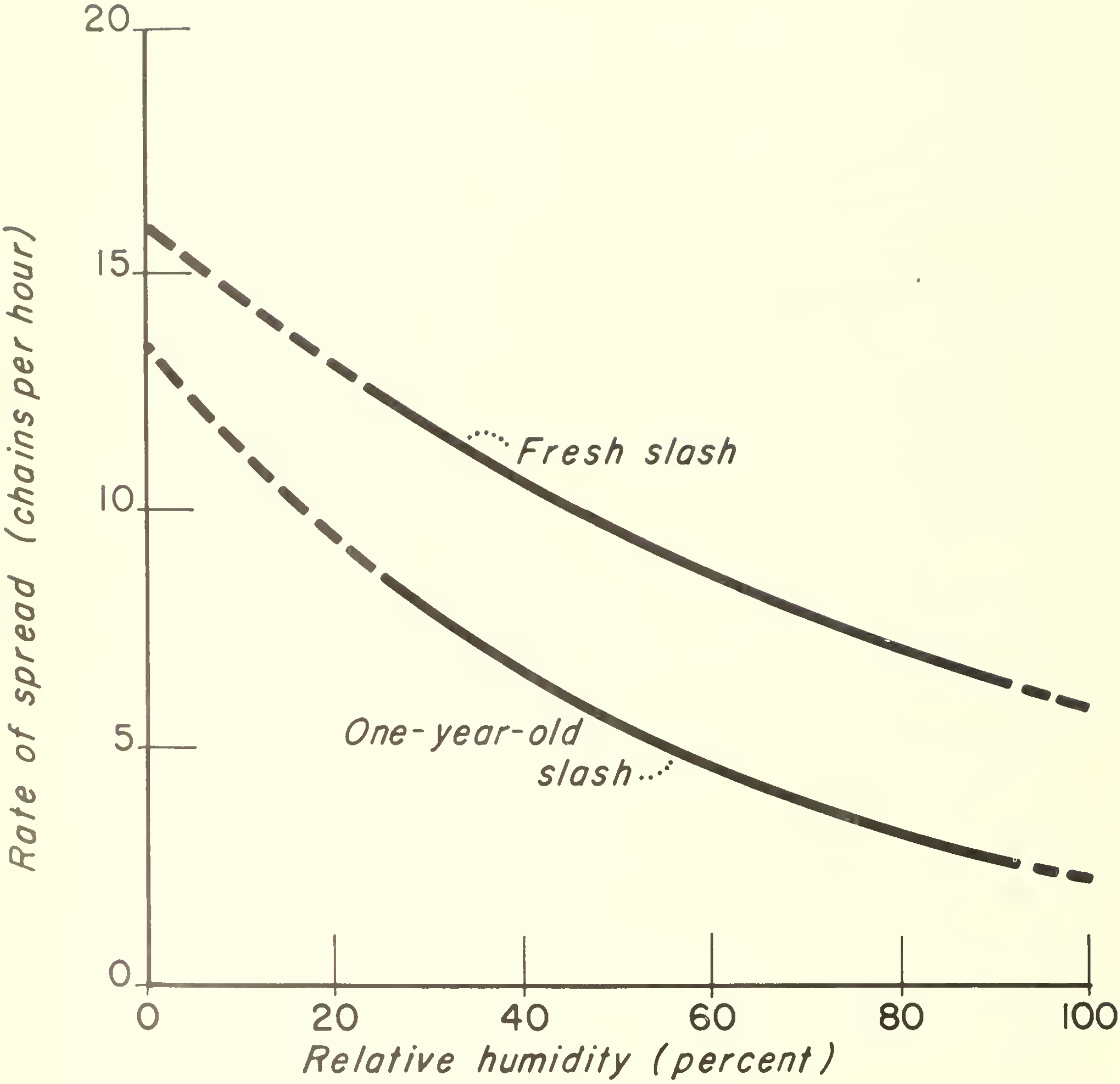


Figure 20. Effect of relative humidity on rate of spread in 20-ton-per-acre slash.

INTERPRETATION OF FINDINGS ON RATE OF SPREAD

Evaluation of Relative Flammability

Results of experimental burning, as summarized in figure 19, can be used for rating relative slash flammability to the extent that it is represented by rate of fire spread. A logical starting point is rate of spread for the most hazardous fuel at the probable maximum quantity per acre. If the high rate of spread in larch slash is discounted as being due to artificiality in the experiment, western white pine and its associates in Group 2 (fig. 19) emerge as the most dangerous. For calculating relative flammability, probable maximum quantity of available fine fuel per acre may be postulated as 25 tons. By coincidence, rate of spread of species in Group 2 corresponding to 25 tons per acre is 10 chains per hour, a convenient figure on which to base comparisons. Relative rate of spread, on the basis of 10 = probable maximum, can be read directly off the curves in figure 19 for any species or group and quantity of fresh and 1-year-old slash. A combination of species, with measured quantities for each, can be given a composite rating by the following procedure (refer to table 14):

1. Determine total weight of slash per acre (refer to MEASURING SLASH, pages 00 to 00) and percent of this total represented by each species as in "Tons per acre" and "Percent of total" columns under "Quantity" table 14. Total these columns.
2. From figure 19 record the factor for each species and age represented corresponding to the *total* tons per acre of slash for all species (20 T/acre in table 14); e.g. for fresh western white pine (Group 2) the factor taken from the curve directly above the 20 T/acre mark is 8.
3. Multiply the individual factors determined in step 2 above by their respective percentages from 1 above to get individual proportional ratings.
4. Sum the proportional rating product for fresh slash and for 1-year-old slash.
5. These totals are the proportional ratings on the basis of 10 = probable maximum. In the example (table 14) the flammability of the slash is 86 percent of the probable maximum while fresh, only 44 percent at the end of a year.

Table 14.--Sample calculation of relative rate-of-spread ratings for a combination of species and quantities of slash

Species	Quantity		Rate-of-spread rating			
			Fresh slash		1 year-old slash	
	Tons per acre	Percent of total	Factor	Proportional rating	Factor	Proportional rating
Western white pine	5	25	8	2.0	6.2	1.6
Western redcedar	4	20	8	1.6	6.2	1.2
Douglas-fir	2	10	8	.8	3.6	.4
Western hemlock	4	20	8	1.6	3.6	.7
Grand fir	2	10	8	.8	2.0	.2
Western larch	3	15	12	1.8	2.0	.3
Total	20	100		8.6 8.6 = Rating for area = 4.4		

Slash as a Fuel Type

Up to this point, discussion of actual rates of fire spread in slash has been avoided deliberately, but values are available in figure 19. Because the artificialities of the burning experiment were recognized, expression of flammability in relative terms appears to have more value. However, comparison of rates of spread in experimental slash with those that have been determined for fuels occurring naturally cannot and should not be neglected completely. This section attempts to interpret what happened on the experimental plots in terms that are familiar to foresters and fire control men.

A major obstacle to generalizations from results of experimental burning is the fact that slash on the plots had been distributed artificially. In the cutover forest such uniform distribution, both horizontal and vertical, would never be found. Unfortunately the effect of fuel arrangement (vertical) and continuity (horizontal) has never been measured satisfactorily. Barrows (*3*) and others have tried to express the effect of continuity but have not provided numerical values to represent their estimates. For slash the best assumption appears to be that the uniformity existing on the experimental plots adequately represents all other arrangements. Very large gaps in body of slash would result in the scattered islands of bad fuel being considered as separate concentrations, each to be rated on its own merits. During severe fire weather, spotting between rather widely separated concentrations occurs commonly and the resulting rate of spread may equal or even exceed that in continuous slash. Therefore the uniform fuel bed, which can be reproduced at will and visualized uniformly by everybody, is the best premise on which to base calculations.

A second difficulty in generalizing from the results of experimental burning is that in a forest some fuel besides slash is always present. For present purposes it is assumed that this "natural" fuel is a "low" rate-of-spread type. Barrows (*4*) indicates that average rate of spread in the "low" type is 2.5 chains per hour at Burning Index 40, the approximate average Burning Index that prevailed while the experimental slash plots were being burned. The further assumption is made that rates of spread measured on the plots would be increased in cutover areas by the rate characteristic of associated natural fuels. Therefore, to find the position of slash of different descriptions with respect to classified fuel types, 2.5 chains per hour are first added to the values shown in figure 19. The adjusted values are then compared with average rates of spread for northern Rocky Mountain fuel types. Table 15 classifies fresh and 1-year-old slash on this basis by species and quantity per acre.

Obviously the methods used in deriving table 15 are somewhat arbitrary. Nobody is sure at this time just how combining two dissimilar fuels affects rate of spread. However, it appears certain that fire would have spread through plots that did not burn if a duff-and-litter layer had been present. It appears equally certain that addition of even very small amounts of better aerated fuels would increase rate of spread roughly in proportion to the quantity of the additional fuel. Table 15 is the best available estimate of the resultant rates until more precise information becomes available.

The slash rate-of-spread type ratings in table 15 were derived directly from experimental results without application of judgment beyond that which led to grouping the species. Experience indicates that some of these ratings are probably too high, others too low. For example, fresh western larch slash almost certainly is rated too high, while redcedar, particularly 1-year-old and older, appears underrated. Like the general fuel-type ratings, those proposed for slash are suggested as guides to judgment, not substitutes for it. Local conditions must be considered, such as variations in weather patterns due both to climatic differences and topography. These variations commonly affect slash characteristics and especially slash deterioration with age. If table 15 is taken only as a rough guide, it can be useful; if taken as a precise measure of fuel type, it may cause confusion.

Apparently slash was seriously underrated by the U. S. Forest Service, Region 1, fuel type classification system developed in the 1930's (*42*). Of 19 fuel types involving recently cutover areas, only three were given an "Extreme" rate-of-spread rating, and two were actually rated "low." Table 15 shows no fresh slash in volumes greater than 4 tons per acre in any cate-

Table 15.--Equivalents of U.S. Forest Service rate-of-spread types for Montana and Idaho by species, quantity, and age

Species	Rate-of-spread type							
	Low and medium	High	Extreme	Flash	Low and medium	High	Extreme	Flash
	Fresh slash				1-year-old slash			
	Tons per acre							
Western white pine	<2	3-7	8-17	>17	<2	3-12	13-22	>22
Lodgepole pine	<2	3-7	8-17	>17	<2	3-12	> 12	1/ --
Ponderosa pine	<2	3-12	13-22	>22	<3	4-22	> 22	--
Western redcedar	<2	3-7	8-17	>17	<2	3-12	13-22	> 22
Douglas-fir	<2	3-7	8-17	>17	<3	4-22	> 22	--
Western hemlock	<2	3-7	8-17	>17	<3	4-22	> 22	--
Engelmann spruce	<2	3-12	13-22	>22	<3	4-22	> 22	--
Grand fir	<2	3-7	8-17	>17	<7	> 7	--	--
Western larch	<1	2-4	3-9	> 9	<7	>7	--	--

1. Blanks indicate that slash of species concerned does not occur in sufficient quantity to fall into indicated rate-of-spread type.

gories except "High," "Extreme," and "Flash." Apparently preoccupation with huge, unbroken expanses of bad fuels in old burns prevented adequate recognition of fuels as bad as or worse on smaller areas. *Evidence from both analysis of wildfires*[3] *and experimental slash burning indicates that henceforth slash should be recognized as an "Extreme" rate-of-spread type.*

INTENSITY OF SLASH FIRES

Intensity is as important a characteristic of fire as rate of spread. Some fires spread very rapidly and grow large without causing much damage or being especially hard to control. Others, spreading at the same rate or slower, become unapproachable infernos. Usually the prime requisite for the occurrence of high-intensity fires is an abundant supply of finely divided, available fuel. Logging slash, particularly fresh logging slash, provides such fuel. Therefore information about the intensity of small experimental slash fires indicates what intensities might be expected when large volumes of slash burn uncontrolled.

Intensities of experimental fires were assessed chiefly by observing height and movement of flames and by measuring radiated heat. In addition, completeness of combustion, a further indicator of fire intensity, was determined for representative plots. Observations of flame characteristics were augmented by both still photographs and time-lapse movies. The preliminary analysis of fire intensity data thus far completed provides a measure of relative intensities of fires in fresh and 1-year-old slash as affected by species and quantity. Full-scale analysis of data on heat radiation in conjunction with measurements of flame area and convection column speed, obtainable from movies taken simultaneously, is expected to add significantly to the scanty existing knowledge of the heat budget of free-burning fires in dangerous fuels.

FLAME CHARACTERISTICS

Because of the virtual absence of wind, each experimental slash fire tended to spread outward rather uniformly in all directions from the ignition point except where restricted by voids in the fuel bed. Immediately after ignition the flames roughly formed a cone that increased in height as long as all fuel within the periphery of the fire was burning actively. When fuel near the center of the burning area became depleted, the fire broke down into a ring of flames usually about half the maximum height of the earlier cone. The cone was most distinct and reached its greatest diameter in heavy concentrations of slash, especially if foliage was present. A strong central convection column and intense radiation from the entire burning area persisted after the flames had retreated from maximum height, sometimes until the fire reached the plot boundaries. In lighter concentrations of fuel, the cone was less well-developed and often short lived. Radiation from within the subsequent ring of flames was slight, and convection was weak and diffuse.

Height of flames varied greatly with quantity and type of fuel. On 7.5-ton plots of slash without needles, flames usually were less than 1 foot high, flaring higher only at an occasional cluster of fine twigs. At the opposite extreme, maximum heights of 15 to 20 feet were attained by flames on 32.5-ton plots of slash with needles attached. These heights surprised observers because mean depth of fuel seldom exceeded 1.5 feet, and wind speed was near zero. Fresh western white pine, lodgepole pine, and Douglas-fir slash burned with the highest flames and with apparently the greatest intensity. Flames from 1-year-old white pine and lodgepole slash were quite similar to those from fresh slash, but 1-year-old slash of other species burned with much lower flames than fresh slash. Figures 21, 22, and 23 show how flame size was affected by slash characteristics.

Detached ignitions, or flashes, occurred rather commonly in the convection columns above the hottest fires. Flashes result from de-

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3/In testing an experimental rate-of-spread computer during 1951 and 1952 the author found that fires in slash areas consistently spread at rates characteristic of "Extreme" fuels for existing weather conditions.

layed ignition of flammable gases driven off by heating too rapidly for complete combustion with the available supply of oxygen. They are frequently observed in high-intensity fires. Figure 23 shows very high flames that are likely to have detached ignitions above them.

The flames of some very hot fires pulsated regularly in height at approximately 1-second intervals. No reference to or explanation of such pulsations has been found in the literature. Probably, like detached ignitions, they are related to a critical balance between rate of heating and available oxygen. Both phenomena usually occurred in completely calm air.

HEAT RADIATION

Radiation was measured continuously during the burning of nearly every plot. The radiometer used in 1952 was suspended above the fire. Consequently it measured varying amounts of convectional heat together with radiation, with the result that the readings obtained were not reliable and could not be compared with those made in subsequent years. A directional radiometer was used in 1953, and a flat-plate total hemispherical one in 1954 and 1955 (*45*). Readings for the 3 years were adjusted mathematically to those expected for the flat-plate radiometer at the most commonly used distance, 28 feet from the plot center. Simultaneous readings with the two instruments on six plots indicated that corrected values were sufficiently accurate and consistent to support valid comparisons based on major differences in slash characteristics.

Maximum Fire Intensities

Table 16 summarizes the usable radiation data for 20.0- and 32.5-ton plots. The few readings obtained from 7.5-ton plots were erratic and apparently depended more on location of the active fire edge than on intensity of radiated heat.

Although not conclusive, the data indicate several probable relations that can be used, pending final analysis, in estimating relative flammability:

1. On an average, fire intensity (as indicated by maximum heat radiation) is three times as high in 32.5-ton-per-

Figure 21. Effect of fuel weight on peak fire intensity in fresh western larch slash: **upper,** 7.5 tons per acre; **lower,** 32.5 tons per acre.

Figure 22. One year's aging considerably reduces peak intensity of fire in slash that loses its needles during the year after cutting (Douglas-fir, 32.5 tons per acre). **Upper**, current year's slash with needles attached; **lower**, 1-year-old slash with needles fallen.

acre slash as in 20.0-ton. Thus, fu quantity apparently affects intens more strongly than it affects rate spread.

2. Fire intensity declines more rapidly the year after cutting than does the ra of spread. The reduction is about percent for species that retain the needles and more than 80 percent f the others.

3. If quantity calculations, experiment rate-of-spread measurement, and fie observations are considered, the follo ing intensity groupings appear to justified:

   High intensity--fresh and 1-year-c slash of western white pine, lodgepc pine, and western redcedar; fresh sla only of Douglas-fir, ponderosa pir and grand fir.

   Medium intensity--fresh and 1-year-c slash of western hemlock; fresh sla of Engelmann spruce; 1-year-old sla of ponderosa pine.

   Low intensity--all ages of western lar slash; 1-year-old and older slash Douglas-fir, Engelmann spruce, ar grand fir. As with rate of spread, u der field conditions the pound-fc pound comparison made here may altered by the relation of quantity species, by site conditions, and by t fuels that occur naturally with slas

Peak radiation usually occurred after t initial cone of flame subsided, but while t interior of the fire was still very hot. The redu tion in height of flames was more than offs by increases in thickness and in diameter of t fire. Radiation from fires in fresh 20.0- ar 32.5-ton-per-acre slash tended to increase un fire diameter closely approached or actua reached its possible maximum of 20 feet. Di meter at maximum intensity was somewhat le in 1-year-old slash of the same weights becau the flames were not so thick. When a fire quic ly broke down into a thin ring of flame, the a proach of the flames to the radiometer was t main factor affecting apparent intensity.

Although flame temperatures of wood fires vary somewhat, variation in measured radiation from slash plots indicates differences in rate of heat transmission rather than in flame temperature. Differences in flame temperature probably were quite small, but differences in radiating flame area and in thickness of flames were large. Fire emissivities were calculated on the basis of an assumed flame temperature of 1,500°F. and an assumed shape of fire. Average maximum emissivity for fires in 32.5-ton per-acre lodgepole pine slash was 0.26, slightly below that quoted by Hottel for powdered coal flames (*19*). This appears to be a reasonably reliable figure because the actual shape of the flames closely resembled the assumed shape. Emissivities calculated for less intense fires ranged downward to 0.04, but these values are unreliable because of variation in the shape of the radiating areas.

Intensity and Rate of Spread

Fire intensity is proportional to rate of fuel consumption, which may be regarded as the product of rate of spread and quantity of fuel available. Quantity of fuel was by far the dominant influence on the rate of spread of experimental slash fires. Therefore, rate of spread was almost a direct measure of rate of fuel consumption. Figure 24 shows that fire intensity bore the type of relation to rate of spread that would be expected under the circumstances.

The faster a fire spreads, the sooner the greatest possible quantity of fuel is burning simultaneously. Time to maximum intensity is an important consideration affecting speed and strength of initial attack. Figure 25 shows the intensity-time relationship for the three weights of lodgepole pine slash.

Efficiency of Combustion

In 1955, unconsumed residues, including both ashes and charcoal, from 10 plots of 1-year-old slash were collected, ovendried, and weighed. Two 7.5-ton and four each of 20.0- and 32.5-ton plots were sampled. The 7.5-ton plots were grand fir and ponderosa pine; in addition to these two species, 20.0- and 32.5-ton plots included lodgepole pine and western larch. The small number of samples does not permit statistical comparisons between species. Fuel

Figure 23. Aging for 1 year only slightly affects peak intensity of fire in slash that retains its needles (western white pine, 32.5 tons per acre). **Upper,** current year's slash; **lower,** 1-year-old slash.

Table 16.--Average maximum radiation received by radiometers adjusted to instrument distance of 28 feet from plot center

Species	Fresh slash				1-year-old-slash			
	20.0 tons/acre		32.5 tons/acre		20.0 tons/acre		32.5 tons/acre	
	Plots	Heat	Plots	Heat	Plots	Heat	Plots	Heat
		Btu per sq ft /hr		*Btu per sq ft /hr*		*Btu per sq ft /hr*		*Btu per sq ft /hr*
Western white pine	--	--	--	--	2	193	3	628
Lodge pole pine	2	523	2	2,003	3	317	3	885
Ponderosa pine	2	359	2	1,245	4	142	4	297
Western redcedar	--	--	--	--	2	138	2	279
Douglas-fir	--	--	--	--	2	98	2	156
Western hemlock	--	--	--	--	2	110	1	176
Engelmann spruce	3	245	3	317	2	130	1	60
Grand fir	2	263	2	902	3	49	4	216
Western larch	2	478	3	957	4	64	4	258
Mean		362		1,010		136		364

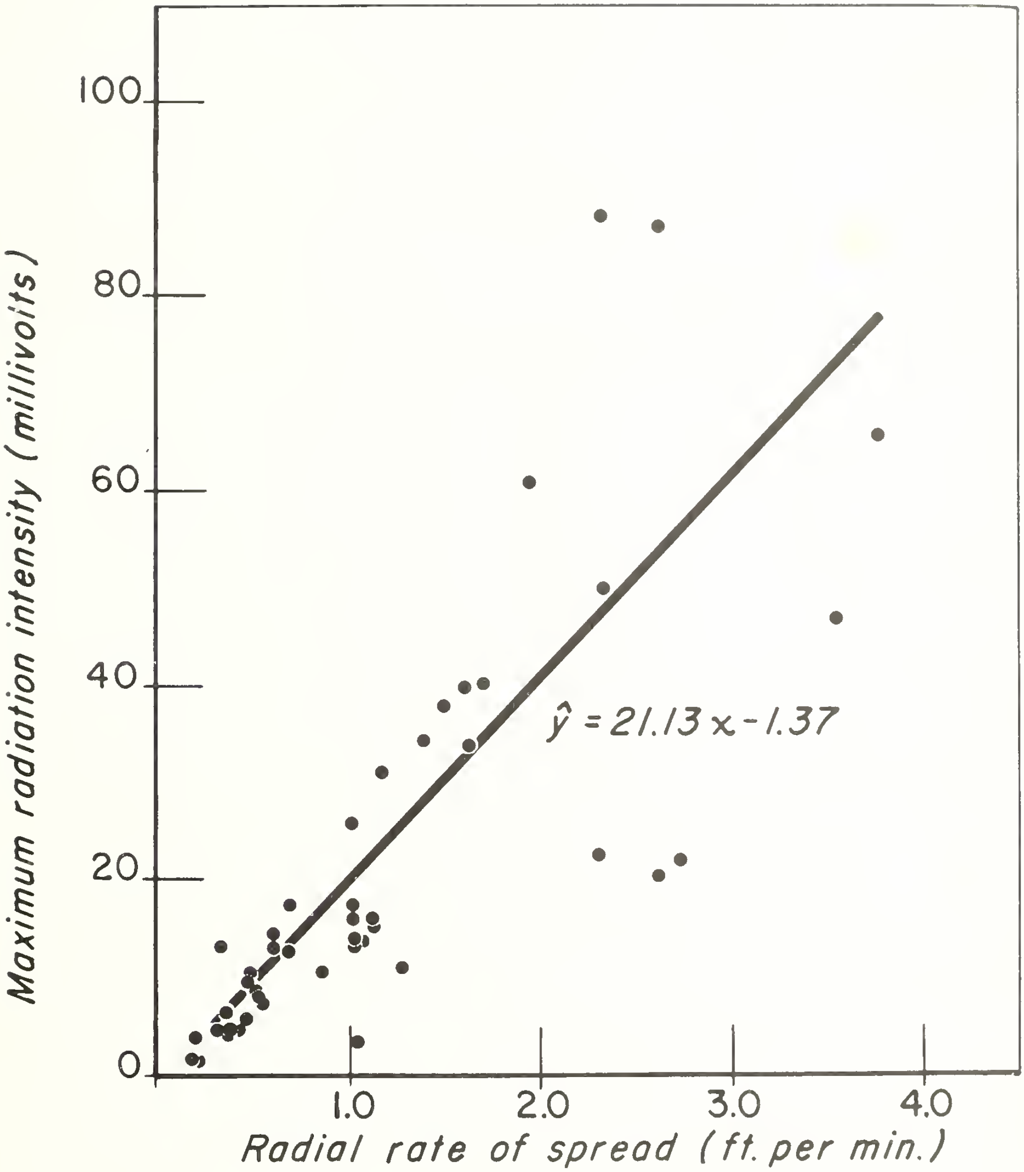

Figure 24. Fire intensity in relation to rate of fire spread in fresh and 1-year-old slash of lodgepole pine, ponderosa pine, grand fir, and western larch. **Basis:** 48 fires.

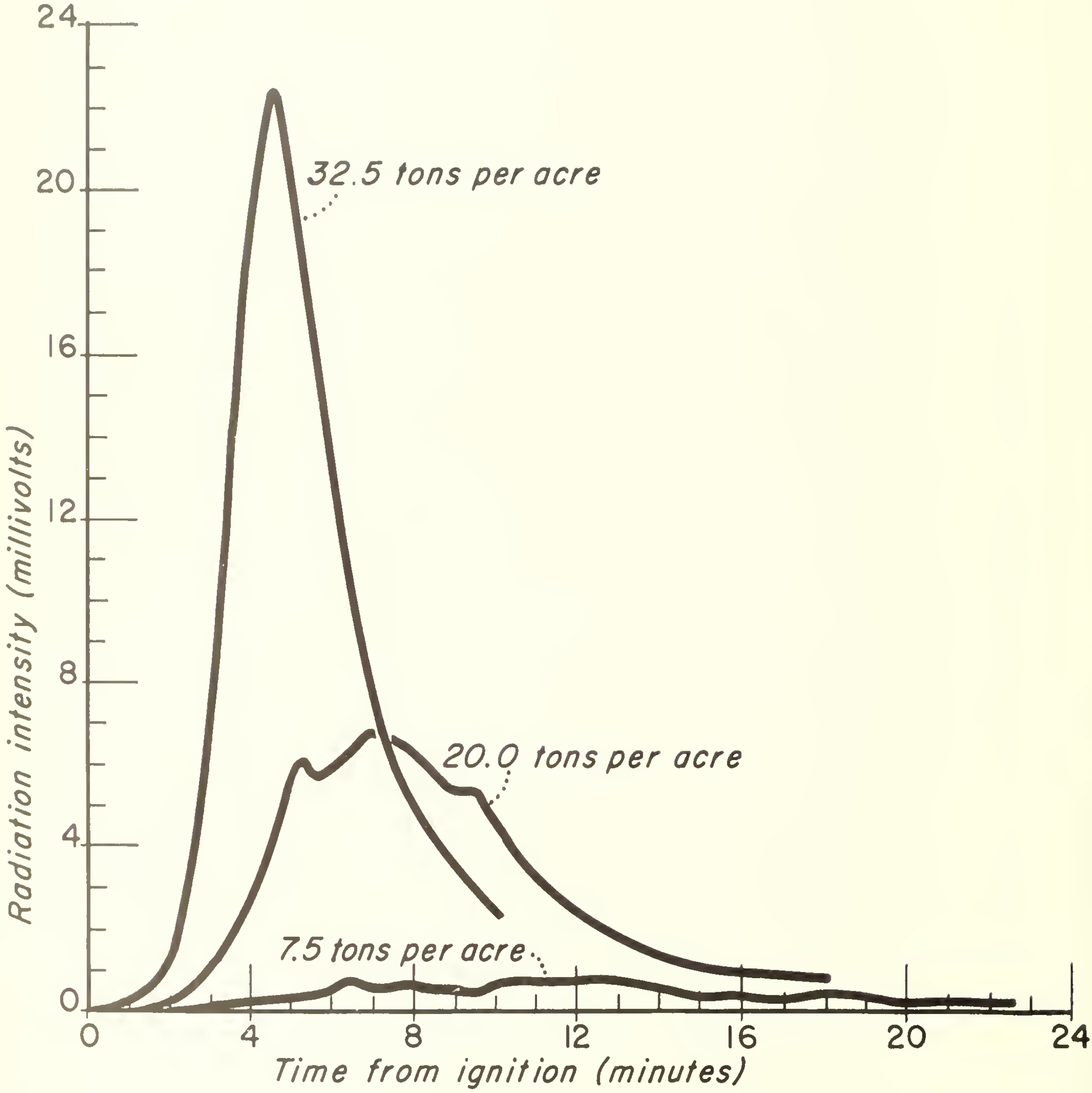

Figure 25. Radiation intensity in relation to time from ignition for three weights per acre of lodgepole pine slash.

consumed for each weight of slash averaged as follows: 7.5 tons, 56 percent; 20 tons, 71 percent; and 32.5 tons, 79 percent.

Some of the increase in combustion efficiency with weight results from continued burning of more large material after the fast-spreading phase of the fire is over. It stands to reason, however, that increasing the amount of fine fuel causes more coarse material to burn during the early stages of the fire also, thereby further intensifying heat output.

Use of Fire Intensity Data

Until combustion in free-burning fires is more fully understood, intensity data like those obtained by this slash flammability study can be interpreted and applied only very generally. Close agreement with rate-of-spread findings indicates that ratings based on rate of spread usually will represent adequately the fire-intensity factor of slash flammability. Flammability ratings of western white pine and lodgepole pine can be given a plus mark to indicate the high heat output and violent flame behavior that characterize fires in both fresh and 1-year-old slash. Rapid build-up of heat energy output also is a very important characteristic of the slash species that burned hottest experimentally.

SLASH TREATMENT IN RELATION TO FLAMMABILITY

The preceding sections have described results of various phases of the logging slash research program and have suggested some specific ways of applying those results. Although these individual applications may help to provide a sound basis for selecting the best slash treatment for a particular situation, all pertinent information on slash flammability must be integrated and considered in conjunction with other factors. By "treatment" is meant any and all measures undertaken to offset the effects of increased flammability. Included under "treatment" are slash disposal, extra protection, modified cutting practices, and any other possible actions. Flammability rating will indicate whether individual slash areas require special attention, but other considerations probably will dictate the type and intensity of treatment.

INTERPRETATION OF FLAMMABILITY

The Flammability Rating to Use

The section on FIRE SPREAD IN SLASH shows how relative flammability ratings can be calculated for slash by species, quantity, and age. Slash treatment priorities are indicated more accurately by numerical flammability ratings than by estimated fuel type, which heretofore has been the basis for deciding whether to treat slash areas. Addition of quite small quantities of slash per acre produces a fuel type that warrants either disposal or extra protection. However, the variation of slash quantity, and hence the relative flammability rating, within each hazardous fuel type is large--more than 100 percent of the lower value in some types. Now this variation, which has long been recognized to some degree in practice, can be measured.

The flammability rating of fresh slash is not a satisfactory basis for selecting appropriate treatment. Slash is most hazardous and shows the least difference among species during the season of cutting; therefore, disposal should be accomplished then. However, this ideal is seldom attained. Furthermore, when extra protection is selected in lieu of disposal, the first fire season is only a small portion of the time during which protection must be provided. As a practical matter, slash disposal usually can be accomplished by the end of the year after logging if it is going to be done at all. Therefore, it appears realistic to base treatment priorities on relative flammability of 1-year-old slash, in which interspecies differences that appear likely to persist for several years can be recognized.

Total Flammability Versus Fuel Flammability

Since all experimental burning was done in the early evening, when burning conditions were essentially the same in the open as in dense timber, only flammability of the fuel was measured. Arnold and Buck (*1*) showed that complete removal of forest cover reduces fuel moisture by as much as one-half and increases wind speed up to tenfold. In the northern Rocky Mountains these changes result in approximately doubling expected rate of fire spread under common, summer afternoon burning conditions. For northern Rocky Mountain fuel types, which take into account the effects of exposure to weather factors, the following relative rate-of-spread ratings have been found to exist among fuel types:

Low and medium	1
High	3
Extreme	5
Flash	15

However, it has been shown that addition of slash alone, without allowance for change in microclimate, is sufficient to place rate of spread in the "Extreme" class. Obviously, density of the residual stand must be considered in rating total slash flammability. Clear cutting results in maximum hazard by subjecting abundant fuel to severe burning conditions. When cutting is lighter, total flammability is proportionally lower because of both smaller quantity of fuel and greater density of the residual stand. When increases in both amount of fuel and severity of microclimate are considered, cutting that results in fuel flammabilities having the above 1-3-5-15 ratio may produce total flammabilities in a 1-6-10-30 progression.

SELECTION OF SLASH TREATMENT

Several factors in addition to flammability help to determine the most appropriate slash treatment for a given situation. Although not subjects of the research described herein, these factors must be considered in order that their relation to flammability can be understood. In some instances flammability is a conditioning influence on another factor; in others there is little connection. No attempt is made here to discuss factors in order of priority, since priorities usually change from one situation to the next.

Values to be Protected

All protection is undertaken because of the values involved. Very often no accurate measure of values is available. Nevertheless, consideration must be given both to the values themselves and to the amount of damage these values are likely to sustain. After logging, flammability rating expresses the potency of the damaging agency; physical and biological nature of the resource determines the degree of damage possible; social and economic considerations define the damage that can be tolerated. For a given flammability rating, slash treatment should be most intensive where values are highest and most subject to damage.

Ability to Abate Slash Hazard

Both fuel flammability and total flammability must be considered in relation to available means of hazard reduction. In some instances adequate fuel reduction is out of the question with known techniques or reasonable expense; in others, the change from closed to open stand conditions may prevent fuel reduction from adequately abating total flammability. A realistic appraisal of ability to reduce hazard is an absolute necessity. There is no point in spending money for slash disposal if the effect of treatment will be insufficient to reduce appreciably the expense of protecting an area.

Ability to Protect the Area Without Hazard Abatement

Fuel type is one important criterion of ability to provide effective protection. However, improved accessibility and advances in protection techniques and equipment permit protection of hazard areas that 10 years ago would have required major fuel reduction measures. Relative effectiveness of hazard reduction and extra protection must be reevaluated constantly to account for improvements in slash disposal methods and in the capabilities of the protection force.

Relative Costs of Hazard Reduction and Extra Protection

Costs of slash disposal are relatively easy to determine; the cost of effective protection is not, but some estimate must be made. Availability of manpower and equipment for carrying out the two alternatives is an important consideration. Relative costs must be considered along with actual ability to abate hazard and to protect high hazard areas. Flammability studies indicate that slash that retains its needles more than 1 year should have top priority for disposal, and that extra protection has the best prospect of success in slash that loses its needles soon after cutting.

Effect of Slash Treatment on Land Management Objectives

Values, both tangible and intangible, require consideration in connection with the effects of slash treatment as well as with the effects of wildfire. Sometimes drastic, expensive, and apparently damaging slash treatments fit well with management objectives and techniques; at other times less strenuous measures can largely destroy the values they are intended to protect. The latter situation sometimes justifies tolerating a serious hazard, especially if risk of wildfire occurrence is rather low. Observation of some areas raises the questions of whether a wildfire would have been more damaging than the slash disposal job. *The public is likely to be more tolerant of damage caused by wildfire than of damage caused by ill-conceived or poorly executed slash disposal.*

NEED FOR FURTHER RESEARCH

Results of this study indicate numerous opportunities for further productive research. Continuation and extension of several studies described on preceding pages are necessary to develop techniques for more precise appraisal of flammability. However, the greatest need is to develop means of determining the most efficient methods of treating slash. This problem touches many phases of wildland management for which various subject matter specialists are best able to propose appropriate research. The purpose of this section is to suggest studies that will lead to greater competence in protecting cutover land from fire.

EXTENSION OF PRESENT STUDY

Experimental Burning

Experimental burning of 5-year-old slash will be completed in 1960 to yield information on the effect of age on rate of spread and fire intensity. Depth measurements and descriptions of slash fuel beds will continue to provide information on compaction and rate of decomposition.

Experimental burning should be extended to obtain information on rate of spread and fire intensity under conditions not yet sampled. Small plots of fresh 20.0- and 32.5-ton-per-acre slash, like those described in this publication, should be burned at relative humidities below 30 percent to obtain fuller information how low humidity affects fire spread in heavy fuel concentrations. This burning should be done in a forest fire laboratory where effects of wind could be eliminated. Plots of 7.5-ton slash should be burned on natural duff beds to determine how fire spreads in light concentrations of slash when continuous, slow-burning, natural fuels are present.

Rather large-scale burning experiments are needed to test the effect of fuel arrangement on rate of spread. One very important and very controversial question to be answered is whether fire spreads faster where fuel is continuous or where it is concentrated in piles or "jackpots" that burn hot enough to throw brands capable of causing spot fires.

Check on Measurement

A basis for measurement of slash quantity has now been established. The next step is a field check for accuracy. This would consist of estimating total crown weight on a series of plots by methods described above under MEASURING SLASH, then cutting the trees and weighing the crowns. In addition to checking the accuracy of the weight estimation method, this project should be designed to yield information about how site index, stand density, and stand health affect crown weight per acre. A related study of slash measurement that may ultimately have economic value is determination of amount of raw material available for products not yet developed.

Characteristics Of Slash

Better knowledge of the physical and chemical characteristics of slash will lead to better understanding of flammability. More intensive study of the moisture content of tree crowns is needed, especially to find out how moisture content varies with season of the year and variation in the precipitation pattern. Investigations of brush and herbaceous vegetation (*12*, *35*) have shown that moisture content varies enough to affect fire behavior strongly. Similar studies of living tree crowns might provide one gage of crown fire potential.

Although physical characteristics and moisture content appear to be the main attributes of slash that affect flammability, studies of chemical composition are warranted. Determination of the quantities and combustion characteristics of needle fats and oils should have first priority. Study of flash points of green and dry forest fuels has been elementary so far (*20*, *37*). Further research should give useful information applicable to both surface and crown fires.

EVALUATION OF SLASH TREATMENT

The greatest current need of the slash disposal program in the northern Rocky Mountains is to determine whether the right measures are being employed with appropriate intensities in the problem areas. The questions to be answered are both technical and economic. Slash treatment must provide adequate fire protection, and must do it at acceptable cost. Slash measurement techniques and flammability ratings developed by the present study provide means for examining critically the need for slash treatment and the effectiveness of disposal operations, both of which are basic considerations in determining how much should be spent to combat the slash fire hazard effectively. The type of applied research required provides excellent opportunity for cooperative endeavor by research and administrative agencies. Because economic conditions change continually, need for evaluation of slash treatment programs will also continue.

Technical Evaluation

The two most important things to be learned in studying the technical effectiveness of slash treatment are: (1) whether effort is being directed against hazards in proportion to their severity, and (2) whether the measures employed are accomplishing their purpose. Inspection of many cutover areas supports the opinion that the intensity of slash disposal practiced frequently is not in proportion to the need for it. Learning whether this is true may strongly influence the amount and allocation of funds collected for both slash disposal and extra protection. Measuring accomplishment is most important where slash has been piled by hand. Prescribed burning and bulldozer-piling usually eliminate slash almost completely on the area treated, but examination is necessary to see whether new hazards have resulted from escape of slash fires or mechanical damage to the residual stand.

If extra fire protection measures have been employed in lieu of slash disposal, evaluation will be especially difficult. In the first place, the presumed extra protection commonly is very difficult to measure and, indeed, even to identify as something distinct from the general fire control effort. In the second place, accomplishment can be measured only in terms of decreased frequency, size, and cost of fires, all of which are influenced by so many other factors that the effect of variation in fuel is extremely difficult to measure.

The most useful technical evaluation will result from on-the-ground study of recent slash disposal operations. One procedure should consist of determining, in the order given, (1) flammability after logging, (2) slash treatment applied, and (3) flammability after treatment. Initial postlogging flammability ratings can be calculated in the office from cruise or cutting records but should be corroborated by field examination to take into account features that are not recorded, such as number of snags and windfalls. Kind of treatment used usually is recorded, remembered, or obvious from evidence on the ground; but degree of treatment is difficult to measure except in terms of cost. Flammability after treatment is the crux of the whole problem, and it also is hard to measure. Thus within the larger study of the effectiveness of slash disposal as a measure for hazard reduction are two opportunities for development of research methods (1) for expressing slash treatment quantitatively, and (2) for rating flammability after treatment.

A second research procedure is examination of information available about fires that have burned in cutover areas. This type of study has been rather unfruitful in the past, possibly because of insufficient or inaccurate information both about the fires and about the physical conditions of the cutover areas before they burned. Nevertheless, periodic analysis of mass statistics and individual fire case histories remains a potential source of valuable knowledge and of leads to follow in starting other types of research.

Economic Evaluation

Cost and accomplishment of slash treatment need to be tested against the least-cost-plus-damage criterion. The present annual cost of slash treatment in the Inland Empire is about $3.75 million, but the annual cost of suppressing slash fires and the damage sustained from these fires is much less. Possibly the total bill would be smaller if different treatments were applied. Technical evaluation of slash treatment will answer some financial questions, but economic analysis of the slash disposal field and of individual cases also is necessary.

The economics of slash treatment can be studied partially by compiling and analyzing fire reports and examining case histories of individual fires. Such studies should be pursued concurrently with the similar analyses of technical accomplishment mentioned earlier. Unfortunately, incomplete records of past fires, inadequate representation of important conditions, changing methods of fire control, and new facilities for fire control seriously complicate the interpretation of past occurrences in terms of future probabilities. Therefore statistical and case-history studies may only suggest what type of research is needed to provide definite answers. One possibility that should be considered is large-scale, long-term comparison of two or more similar areas on which the slash problem would be handled in different ways. The areas might need to be whole national forests; the duration of such an experiment should be 5 to 10 years.

Any attempted method of economic analysis will be impeded by lack of a satisfactory method of appraising fire damage. Without realistic damage appraisal, it will be difficult to compare the cost of slash treatment with that resulting from omitting treatment. Arbitrary guidelines and values can be used temporarily for research purposes, but economic analysis should help point the way to development of better methods of damage appraisal.

DEVELOPMENT OF EQUIPMENT AND TECHNIQUES

Although this study of flammability was not directly concerned with slash treatment, it is impossible to think about slash without also theorizing about methods that might revolutionize present practice. Usually this theorizing revolves about "magic" chemicals that would decompose slash quickly or machines that would grind it up. Such dream-stuff is unlikely to materialize in the near future, but the whole operation of slash disposal offers virtually limitless possibilities for devising and perfecting machinery and techniques, an activity that seemingly should afford opportunity for highly productive use of slash disposal funds.

The bulldozer has come into its own for piling slash on favorable ground, but important and troublesome situations remain: (1) Some slopes are too steep or too erosive to permit use of bulldozers, and (2) some partially cut stands contain enough slash to require disposal and also a residual stand that would be harmed by use of fire or of heavy machinery. Full-tree logging might solve these problems. With this technique, now used rather extensively in Russia but barely tried in the United States (*24*), entire trees are skidded to the landing. There the desired raw products are cut, and the tops and limbs are burned or chipped. Full-tree logging appears to be an especially good technique for use on relatively small trees, such as those cut for poles, piling, and pulpwood. Obviously slash disposal or use will be facilitated if the slash is concentrated in one place; accurate comparative tests against conventional methods might reveal additional advantages.

Several possibilities have been suggested for development of slash disposal equipment; little work has been accomplished to date. One possibility that would apply to steep terrain is a lightweight winch equipped with a haul-back and some sort of grapple to skid slash up or down hill. For partially cut stands especially, a good chipper or brush chopper will become increasingly desirable. Experimental development should improve models now available by increasing their compactness and mobility and by incorporating self-feeding apparatus.

USES AND EFFECTS OF FIRE

The chief purposeful use of prescribed burning in forests of the inland West is for slash disposal. After decades of experience, foresters still burn on the basis of experienced judgment rather than on proved fact and measurement. Rarely does a year pass without some slash fires escaping because of "unexpected" behavior at one extreme and excessive time being wasted on attempting to burn fuels that will not burn at the other. The findings on rate of spread and fire intensity in slash point toward development of a body of knowledge that can be expressed quantitatively and used as the basis for instructions or rules for burning.

One very important opportunity for improving use of fire is the extension of time during which prescribed burning can be done safely and effectively. Techniques of area ignition hold promise for the burning of relatively sparse or green fuels and for burning during damp weather. On the other hand, with proper precautions based on better knowledge of fire behavior, slash area preparation, and local weather, burning undoubtedly can be done safely in drier weather than is now usually selected. Both possibilities are promising enough to warrant testing even at the risk of sacrificing a few hundred acres of green timber.

Some practical questions that need answering relate to (1) minimum quantity of fuel that can be burned, (2) maximum quantity that can be burned safely under given conditions, and (3) precautions that are required for different combinations of topography and weather.

The whole subject of fire effects is ripe for pioneering research. Direct effects of heat on vegetation are particularly appropriate for study in connection with slash flammability because slash fires now damage many trees unnecessarily. Research is needed (1) to rate the various commercial species according to their fire resistance, (2) to measure what degrees of heat each can tolerate, and (3) to determine at what distance from slash fires damage occurs under varying weather conditions. Better knowledge of effects of heat on soil organisms could be used to advantage for prescribed burning to destroy *Ribes* seed in the duff of cutover western white pine stands.

USES FOR SLASH

The best treatment for a troublesome waste product is use. Approximately 2 million tons of tree crown material are cut annually in Idaho and Montana alone. Technology has devised uses for all this raw material: chipped slash can be used for cattle bedding, soil amendment, and agricultural mulch; it can be burned for fuel, pressed into particle board, and pulped for fiberboard. Economically these uses are not yet feasible because other raw materials--sawmill residues, topwood, snags, and windfalls — are more readily available and easier to process. However, Europe's experience strongly suggests that product specifications will become less particular and that ultimately virtually 100 percent of the woody portion of every tree will have to be used. Research should start now to develop uses for fine slash components. Possibilities for productive studies range from means of concentrating and cleaning slash in the forest to complex processes of manufacturing. The incentive is twofold: removal of a fire hazard and utilization of what is now waste.

In continuation of work already begun as well as in the other lines of study suggested, the possibilities for productive research far exceed present prospects for accomplishing it. Direct applicability of results to pressing administrative problems makes research on logging slash an especially attractive subject for cooperative effort.

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PRODUCTION-DISTRIBUTION TRENDS AND FREIGHT RATES AS THEY AFFECT MOUNTAIN STATES LUMBER PRODUCERS

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PRODUCTION-DISTRIBUTION TRENDS AND FREIGHT RATES AS THEY AFFECT MOUNTAIN STATES LUMBER PRODUCERS

By

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INTRODUCTION

The Mountain States[1] have a lot of wood to sell. Their chronic difficulty has been that of having more wood than immediate markets for wood. This situation has risen because distance to market, topography, and other factors have imposed handicaps on development of the timber industry. However, recent events have shown that increasing national needs for wood and declining timber supplies are reducing these handicaps. They give reason for new hope and anticipation concerning future development of timber industries in general and the lumber and pulp industries in particular. This brighter outlook has, of course, underlined the importance of studies of resource development. A recent report published by this experiment station discusses the market opportunity for the timber of the region;[2] another, the potentialities of lodgepole pine for lumber.[3] Other studies, completed and under way, analyze development problems of specific areas.

The following pages look at two other facets of the situation:

1. The changing pattern of lumber production and consumption, and
2. Relationships that exist between rail transportation costs and lumber distribution patterns.

While production and consumption trends are results rather than causes, they do suggest the shape of things to come; and, although rail transportation is only one of the factors influencing where lumber goes, it is certainly an important one.

The following discussion and analysis is based mainly on lumber consumption and distribution data for 1922 and 1940 by the Bureau of the Census and the U. S. Forest Service, and waybill statistics for 1953, 1954, and 1955 compiled by the Interstate Commerce Commission. The surveys of lumber distribution made in 1922 and 1940 have certain inadequacies and inaccuracies which require that we interpret them with caution. The waybill statistics appear to be an accurate sampling of rail freight traffic, but to show the complete lumber distribution picture, it was necessary to estimate truck shipments. Since data on truck shipments are not available, it was assumed that they were all intraregional. While some lumber is hauled between regions by truck, in terms of the total lumber distribution in the West, these shipments are believed to be of minor significance.

An additional difficulty is that there is apparently no published information on the distribution pattern by species. This is unfortunate, as the higher quality, higher priced woods which can carry a bigger freight cost are undoubtedly shipped further on the average than the lower value species associated with them.

Although these limitations of present data make a detailed analysis impossible, the information in the following pages is nevertheless definitive enough to indicate:

- Where Mountain States lumber is now being marketed.
- Production and distribution trends that have influenced the lumber industry in this region.
- The significance of freight rates to lumber marketing.
- Additional study that may be helpful in improving the market situation.

[1] Montana, Idaho, Wyoming, Utah, Nevada, Colorado, New Mexico, and Arizona.

[2] Hutchison, S. Blair, 1957. Market Prospects for Mountain States Timber, U. S. Forest Service, Intermountain Forest and Range Experiment Station Research Paper 50.

[3] Wikstrom, John H. 1957. Lodgepole Pine—A Lumber Species, U. S. Forest Service, Intermountain Forest and Range Experiment Station Research Paper 46.

Table 1.--**Lumber production in the Mountain States, 1954**

	Million bd. ft.
Idaho	1,399
Montana	738
Wyoming	81
Colorado	174
Utah	51
Nevada	28
Arizona	258
New Mexico	222
Total	2,951

Source: Bureau of the Census, U. S. Dept. of Commerce

Sawmills in the Mountain States produced 3 billion board feet of lumber in 1954 (table 1). The commercial forests in these States probably could sustain twice that production of lumber and in addition grow large quantities of pulpwood and other timber products. However, to market even 3 billion board feet, local sawmills must ship their products to the far corners of the United States. Every State in the Union, from Maine to Florida, from Oregon to New York, buys some lumber from the Mountain region. Figure 1 shows that half of the Mountain States lumber is shipped to eastern states.

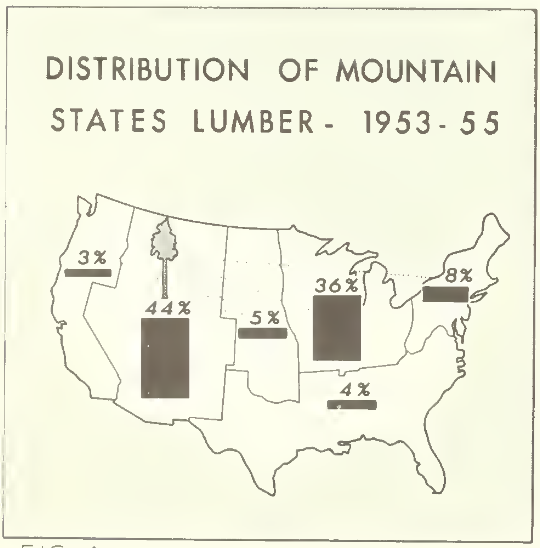

FIG 1

The large volume of lumber going out of the region reflects partly the fact that these eight States, which have about 3½ percent of the population, produce roughly 8 percent of the Nation's lumber, or considerably more than they could possibly use. The wide distribution of Mountain States lumber also reflects a utility factor that should not be overlooked. Timber has been important in the development of this Nation, partly because it has been abundant and partly because there has been a wood for every purpose. The strength of southern pines and Douglas-fir, the beauty of the hardwoods, and the workability of other species satisfy a variety of national wood needs. Unfortunately, however, the qualities sought in lumber are not all found in the same species nor are they evenly distributed from a geographical standpoint. In other words, more or less local supplies must serve a national purpose and must be marketed nationally to command highest prices. This is true of California's redwood, of the many quality hardwoods grown in the East, and of soft-textured woods like ponderosa pine and white pine, found mainly in the West. These two pines, along with spruce, sugar pine, and lodgepole pine, are part of a soft-textured lumber category much in demand, but in relatively short supply. Although Mountain States sawmills produce only 8 percent of the total lumber cut, they produce almost one-third of the lumber in this particular soft-textured category. Moreover, the region probably has 40 percent of the producing capacity for this type of timber.

Table 2.--**Apparent annual consumption of domestically produced lumber in the United States[1] by major regions**

Consumer region	1922	1940	Average 1953-55
	Billion board feet		
East	27.3	22.8	28.8
Mountain	1.0	1.2	1.9
Pacific Coast	5.3	6.3	7.3
United States	33.6	30.3	38.0

[1] Lumber distribution and consumption data for 1922 and 1940 in this report were compiled from estimates by the Bureau of the Census and the U. S. Forest Service. Data for 1953-55 are estimates based on statistics of rail and water traffic and lumber production from various sources.

Even though much of the Mountain States lumber production is shipped out, the region is in the singular position of also being a substantial importer of lumber. It imports one board of every three it uses. Table 2 shows that in the period 1953-55, an average of 1.9 billion board feet was consumed annually in the Mountain States. Of that amount, approximately 600 million board feet came from the Pacific Coast. The size of these imports is significant because except for a few specialty woods, the Mountain States region has the kind of timber required to meet its own lumber needs.

Of course, it is unrealistic to suppose that Mountain States sawmills can capture all of the local market. The 53 million acres of commercial forest in the region are widely scattered, but most of the best stands are in central and northern Idaho, western Montana, and on the Coconino Plateau of Arizona and New Mexico. To date, lumbering has been concentrated in these areas. Actually, three-quarters of all the lumber produced in the Mountain States is cut by Idaho and Montana mills alone (table 1). The Denver and Salt Lake City trade areas, on the other hand, are the big, choice markets within the Mountain States. High operating costs and other factors have kept sawmills near Denver and Salt Lake from capturing these markets. At the same time, the lumber companies in Montana, Idaho, New Mexico, and Arizona have not moved into them to a great extent. The main rail lines run east and west, so north-south rail transportation is, generally speaking, awkward. In the period 1953-55, for example, only 3 percent of the lumber shipped by rail from Montana went to other Mountain States. It should be remembered that this figure is for rail shipments only. In recent years, an increasing volume of lumber has moved from the north and south into the central Rocky Mountain market by truck; but before the modern truck transport was developed, the rail situation helped west coast mills capture much of this central Rocky Mountain market, most of which they still hold.

However, the changing complexion of the national lumber situation (which will be discussed later) is improving the opportunity for mills in the Mountain States to sell more of their lumber locally. Table 2 shows that use of lumber in the Mountain States has almost doubled since 1922. Moreover, whereas less than half of the lumber consumed in the region in 1922 was home grown, two-thirds of it is today (fig. 2).

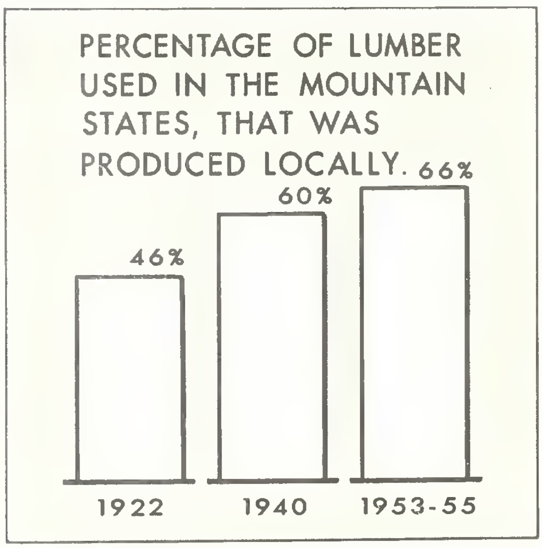

FIG 2

HALF OF THE MOUNTAIN STATES LUMBER GOES EAST.

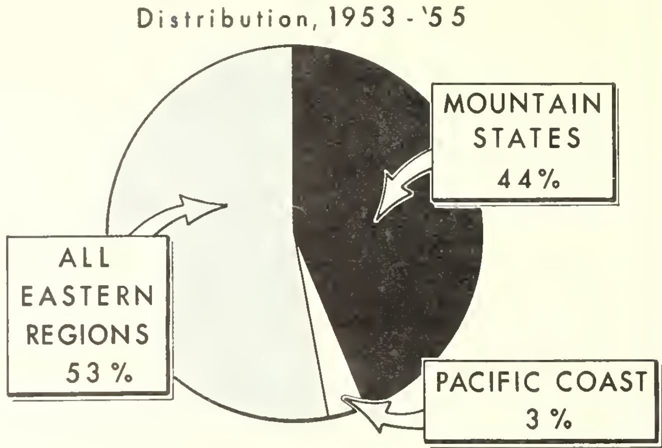

FIG. 3

THE MOUNTAIN STATES ARE A GROWING MARKET FOR LUMBER.

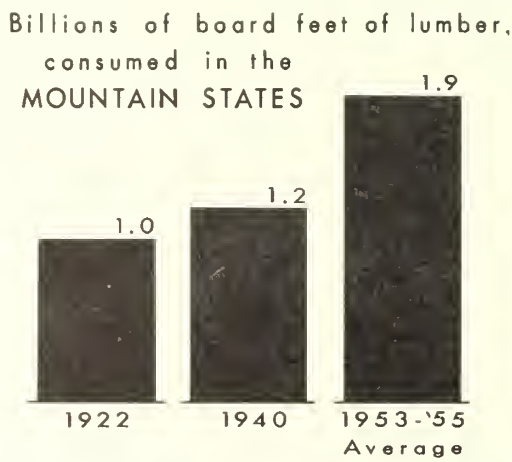

FIG 4

IDAHO AND MONTANA BUY MORE OF THEIR LUMBER FROM WITHIN THE REGION THAN THE OTHER MOUNTAIN STATES.

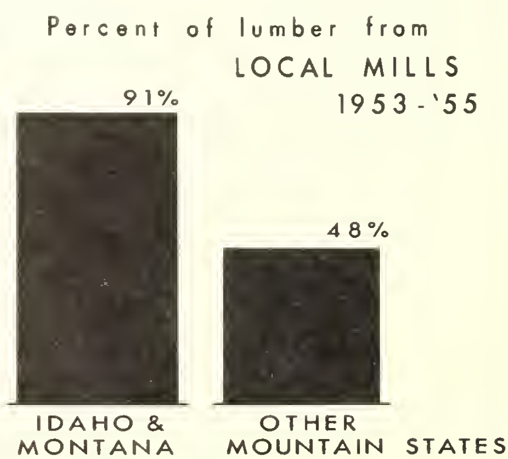

FIG 5

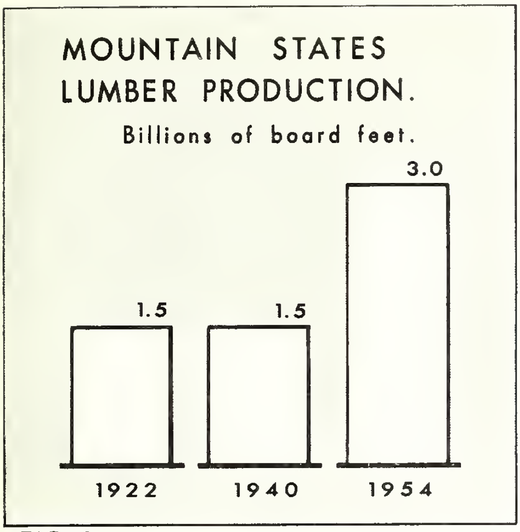

FIG. 6

The gratifying upswing of Mountain States lumber production since 1940 (fig. 6) can hardly be ascribed to the increasing appetite of a growing Nation because the country is not using much, if any, more lumber than it did several decades ago. From its deep slump in the depression thirties, United States lumber output has climbed back to where it was in the 1920's. The specific relationship varies depending on the years compared. For example, lumber production in the period 1920-24 averaged 36 billion board feet as compared with 37 billion in the 5 years 1950-54. In 1922, lumber output was 35 billion board feet; in 1954, 36 billion; but, no matter which figures are used, the conclusion is the same: The over-all trend of lumber output in the last 30 years has not been significantly up or down.

The opportunity for the Mountain States to sell more lumber in recent years is partly the result of a decline in lumber production in eastern United States, particularly in the South. From 1900 into the 1920's, lumber producers in the South were riding the crest. The 11 Southern States from Virginia to Texas were producing close to half of all the lumber used in the United States; but, as the old growth timber supply dwindled, lumber production in the South declined. In the 5-year period, 1950-54, one-fourth less lumber was produced in that region than in the period 1920-24. Sawmills in the Northeastern, Central, and Plains States are likewise turning out fewer boards than they did 30 years ago.

That western lumber moved into the gap is very evident. In the 1950's, the combined sawmill output of the Pacific and Mountain States was 60 percent greater than it was in the early 1920's. These States, which produced one-third of the lumber cut in the 1920's, now supply one-half of the Nation's lumber needs.

Table 3.--**Shipments of Mountain States lumber to the East**

	1922	Average 1953-55
	Million bd. ft.	
Northeast and Central	794	1,287
South	6	119
Plains	129	148
Total	929	1,554

The shift of the lumber industry to the West has greatly affected the pattern of lumber distribution. As figure 7 and table 3 show, western lumber has made gains in all markets. The biggest volume gains have been made in the Central-Northeastern market area.[4] However, a dramatic change has also taken place in the South. In 1922, and even in 1940, only a very small amount of lumber went to the 11 Southern States; but, today, the South buys about 1.5 billion board feet of western lumber, including 100 million from the Mountain States. This invasion took place mainly in Texas, but figure 7 shows that western lumber has effectively penetrated all southern markets.

Several factors account for the increased sale of western lumber in the South, not the least of which is the ability of west coast producers to undersell in almost every market. Increased consumption of Mountain States lumber in the South undoubtedly has resulted from a demand for soft-textured softwoods that is not being filled from elsewhere. Whatever these competitive factors are, they have been bolstered by the shortcomings of the

[4] Some lumber from the West is first shipped to intermediate points, such as the Minnesota Transfer, from which it is rebilled to a final destination on a new waybill showing the transfer station as the point of origin. This fact reduces the reliability of the statistics for the purposes here. It makes it particularly difficult to know how much lumber goes to the Northeast alone and to Central States alone. However, it is obvious that shipments to the Central States have increased relatively much more in the last three decades than shipments to the Northeast.

DISTRIBUTION OF ALL WESTERN LUMBER

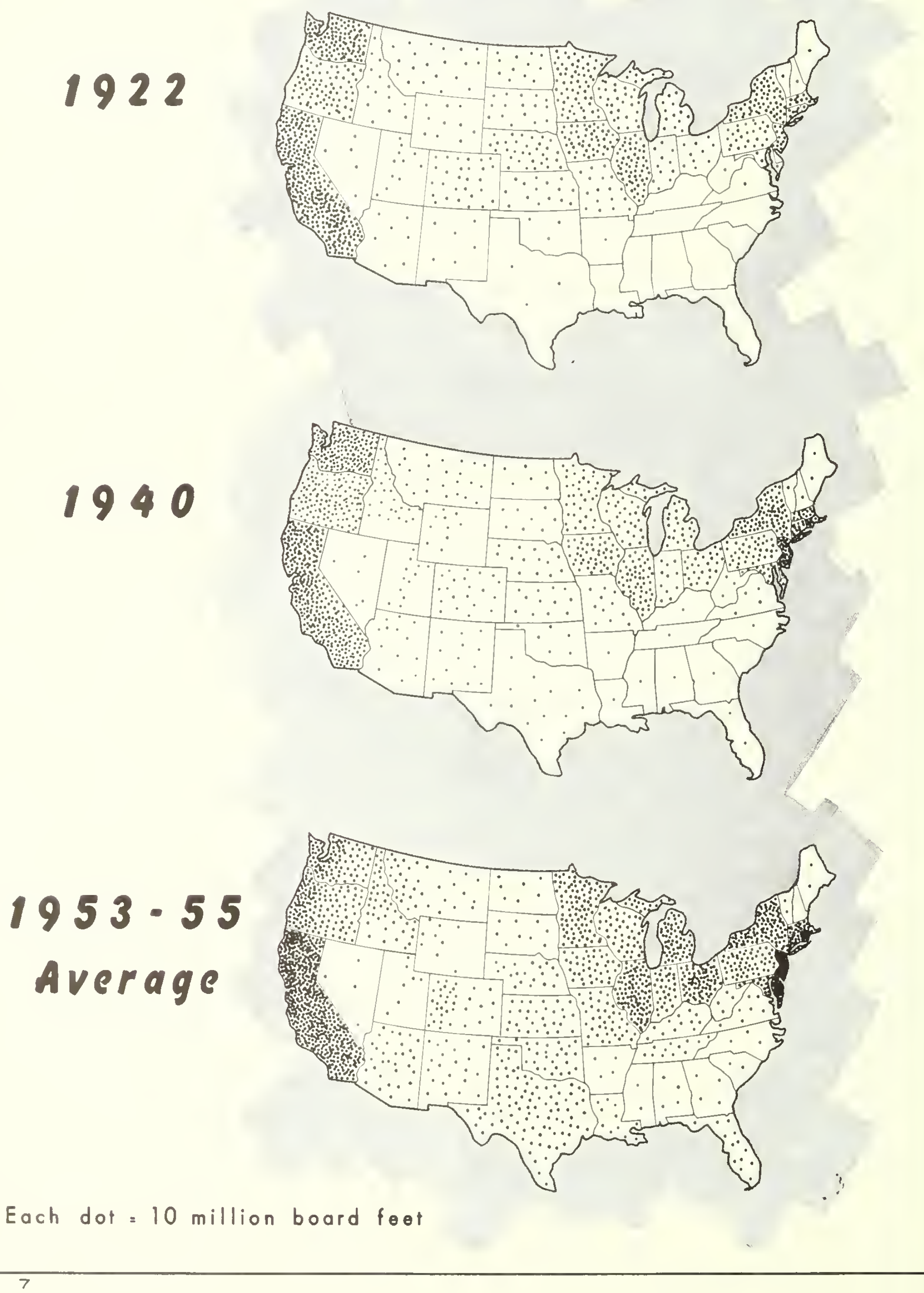

FIG 7

southern pine lumber industry itself. This segment of the lumber industry is cutting second growth timber that produces poorer quality lumber than the virgin stands. It is plagued by the problem of substandard manufacturing, a situation that has been aggravated by the predominance of small sawmills lacking the equipment, financing, and technical capacity to produce top-grade competitive lumber. It has been estimated that less than 20 percent of the lumber produced by the southern pine mills is sold by grade, which is hardly a sign of industrial strength.

A recent trend toward larger sawmills in the South should result in better quality and more efficiently produced pine lumber. In 1958, southern building code restrictions on moisture in lumber were tightened. This action will handicap west coast sawmills that have been shipping in green lumber. However, the net effect of these changes on the competitive situation in the South remains to be seen. There is every reason to suppose the South will continue to be an important market for western lumber in general and Mountain States lumber in particular.

Table 4.--**Increase in real price of lumber, 1939-54**

	Percent
Douglas-fir	50
White pine	84
Ponderosa pine	89
Spruce	72
All lumber	60

Source: Western Pine Association

There is another factor behind the rapid increase in lumber production in the Mountain States since 1940. A tightening timber supply situation in the South and East created the opportunity for the western industry as a whole to grow. Now a similarly tightening supply situation in the west coast States opens the way for further expansion of the Mountain States lumber industry. In the past, the capacity of Washington, Oregon, and California mills to outproduce and undersell Mountain States mills has fenced in all but the most efficient producers and the best timber. That advantage enjoyed by the west coast is now weakening. Southwestern Oregon and California were the only areas along the west coast where lumber production jumped in response to the higher prices following World War II. This strongly indicates that liquidation of virgin timber in Washington and the rest of Oregon has reached the point where the shoe has begun to pinch. Higher prices, engendered by the shortening supply, are enabling the Mountain States to compete on a somewhat more even footing than was possible in the past.

The fact that the Mountain States commercial forest runs heavily to soft-textured softwoods has also favored the recent rapid growth of the industry here. If price is any indication, softwoods like ponderosa pine are now harder to get than the softwoods serving structural purposes. Table 4 shows that prices of these softer woods advanced considerbly more than the price of Douglas-fir between 1939 and 1954. This not only has underlined the importance of already well-established species like ponderosa pine and white pine; it has opened the door to more complete development of species having comparable wood properties, such as spruce and lodgepole pine. The Mountain States have a lot of this soft-textured softwood timber.

Mountain States sawmills have, of course, also been favored by the fact that even though the total United States consumption of lumber has not changed much, the local market has increased considerably since 1920. Tremendous population growth in the Los Angeles area has created some new markets for Mountain States lumber there also. These factors and the region's better competitive situation in all markets have accounted for the big gains in production. Although the Mountain States lumber industry is still dwarfed by the industry of the west coast States, the relative increase in production in this region has been greater than that in the three coast States combined.

U. S. LUMBER PRODUCTION HAS CHANGED LITTLE SINCE 1920 . . . .

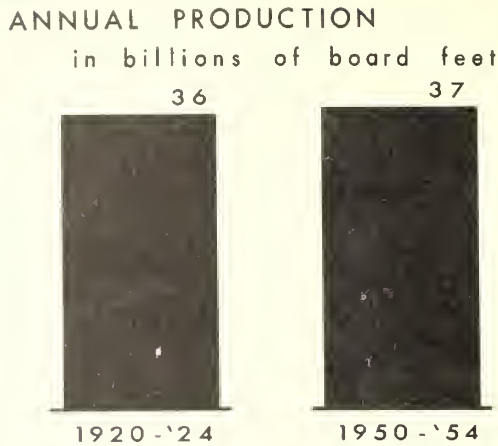

FIG 8

. . . . BUT MAJOR SHIFTS HAVE TAKEN PLACE IN REGIONAL PRODUCTION.

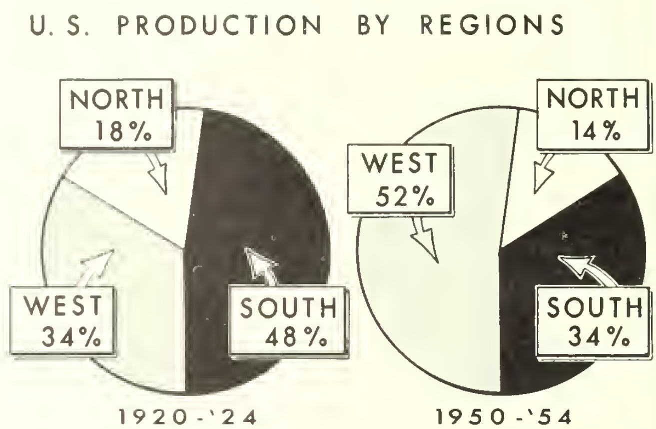

FIG. 9

THE LARGEST RELATIVE PRODUCTION GAINS HAVE BEEN IN THE MOUNTAIN STATES.

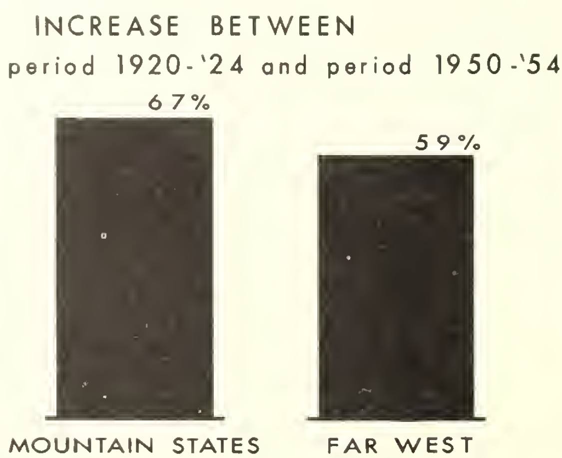

FIG 10

Table 5.--**Distribution of domestic lumber within continental United States**

Destination region	Origin region: Far West	Mountain	South	Plains Central East	Total
	Million board feet				
			1922		
Northeast	984	260	4,655	2,689	8,588
Central	2,022	534	5,590	3,428	11,574
Plains	645	129	708	158	1,640
South	51	6	5,440	27	5,524
Total East	3,702	929	16,393	6,302	27,326
Mountain	518	480	34	3	1,035
Far West	5,115	63	54	16	5,248
United States	9,335	1,472	16,481	6,321	33,609
			1940		
Northeast	1,885	195	1,663	2,250	5,993
Central	2,081	398	2,991	2,375	7,845
Plains	393	72	217	166	848
South	230	25	7,765	50	8,070
Total East	4,589	690	12,636	4,841	22,756
Mountain	483	744	6	5	1,238
Far West	6,153	94	27	5	6,279
United States	11,225	1,528	12,669	4,851	30,273
			Average 1953-55		
Northeast and Central	6,739	1,287	--	--	--
Plains	773	148	--	--	--
South	1,432	119	--	--	--
Total East	8,944	1,554	12,978	5,301	28,777
Mountain	625	1,261	19	10	1,915
Far West	7,111	81	129	18	7,339
United States	16,680	2,896	13,126	5,329	38,031

Economic data tend to age rapidly and transportation cost statistics are no exception. There have been some rail rate changes since 1955 which affect the market position of Mountain States sawmills. No doubt the most significant of these was a 1958 rate reduction from Montana to some midwest points. These reductions probably averaged something less than 3 cents per 100 pounds for the area involved. Nevertheless, they were not large enough to materially alter the relationships discussed in the following pages.

The Mountain States lumber industry's heavy dependence on outside markets is likely to continue for a long time. Interregional freight costs, therefore, are a matter of continuing importance. Freight charges can amount to as much as 30 percent of the cost of a board to a consumer. While the economic position of the lumber industry in this region involves a number of other factors beside freight costs, the rate structure can either hamper or facilitate resource development.

The statistics on rail freight revenues point to a few general conclusions relating to lumber transportation costs in the Mountain States. First is that average transportation costs on lumber shipped out of Idaho and Montana are higher than for lumber shipped from the other six Mountain States.

Table 6 shows that the central and southern Mountain States (represented by Colorado and Arizona) have an important transportation advantage in shipping to midwestern States. For example, Colorado mills paid 40 cents per hundred pounds less to ship lumber to Illinois than did Montana mills in the year 1955. The advantage of Colorado mills in shipping to Illinois is a factor of distance. The rates and hauling distances from Montana and Colorado are proportional. However, distance is not the only consideration. Arizona and Montana are both 1,500 miles from the Illinois market; yet it costs about 25 percent less to ship lumber from Arizona than from Montana.

[5] Rail freight costs as discussed here are actual charges for lumber shipped in the 3-year period of 1953-55. They tend to be somewhat higher than the basic published rates because the charges per 100 pounds on carloads not meeting minimum weight requirements are higher than the published rates.

Table 6.--**Reported revenue on lumber shipped by rail from Montana, Washington, Colorado, and Arizona, 1955**[1]

Destination state	Montana	Washington	Colorado	Arizona
	Cents per 100 pounds			
North Dakota	85	97	(2)	(2)
South Dakota	98	97	(2)	(2)
Kansas	103	107	15	81
Wisconsin	113	115	83	(2)
Illinois	116	122	76	87
Ohio	127	124	(2)	96
New York	131	126	112	125

1/Because of lightweight carloads (a problem more common with Mountain States species than with west coast Douglas-fir), rail revenues do not precisely reflect freight rate differences. For example, the basic freight rote to New York from Montana ond Washington is the same. However, voriations due to light loads do not obscure the foct that the lumber freight rote position of Montana and Idaho is not os favorable os their geographical position in relotion to mid-western and eastern markets.

2/No shipments recorded.

Source: Interstate Commerce Commission.

Table 7 shows the net effect of favorable and unfavorable freight rates and of longer and shorter shipping distances. It also shows that compared to Montana and Idaho, the other Mountain States enjoy an advantageous position in relation to both the Plains and Central States markets, either because they are closer or because rates per mile shipped are lower.

The second conclusion that can be drawn from statistics on rail freight revenues is that some of the Mountain States are not fully exploiting certain marketing opportunities. For example, Colorado and Wyoming, the two States best situated from a market standpoint, do not have as large a lumber industry as might be expected. This indicates that shipping costs are not the sole factor influencing industrial development. The lag of the industry in these two States probably can be ascribed to the fact that they have relatively little ponderosa pine timber, and have not developed a highly competitive industry. For example, in 1954 there were 51 sawmills in Idaho and Montana producing 10 million or more board feet of lumber annually; but only two mills this large were operating in Colorado, Wyoming and Utah. Over the years, the larger sawmills with their more complete manufacturing facilities, better utilization, and more effective marketing have been the strong, competitive segment of the Mountain States lumber industry (fig. 11). One of the problems of the lumber industry in Colorado and Wyoming is to live down a reputation in the minds of some buyers for producing poorly manufactured lumber.[6]

Table 7.--**Average cost of hauling lumber by rail from Mountain States to the Northeast, Central, and Plains States, 1953-55**

Origin state	N. E.	Cent.	Plains
	Cents	per 100	pounds
Montana	131	100	98
Idaho	127	113	98
Wyoming	(1)	85	32
Nevada	113	114	(1)
Utah	(1)	(1)	(1)
Colorado	(1)	71	43
Arizona	(1)	93	79
N. Mexico	(1)	90	(1)

1/Less than 200 tons in sample.

Source: Interstate Commerce Comm.

Certainly, the kind of wood needed, customer desires and prejudices, salesmanship, and quality control can go a long way toward modifying the effect of freight rates on distribution patterns. However, it is also true that once the industrial deficiencies are overcome, Colorado and Wyoming will have an important geographic advantage in marketing lumber.

6/Lange, Robert W., and Corl A. Newport. 1957. Con Native Lumber in Colorado be Made More Acceptable in the Markets? School of Forestry ond Range Monogement, Colorado A&M College, Res. Note 6.

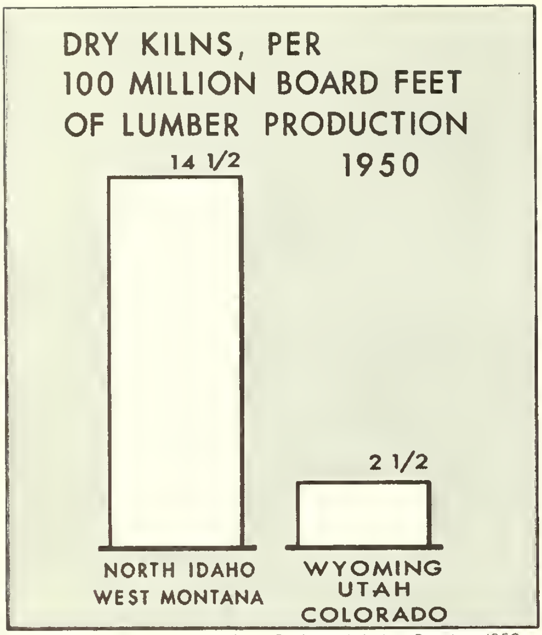

FIG 11 Source: Forest Production Industries Directory, 1950

The third conclusion that can be drawn from available waybill data is that lumber producers in Idaho and Montana extract little advantage from their position on the map. They are 200 to 900 miles nearer to Plains, Central, Northeastern, and Southern States than Washington, Oregon, and California plants, but that fact is not especially evident in lumber shipping costs in the 1953-55 period.

Consider the following:

The actual lumber haul distance from the Pacific Coast States to the Northeast was 18 percent longer7/ than from Montana and Idaho, but the rail freight cost per 100 pounds was identical.

The actual Pacific Coast haul to the Central States was 35 percent longer, but the shipping cost was only 9 percent higher.

The actual Pacific Coast haul to the Plains States was 36 percent longer, but the shipping cost was only 7 percent higher.

State-to-state average freight revenues must be interpreted with caution because rates are actually established between specific points, and there may be substantial differences between rates from or to cities in the same state. Nevertheless, waybill summaries sharply emphasize that Montana and Idaho lumber producers are in no way favored by the rate structure to the Plains States and points beyond.

The comparison is not simply a matter of west coast mills getting a lower rate per mile because they ship farther. Figure 12 shows that for *equal* distances from 800 to 2,100 miles, Idaho and Montana rail rates averaged higher than Washington, Oregon, and California rates for the same distances. For example, for a 1,000-mile haul, an Idaho or Montana sawmill paid more than a Washington, Oregon, or California sawmill for the same length of haul.

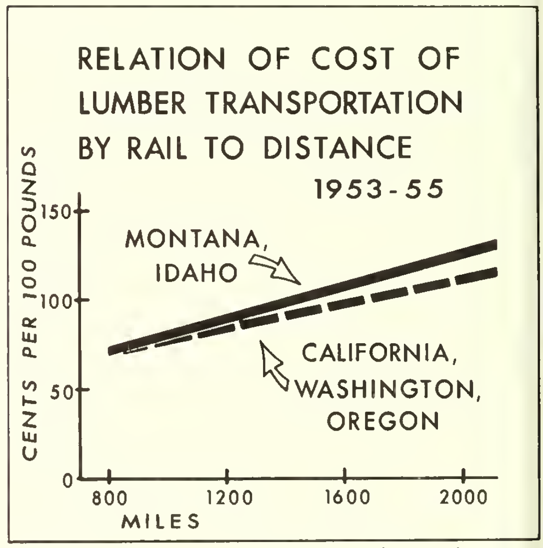

FIG. 12 Source: Interstate Commerce Commission

The above linear curves are fitted to weighted average hauling costs and distances, origin states to destination states. Slope of Idaho and Montana curve = 0.045; Oregon, Washington, California curve = 0.0034. Difference between slopes very highly significant (t = 37.7***).

7/ The rail distance figures are based on the weighted average haul of actual lumber shipments during 1953-55.

There is reason to be encouraged over the way things are going in the Mountain States. Time and circumstance are bringing about progressively greater lumber development in the region. Obviously, there is opportunity to sell more lumber right within the region. Certain transportation advantages to the Plains and Central States markets appear to be open to further exploitation.

Two fundamental situations enter into the outlook. First of these is that the virgin stands elsewhere in the West are progressively being liquidated; this assures that competition from these areas will be somewhat less intense than it has been in the past. Second is the fact that the Mountain States region has a very large part of the soft-textured softwood timber for which there is good demand throughout the Nation.

While the situation is promising, it is not without its problems. The data presented in the preceding pages focus attention on two principal aspects of the marketing situation.

Other factors than transportation costs are holding back development of Mountain States lumber. Obviously freight rates cannot be blamed for failure of sawmills in Colorado and Wyoming to capture more of Plains States and Central States markets. The problem, therefore, becomes one of getting greater acceptance of local lumber and of taking a hard look at the lumber industry itself in some localities. To what extent does the present situation result from substandard manufacturing or inadequate sales effort, or a combination of these factors?

Lumber freight rates are affecting resource development patterns. In the establishment of lumber freight rates from the Southwest, the public interest in full development of the timber resource seems to have been recognized. The evidence indicates that resource development has had less recognition than it should have had in some other parts of the Mountain States region. This seems particularly evident in regard to rates from Montana and Idaho eastward.

Removing all the inconsistencies from a patchwork, piecemeal rate structure is perhaps an impossible task. Nevertheless, a complete and objective analysis is needed to indicate what changes in rates might be justified in the interest of facilitating development of the timber resource. In some localities the gain from more favorable rates would be larger lumber production. Elsewhere, however, the main gains would be better balanced utilization so that a proper share of the lumber cut comes from the smaller, less valuable and less accessible timber not now being fully utilized. This would mean, of course, sustaining a larger lumber cut in the long run.

esearch Paper No. 60

May 1960

DWARFMISTLETOES OF THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN REGIONS AND SUGGESTIONS FOR CONTROL

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DWARFMISTLETOES OF THE INTERMOUNTAIN AND NORTHERN ROCKY MOUNTAIN REGIONS AND SUGGESTIONS FOR CONTROL

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INTRODUCTION

Dwarfmistletoes cause the greatest single growth impact (mortality plus growth loss) to commercial tree species in the Northern Rocky Mountain Region according to the best available estimates. In the Intermountain Region the losses in coniferous stands charged to these parasites rank next to those from heart rots. The full impact of dwarfmistletoes on the productive capacity of coniferous stands has not yet been definitely determined, even though the general prevalence of these pests and the damage they cause were recognized more than 40 years ago (8).[1/] Reduction of losses from dwarfmistletoe is now considered the most important problem in forest disease control in these two regions.

Some valuable information on the proper treatment of affected forests has been gained in recent years. However, more research both basic and applied is needed for a thorough understanding of these parasites and their control.

This paper has been prepared primarily for the use of forest managers in the Intermountain and Northern Rocky Mountain Regions who are faced with the immediate necessity for dwarfmistletoe control and cannot afford to wait for results of further research. It assembles and summarizes pertinent published information and presents other known facts that may be useful in planning control of the principal dwarfmistletoes in these regions. In the absence of certain experimental information on the dwarfmistletoes, use has been made of the accumulated observations of trained pathologists.

SPECIES AND DISTRIBUTION

The dwarfmistletoes are seed-bearing plants belonging to the genus *Arceuthobium*. They can live and thrive only as parasites on living conifers. No extensive areas of coniferous forests anywhere in the Northern Rocky Mountain or Intermountain Regions are completely free of one or more of the dwarfmistletoes. Four species, classified by anatomical characteristics, occur in these regions; one of them includes several forms which have different host preferences. Each species or form normally occurs on a single host tree. However, occasional departures from normal host trees do occur.

The five most important species or forms in the Northern Rocky Mountain and Intermountain Regions and their tree hosts and general distribution are:

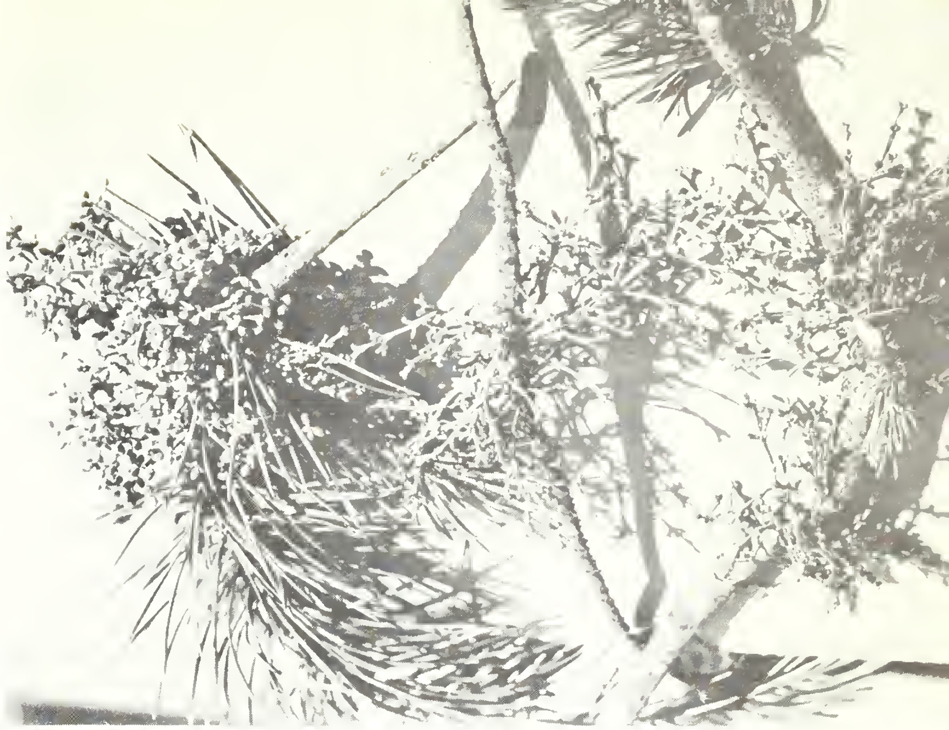
1/ Underlined numbers in parentheses indicate numbered items in Literature Cited.

1. Lodgepole pine dwarfmistletoe: A. americanum (figs. 2, 7) is common on lodgepole pine throughout both regions. This pest is especially prevalent and damaging in eastern Montana, southern Idaho, and northeastern Utah; it commonly appears wherever lodgepole pine grows (3).

2. Douglas-fir dwarfmistletoe: A. douglasii (figs. 1A, 3) attacks Douglas-fir in both regions. In the Intermountain Region, distribution of this dwarfmistletoe practically coincides with the range of the host tree. It is especially abundant in southern Idaho and southern Utah. Many Douglas-fir stands in northeastern Washington, in the Nezperce National Forest in Idaho, and in the Bitterroot and Flathead valleys in western Montana are infected. This pest occurs in other local areas in northern Idaho and western Montana, but has not appeared in eastern Montana.

Figure 1.--Tree crowns infected with dwarfmistletoe: A, Mature Douglas-fir with most of the crown in a series of immense witches'- brooms. B, This western larch does not have a single normal branch; all are broomed and the top has died. C, This ponderosa pine, recently killed by dwarfmistletoes, shows the structure of brooms.

igure 2.--Typical plants of the lodgepole pine dwarfmistletoe. The branch on the left bears a female plant with mature berries. The center and right-hand branches have male plants. Note the typical spindle-shaped swellings where shoots are attached.



3. Western dwarfmistletoe on ponderosa pine: A. campylopodum forma ampylopodum (figs. 1C, 4) commonly grows on ponderosa pine in both regions, ut has not been found in Montana. This dwarfmistletoe grows more abundantly in stands on the drier sites and along the outer fringes of the range f ponderosa pine in the Northern Rocky Mountain Region. This species of warfmistletoe also occurs in ponderosa pine stands in southern Idaho (6).

4. Larch form of western dwarfmistletoe: A. campylopodium forma laricis figs. 1B, 9) grows on western larch and subalpine larch but is economically mportant only on western larch. This form is abundant and destructive hroughout most of the natural range of western larch (7).

igure 3.--Heavy concentrations of shoots of Douglas-fir dwarfmistletoe. Female shoots with berries above, and male shoots on lower branch. Shoots are usually scattered more sparsely among the host needles and are therefore usually less obvious.

5. Southwestern dwarfmistletoe: *A. vaginatum* is important on the Rocky Mountain form of ponderosa pine in the Intermountain Region (1). The range of this parasite does not overlap that of western dwarfmistletoe on ponderosa pine.

Several other forms of the *A. campylopodum* complex have some importance on grand fir, Engelmann spruce, subalpine fir, western hemlock, limber pine, bristlecone pine, pinyon, and singleleaf pinyon in a few local areas. Dwarfmistletoes occasionally occur on other conifers in the two regions (except junipers, western redcedar, and Pacific yew); however they are considered of little importance here.

DWARFMISTLETOE PLANTS

The various dwarfmistletoe plants are quite similar in general appearance, but they often vary between species and occasionally within species, in color, size, form, and in parts of their life history. These differences are sometimes barely evident, but at other times they are pronounced (2).

Aerial Shoots

Aerial parts of the parasites are leafless, delicate, segmented, perennial shoots (figs. 2, 3, 4) on the stems and branches of the host tree. The segments are four-sided at the base to angular or rounded above, and have a pair of minute scales (vestigial leaves) at the top. The color varies from yellow and purplish to brownish or olive green in many shades. Shoots of the Douglas-fir dwarfmistletoe (fig. 3) are smaller than those of any other local species, are seldom more than one-quarter to three-quarters inch in length, rarely branched, and are generally scattered along the young twigs of the host. Shoots of the other species more often occur in tufts (fig. 4); they are typically longer than 1 inch but seldom longer than 8 inches. The lodgepole pine dwarfmistletoe shoots (fig. 2) are more slender and stringy than those of the other species.

Seed Production

The male and female flowers are produced on separate plants, but both sexes may grow on the same host tree or even on the same branch. The Douglas-fir, lodgepole pine, and southwestern dwarfmistletoes bloom in the spring; those in the *A. campylopodum* complex in the late summer. The berries (figs. 2, 3, 4), containing a single seed, mature the second autumn after pollination. The berries ripen and seeds are disseminated in September or early October, except for *A. vaginatum*, which matures in late July or early August.

At maturity the berry develops an internal pressure which triggers an explosion and expels the seed forcibly into the air. The seeds, covered with a sticky substance called viscin, may glance off from objects near the point of explosion, but they usually fasten themselves wherever they hit.

Figure 4.--Typical plants of western dwarfmistletoe on ponderosa pine: A, female plant with mature berries; B, male plant.

Germination and Growth

Infection can occur most easily when the discharged seed adheres to the bark of 1- to 3-year-old twig growth on a susceptible host. However, older growth in ponderosa pine, lodgepole pine, and probably other species is sometimes susceptible to infection (3, 4). Germination may follow in a month or so in *A. vaginatum* but is probably delayed until spring in most species of dwarfmistletoe. The seed sprout grows along the bark or needle surface (fig. 5); if it reaches a suitable obstruction, a padlike holdfast forms at its tip. From this a primary haustorium develops and penetrates the tender bark; from there an absorption system is established inside the bark tissue of the host

Figure 5.--A germinated seed of the Douglas-fir dwarfmistletoe fastened at the base of needles on a young twig of Douglas-fir. Note the seed sprout obstructed by the base of a needle, where a holdfast is forming, and from which a primary haustorium will develop that will penetrate the thin bark of the twig. (Photo by C. W. Waters.)

(fig. 6). The parasite cannot penetrate wood tissue. The absorbing system consists of threadlike strands in the inner bark and wedge-shaped structures called sinkers, which become imbedded in the wood by the formation and growth of wood tissue around them. The sinkers maintain contact with the strands in the bark and provide them with water and dissolved materials from the sapwood. The strands produce buds that push through the host bark (fig. 6C) to form the aerial shoots.

A single infection may produce a large absorbing network in the host tissue from which many crops of aerial shoots arise (fig. 6). The absorbing system advances in distal, proximal, and tangential directions. Distal rate may be faster in some species like A. douglassii. This absorbing system may become systemic in character and live for many years without producing aerial parts of the parasite.

The life cycle of the dwarfmistletoes from seed germination and infection to seed production undoubtedly varies between and within species. After infection by A. vaginatum, at least 2 years--usually 4 or more--elapse before the first aerial shoots are produced. Generally the life cycle of this species requires 5 years or longer (1). The complete life cycle of other dwarfmistletoe species is unknown but is probably similar to that of A. vaginatum.

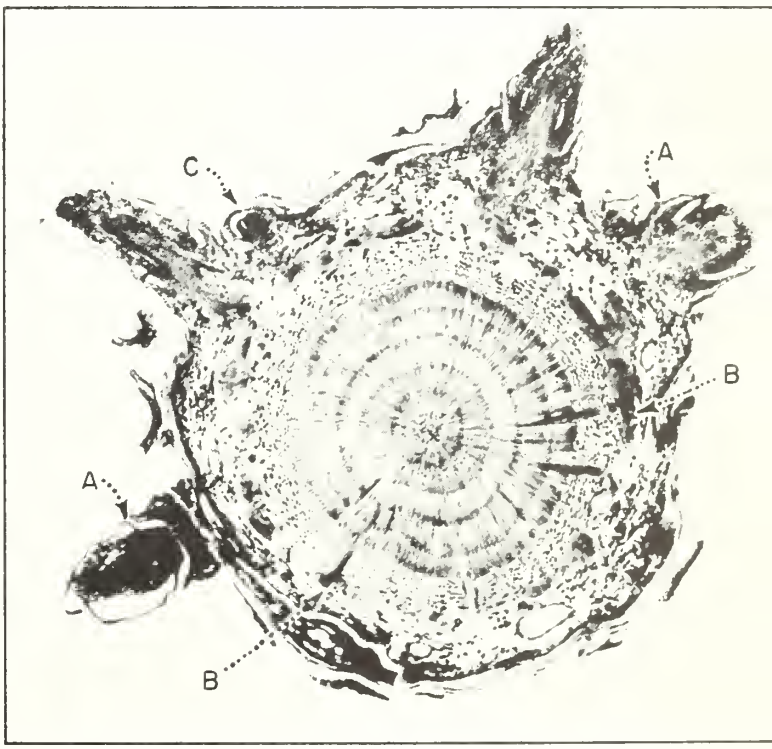


Figure 6.--Enlarged cross section of lodgepole pine branch infected with dwarfmistletoes: A, Basal cup on bark surface with portion of aerial shoot attached. B, Absorbing strands of the dwarfmistletoe plant in the inner bark from which shoots arise, and from which the sinkers originate and extend into the wood. C, A new shoot bud breaking through the bark.

Means of Spread

Effective spread of these parasites results from the explosive force of the fruits. Because of the position of the berries, the seeds usually shoot upward and arch outward. By this means, new dwarfmistletoe plants continuously become established progressively higher in the crowns of infected trees. The degree of infection in an individual branch may be intensified by the advancement of the absorbing strands in the host tissues, as well as by seed dispersal.

Seeds that do not stick to the upper part of the host tree continue their flight outward and may infect surrounding trees within range. Spread to new trees is most effective where the seeds pass from overstory to understory. Most of the dwarfmistletoe seeds in an infected overstory tree are broadcast into the surrounding understory for a radius of 30 to 60 feet. Probably the angle at which a seed is discharged is the most important factor that determines the distance of spread. The effects of size of seed, height of seed-producing plants, steepness of ground slope, intensity of wind, and vigor of the host tree on the distance of spread have never been accurately determined. Spread is probably at least twice as fast in stands of mixed size classes as in even-aged stands.

It is believed that stand origin and history over past centuries are the major factors responsible for the widespread occurrence and distribution of the dwarfmistletoes. Various agents, such as birds and mammals, presumably could carry seeds for long distances. The part that such agents play in the spread of the parasite is unknown but is believed to have only minor practical importance.

SYMPTOMS OF INFECTION

The surest indication of infection is the presence of the dwarfmistletoe shoots. If shoots have dropped off, the small basal "cups" from which they came often remain on the bark (fig. 6). Infected stands or trees (figs. 1, 7, 8) are usually recognized by the accompanying witches'-brooms, spike-tops, cankers, swellings, and other abnormalities of trunk and branches.

Witches'-brooms.--Witches'-brooms, or malformed and swollen growths of twigs and branches in clumps (fig. 1), are striking symptoms of long-standing infection. Not all witches'-brooms are caused by dwarfmistletoes. Whenever the cause of brooming is questionable the broom should be examined for the presence of dwarfmistletoe shoots or basal cups. Brooming may be confined to a single limb, may occur on numerous limbs, or may include the entire crown. Typical brooms on lodgepole pine and Douglas-fir are practically spherical balls of dense growth, while those on larch radiate from a common point of origin. The typical brooms on ponderosa pine are spherical, but may not be very conspicuous because of the normal loose-branching habit of the host. Abnormally enlarged, swollen, or crooked branches usually occur even where brooms are inconspicuous.

Figure 7.--Mature stand of lodgepole pine breaking up from heavy infection of dwarfmistletoes. Note dead trees on the left and heavily infected tree in the center and far right background.

Cankers and Swellings.--Slight to definite, more or less fusiform swellings or cankers usually develop on infected twigs, branches, and stems (figs. 2, 4). When a branch infection extends into a larger branch or the bole, the infected branch is likely to be conically swollen; i.e., broadest at the base, with a marked taper. A cross section through a branch swelling generally shows the wedge-shaped sinkers extending into the wood (fig. 6).

Trunk symptoms of dwarfmistletoe attack are large, elongated, and flattened cankers on one or more sides of the trunk or spindle-shaped swellings that include the entire circumference of the tree. They result from persistent infection on the main stem that started early in the life of the tree. Trunk symptoms commonly appear on western larch (fig. 9), lodgepole pine, and ponderosa pine and occur occasionally on other species.

Other Symptoms.--The most severe infection usually develops first in the lower part of the tree crown. Dead tops often result when heavy brooming occurs in a large portion of the crown. Spiketops are almost a universal condition in heavily infected larch, Douglas-fir, and lodgepole pine stands. In the portions of the crown not broomed, reduction in foliage density and shortened and lighter colored needles result from the dwarfmistletoe infection.

Light to moderately infected stands are not readily distinguished from healthy ones except by the presence of such symptoms as brooms, cankers, and the dwarfmistletoe shoots. Heavily infected stands, on the other hand, show a ragged and degenerated condition (figs. 7, 8), similar to stands on a poor site. They contain deformed spike-topped, stunted or dying, and dead trees. Understory trees may have an abundance of dwarfmistletoe shoots with some evidence of branch malformation. Excessive mortality sometimes occurs in understory trees.

Figure 8.--Mature stand of Douglas-fir heavily infected and damaged by dwarfmistletoe.

DAMAGE

Dwarfmistletoe damage is extensive but not always spectacular in coniferous forests in the two regions. Trees of any age may be retarded, deformed, or killed. The general nature of dwarfmistletoe injury is a suppressing effect that is probably caused by gradual reduction of effective leaf surface of the tree, or by malfunction of the normal physiological processes of the tree, or both. Severely diseased stands result from a continuous intensification of the parasite over many years. As time passes, tree damage increases and wood productivity decreases.

Damage by dwarfmistletoes falls into the following four general categories:

1. Increased mortality.--Dwarfmistletoes do not usually kill rapidly in the sense that great numbers of larger trees may suddenly die, except in occasional severe drought years. Except for seedlings and young saplings that become infected, death due to the parasites usually results from gradual suppression. Nevertheless, infected merchantable trees do have a shorter life expectancy than healthy ones.

2. Growth reduction.--Dwarfmistletoes reduce tree vigor; this may cause a great reduction in height and diameter growth. Old mature trees, infected

Figure 9.--Trunk swelling and canker on a mature western larch caused by dwarfmistletoe infection. The witches'-brooms have long since disappeared.

for a long time, may be so stunted that they contain only one to three logs of low-quality and excessive taper, rather than the five to seven logs characteristic of healthy trees on the same site. Severely infected immature trees may never attain sawlog size. A reduction in the quantity of merchantable material results from trunk swellings and cankers (fig. 9), and from decay they may harbor, as well as from retarded growth. In infected Douglas-fir stands and to a lesser extent in other species, the ground is often heavily shaded by low, sprawling, and deformed trees. The space occupied by such trees is wholly wasted, and the opportunity for maximum yield from the site is lost.

3. Quality reduction.--Important losses occur from degrade or cull in lumber or logs. Numerous large knots and abnormally grained, spongy wood that is frequently pitchy, reduce quality. Fungi that cause stains and decay often enter open cankers and reduce quality of the wood.

4. Seed reduction.--Seed production and quality are reduced by dwarfmistletoe infection. Increased severity of infection results in a marked decrease in yield of cones and seeds per tree, and the percentage of seed germination. Resulting seedlings may be inferior to those produced by healthy trees.

In addition to these four major types of damage, heavy dwarfmistletoe infection predisposes trees to attack by bark beetles, wood decay and root disease, as well as windthrow and breakage. Large dwarfmistletoe brooms, especially the dead ones, are a fire hazard, and killed trees and spiketops constitute special fire hazard from lightning strikes.

Damage is often light in well stocked even-aged stands, and may be absent in timber stands that have originated from complete burns. Conversely, moderate to severe damage usually occurs in stands that have been protected from fire for long periods or that were selectively cut in the past.

Surveys in the Northern Rocky Mountain Region to determine the distribution and abundance of dwarfmistletoes have shown that these parasites are more severe and widespread than had been previously realized.

CONTROL

Two satisfactory methods of dwarfmistletoe control are known. The "eradication method" consists of the removal of dwarfmistletoe infected trees or infected branches of trees by direct eradication operations or through silvicultural methods; or by a combination of both. The "stand manipulation method" consists of converting an infected stand to one consisting of tree species not susceptible to the dwarfmistletoes present in the area. Any infected stand, whether merchantable or immature, should be individually appraised to determine which control method is most sound.

Current research by forest pathologists and forest managers is aimed at developing and refining these two control methods, and at devising others.

Development of a chemical or antibiotic that will kill the parasites without injury to their host trees appears possible. If such a material is developed, or if some known chemical or antibiotic is determined to be adequate, its application may supplement but is not likely to replace silvicultural control in commercial timber stands.

Some bark-chewing rodents and certain parasitic insects and fungi occasionally reduce, to some degree, the abundance of dwarfmistletoe plants. However, the activity of these biological agents has never been found sufficiently effective to control the parasite.

Individual trees occasionally show resistance to dwarfmistletoe. Resistant planting stock could probably be genetically produced; however, such a project would require considerable time and cost.

Eradication Method

Control may be accomplished by cutting, poisoning, burning, or otherwise eliminating all infected trees, or by pruning infections from them (fig. 10). Any degree of dwarfmistletoe removal less than complete eradication will not give complete control. Partial reduction of the parasites may be desirable at times from the economic standpoint when everything is considered. However, it should be emphasized that control measures that do not reduce the accumulated seed source to an innocuous level or management that does not provide for constant attrition against the parasites could result in both wasted effort and increased dwarfmistletoe damage.

The original cost of eradication may be greater than the cost of some lesser degree of reduction, but the eventual cost in the long run will undoubtedly be greater for partial control because of need for recurrent control operations and the accumulated growth impact on the stand by the disease. As long as the parasites are present, the potential for severe damage exists, and control operations will remain a continuing periodic cost in management. On the other hand, if complete eradication is achieved, complete control will be attained indefinitely.

Direct Eradication

Direct eradication means operations designed solely for the purpose of dwarfmistletoe control. Some direct eradication of dwarfmistletoe infections by tree cutting or by pruning out infected tree branches is required to supplement many silvicultural control operations. Branch infections on young trees may be cut out successfully when they occur a foot or more from the bole; however, this safety margin varies and is somewhat less for small branches and for some host and parasite species. Pruned branches should be cut flush with the tree bole. Bole infections cannot be successfully cut out. In general, trees that have bole infections or branch infections within a foot of the bole must be cut, poisoned, or otherwise killed to eradicate the parasite.

Dwarfmistletoe infections on killed trees or pruned branches die almost immediately, and cannot reinfect living trees. However, control operations should be avoided during the dwarfmistletoe seed dispersal period, if possible, to prevent unnecessary spreading of the seed.

In high-use recreational areas or on certain administrative sites, where values warrant the extra cost, infections in large trees as well as small ones may be pruned out. If, in such areas, it is desirable to retain as many

Figure 10.--Dwarfmistletoe was controlled in this pole stand of ponderosa pine by eradicating the parasite. Dead trees (at right) were poisoned because infections could not be cut out. Pruning eradicated infections from center of tree.

trees and as much tree crown as possible, spread of the parasite may be reduced, and new infections prevented, by pruning out only the active infections that are producing female shoots, leaving any old inactive infections that are not producing shoots and active infections that produce only male parasite shoots. Except for their capacity to start new infections, however, all infections are equally able to damage the host trees. Even though large old brooms may not be producing female shoots, it is usually desirable to remove them to help restore the thrift of the host tree.

Since new dwarfmistletoe infections require several years to produce visible shoots, latent infections previously established will appear after control operations. These latent infections will become manifest for several years after the initial operation. Therefore, followup operations are necessary to detect and remove these infections before they produce berries. The number and frequency of followup treatments will depend on the dwarfmistletoe species and host tree involved and the management objectives of the area. A series of two or three cleanings spaced at 3- to 5-year intervals will probably reduce the parasite to an innocuous level in most stands. After this period, control areas may be checked over occasionally for missed infections and for new foci of the disease.

Silvicultural Control

To obtain maximum timber production will require control of dwarfmistletoe in many coniferous stands in both the Northern Rocky Mountain and Intermountain Regions.

Incorporation of dwarfmistletoe control with silvicultural practices is the most practical and economical way to combat these parasites in affected stands managed for commercial timber production. Obtaining and retaining new dwarfmistletoe-free stands, after harvest cuttings, is the most efficient control procedure. Control in affected young stands of premerchantable age is more difficult and costly, although sometimes desirable and economically practicable. Control in young stands, as in high-use administrative or recreational areas, may sometimes be of the direct type rather than through silvicultural cutting.

Control through silvicultural operations fundamentally consists of dwarfmistletoe eradication coupled with harvest or improvement cuttings, without pruning of infected branches or with a minimum of such direct eradication effort. Most silvicultural control will be conducted at the time of harvest cutting. With some types of harvest cutting, supplemental direct eradication must follow. The harvest cut should remove all infected overstory trees. In stands of mixed species this will require, at the most, cutting all overstory trees of one or two species. After the source of infection has been eliminated from the overstory, all infections must be eradicated from the pole-sized trees and smaller advanced reproduction by pruning out branch infections or by cutting or otherwise killing infected trees.

Stands of a single species, under heavy infection conditions, are best treated by clear cutting (fig. 11). Any advanced reproduction or other unmerchantable residual trees must then be sanitized by direct eradication, or

Figure 11.--Silvicultural control of dwarfmistletoe in lodgepole pine through clear cutting: A, Improper cutting for best control--advanced reproduction and cull trees left standing, and narrow strips of border trees (right background) left protruding into clear-cut area; both are unnecessary sources of infection for new stand, now 7 years old. B, Proper cutting for best control--all advanced reproduction and cull trees cut, and border is smooth line. Such cutting insures infection-free reproduction, except in a narrow strip along minimum border stand.

killed by bulldozing or broadcast burning. Clear-cut areas should be as large and compact as practicable (fig. 11). Clear-cut areas that are broadcast burned and regenerated by seed from the slash or by planting can be large. The shape will usually depend on the existence of natural openings or disease-free areas that will serve as effective control boundaries.

Dwarfmistletoe control is practical on relatively small areas because of the limited distance of direct spread. Much can be accomplished to prevent spread of the parasite into sanitized stands by careful selection of the boundaries of control areas. Natural clearings, such as meadows, lakes, or streams are ideal control boundaries. Wide highways or other cleared rights-of-way may also serve as control borders. Such openings around control areas should be at least as wide as the tallest infected trees outside the control area to prevent spread into the sanitized area. Control boundaries should never pass through heavy infection centers.

When clear-cut areas are regenerated from bordering stands, any infected bordering stands must be cut within 10 years to prevent infection of nearby new reproduction. Likewise, to prevent infection of new reproduction around seed trees, infected seed trees must be removed within 10 years after the first seed crop from them.

In clear-cutting operations, as commonly employed in lodgepole pine stands, the most heavily infected stands should be given the highest priority for cutting.

If a clear-cut area requires planting, those portions that are near infected bordering stands should have planting delayed unless the border will be cut within a 10-year period. The alternative is to plant these strips to tree species not susceptible to the dwarfmistletoe present.

Recommended Procedure for Eradication Method

The following are general suggestions for steps in dwarfmistletoe control by the eradication method:

1. Select highest priority area for control.--Aside from other management objectives, highest priority control areas are those where dwarfmistletoe is doing the most damage, or where potential for damage is greatest. The most volume loss occurs where there is heavy mortality in old-growth stands. The greatest potential loss is in reproduction between 5 and 20 years old that is exposed to infected overstory residuals. Great potential loss also is found in small infection centers in large acreages of young stands otherwise free of the parasite. Occasionally large acreages of young trees, especially stands of fire origin, are free of the pest except for a few small infection centers. Such centers should be rendered dwarfmistletoe-free as soon as possible, while the job is small and the cost low, to protect the larger area indefinitely.

2. Delineate control area on the ground.--Include all infected trees in the control area when it is practical to do so. If infection is general and widespread, select control boundaries carefully so as to utilize natural disease-free boundaries wherever possible, and to avoid boundaries through heavy infection centers.

3. Eliminate overstory infections.--In merchantable stands with a younger understory, first eliminate all sources of overhead infection by removing all merchantable infected trees in the overstory. Unmerchantable overstory trees that are infected should then be killed, or all infections pruned from them.

4. Eradicate infections in the understory.--The understory stand should be sanitized by direct eradication of infection. Dwarfmistletoe growth and development is stimulated by added light. Removal of all or a large part of an overstory causes suppressed infections in the understory to flourish and intensify if not removed.

5. Periodically check the control area.--As previously explained under "Direct Eradication," the control area needs periodic examinations for detection of latent infections. These infections should be removed before their new shoots produce seed.

6. Protect new reproduction.--In clear-cutting operations, areas of infection should be "clean cut" (fig. 11B) or otherwise sanitized by dwarfmistletoe eradication. To protect new reproduction from infection do not expose the cut area to infected bordering stands or infected seed trees more than 9 years.

Dwarfmistletoe control in immature stands often may be incorporated in thinning and crop tree pruning operations. In such operations, it should be remembered that dwarfmistletoe activity is intensified by added light. In even-aged young stands most infections occur in the lower crown; thus many infected trees may be sanitized by pruning. It is advisable always to prune at least one branch whorl above the highest branch infection found. This will eliminate a large percentage of the latent infections that are not yet apparent. The best time for such control is after midsummer when the maximum number of young shoots can be detected.

Stand Manipulation Method

Manipulation of tree species for the control of dwarfmistletoe is sometimes possible because the dwarfmistletoes are host specific. Stand manipulation is best suited to mixed stands having one or more commercial tree species that are not susceptible to the dwarfmistletoes present in the area. However, on certain sites pure stands of an infected species may be converted by planting the area to a tree species that is not susceptible to the local dwarfmistletoe.

Harvest cuttings in infected stands of mixed species should be so designed that the area will become naturally regenerated with one or more tree species not susceptible to the dwarfmistletoes present.

No direct dwarfmistletoe eradication is needed when this control method is used. However, it may be desirable at times to release advanced reproduction of the favored species by cutting out competing trees of the susceptible species, whether or not they are infected.

CONTROL COSTS

Costs of control measures vary with the method or type of control, the intensity of dwarfmistletoe infection, the age and composition of the stand, and the size of the infected areas involved.

Silvicultural control in conjunction with harvest cuttings is the more economical type of control, and it is most economical when the harvest cut is a clear-cutting operation.

When harvest cuttings other than clear cutting are made, control costs will depend largely upon the amount of dwarfmistletoe infection remaining after the harvest cut.

Unit area costs will always be less in lightly infected stands than in heavily infected stands, except when clear cuttings are made.

To keep costs at a minimum, clear-cut units exposed to outside reinfection should have a low ratio of perimeter to area. Large areas approaching a circle or square are the most economical in widespread infections. Cutting of narrow strips should be avoided to keep reinfestation of the sanitized area from the uncut perimeter to a minimum, unless bordering infected stands will be cut within 10 years.

Any cost added to an operation because of dwarfmistletoe control, may be considered part of the control costs. For example, planting may be considered part of control costs where it becomes necessary because of altering procedures to effect dwarfmistletoe control.

Little control of dwarfmistletoe has been carried on in the Northern Rocky Mountain and Intermountain Regions; consequently, few actual cost figures are available. Forest managers are urged to keep cost records on all their dwarfmistletoe control operations so that cost data may be accumulated for conditions in these regions.

Control in ponderosa pine in the Southwest on 16,000 acres cost $4.17 per acre in 1953 to 1956, inclusive (5). This did not include the followup cleanings. A second recleaning operation on 1,052 acres of uncut all-aged ponderosa pine in Bryce Canyon National Park in 1959 cost $4.18 per acre.

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THE OPPORTUNITY TO THIN AND PRUNE IN THE NORTHERN ROCKY MOUNTAIN AND INTERMOUNTAIN REGIONS

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Contents

FOREWORD

This is the first of two reports presenting the findings of an economic study of timber growing and timber industry development undertaken at the request of the Northern Region of the U. S. Forest Service. This publication, by John H. Wikstrom and Charles A. Wellner, points out and evaluates the opportunities for thinning and pruning in the Northern Rocky Mountain and Intermountain Regions.

A second publication will discuss management possibilities and the problem of developing adequate management programs on the national forests of the Clark Fork Timber Development Unit in western Montana.

REED W. BAILEY

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INTRODUCTION

Thinning and pruning do not have high prior-' in Northern Rocky Mountain or Intermountain restry today.[1] This situation arises largely from adequate financing. Partly, however, it stems om a state of mind that has only recently begun change. Thinning and pruning have been ought of only as a part of intensive forestry, that the kind of extra activity that might be used meday to expand forest productivity—but not t; not today.

One can hardly argue against the idea that inning and pruning represent considerably more tensive forestry than is being practiced today in ese two regions; yet there is some question hether these practices can be long postponed ithout a costly sacrifice of future timber yields and lues. In this light, thinning and pruning cease to refinements or frills and become a basic part of restry in these regions. This conclusion is sup-rted by three facts about our regional forestry tuation:

First is the fact that most of the timber types in these regions tend to overstock. Much of our attention until now has been directed toward the more conspicuous problem of understocking, and relatively little toward the problem of overdenseness. Yet, this latter problem is far more serious than most people realize. Unless we deal effectively with the matter of sheer numbers of trees, the very prolificness of nature will sharply limit future timber yields. Conversely, the yields possible by opening up young stands with thinning will be truly startling to persons conditioned to the low productivity of overstocked natural stands so common in the area.

Second is the fact of limb persistence, which discounts quality. Encouraged by a cool, dry climate that inhibits decay, branches tend to remain on trees long after they have died. It will be impossible to produce a high percentage of surface-clear logs and maintain timber quality in the relatively short rotations we are contemplating for the future unless branches are removed artificially from the lower boles.

Third is the fact that operating and management costs in this locality, like the altitude, tend to be high. To keep forestry competitive, these high costs must be offset by high yields.

Purpose and Scope

The purpose of this report is to describe the npact of overcrowding and limb persistence and indicate the emphasis thinning and pruning should have in the Northern Rocky Mountain and Intermountain States. This analysis is not from the usual point of view of treating thinning and pruning as investments in individual trees or acres. Rather, it examines the broader effect of thinning and pruning on the level of yield and financing in the total forestry operation. This report considers:

- The impact of overstocking.
- The impact of limb persistence.
- The case for thinning and pruning as a means of reducing the cost of producing wood.

For this report, we have relied heavily on data from western Montana because they are available and also because statistics for this area cover a wide range of site conditions. Because the data take account of site, they should be applicable anywhere in the Intermountain and Northern Rocky Mountain Regions where such sites occur.

Framework of this Analysis

The discussion in this paper relates to thinning done at the proper stage in the development of young stands; that is, in stands that have not been allowed to become overcrowded and lose vigor. Millions of acres in the Northern Rocky Mountain and Intermountain Regions support timber that has grown beyond the ideal stage to start thinning. No doubt these older, overcrowded stands present the most serious management problem we face. To thin in them would be very expensive. The cost could run as high as $80 per acre. At the same time, response to thinning in many of these stands would be very slow. Just how these older stands should be handled involves considerations that go beyond the scope of this paper. Those stands that have stagnated to the point where they will never produce usable products no doubt will have to be destroyed to make room for new trees, and the quicker this is done, the better. Some of these older stands may contain enough volume that it would be worthwhile to hold them in a hope a market will develop, even though it means carrying them far beyond rotation age. It may be necessary to thin the more vigorous stands in this category, even though the thinning operation itself is a losing proposition, in order to balance out the age class distribution and allowable cut.

However, these are all problems to be worked out later. The more immediate problem is to determine to what extent thinning can stop any more stands from falling into this overcrowded, low-vigor category from which only low per-acre yields can be expected. Also, there is a need to determine to what extent pruning might complement thinning as a means to improve value yields in such stands. It is toward these problems that our study is directed.

[1]Figure 1 (inside front cover) outlines the Northern Rocky ountain and Intermountain Regions, in which this Experiment ation conducts research.

THE IMPACT OF OVERCROWDING

Most timber-inventory systems classify a stand with a closed canopy as "fully stocked" and by implication as "desirable." Yet many fully stocked stands in the Northern Rocky Mountain and Intermountain Regions are seriously overcrowded. In some stands, a closed canopy is associated with a situation worse than no trees at all—total growth capacity has been dissipated on so many stems that few, if any, will grow big enough to be usable (fig. 2).

Figure 2.—This stagnated stand of lodgepole pine 60 years old averages less than 2 inches d. b. h.

A Common Condition

Data from the Forest Service's Timber Resource Review[2] show that 36 percent of the young forest in the Mountain States is well stocked, and 34 percent medium stocked. The stocking profile by types for western Montana,[3] which is pictured in figure 3, is more or less typical of the situation throughout the Northern Rocky Mountain and Intermountain Regions. Except in the ponderosa pine and alpine fir types, well-stocked stands predominate, and medium- and well-stocked stands combined occupy the lion's share of the area. The Mountain We has relatively little poorly stocked forest.

The stocking situation, however, is consid ably less satisfactory than this classification i plies. Probably no more than a handful of t so-called "well-stocked" stands are properly sto ed. Most stands contain too many trees for tr effective growth.

Overstocking is not confined to the well-stoc ed stands. Odd as it may seem, it also occurs stands that by definition are medium or poor stocked. This anomaly arises from the fact th stocking as measured by the Forest Survey is on an indication of the percentage of the area in stand that is occupied by trees. It does not tell ho the trees are distributed over the area they occup Thus, many stands classed as medium or poor stocked consist of overdense clumps of trees inte mixed with areas having no trees at all.

The problem of superabundance is most stri ingly evident in the lodgepole pine type whe stand after stand has failed to produce crop tre

[2]U. S. Forest Service. Timber resources for America's future. 713 pp. Washington. 1958. P. 546.

[3]Montana, west of the Continental Divide.

[4]The 3 million acres of nonstocked forest land in the I termountain and Northern Rocky Mountain Regions constitute special problem not included in the scope of this report.

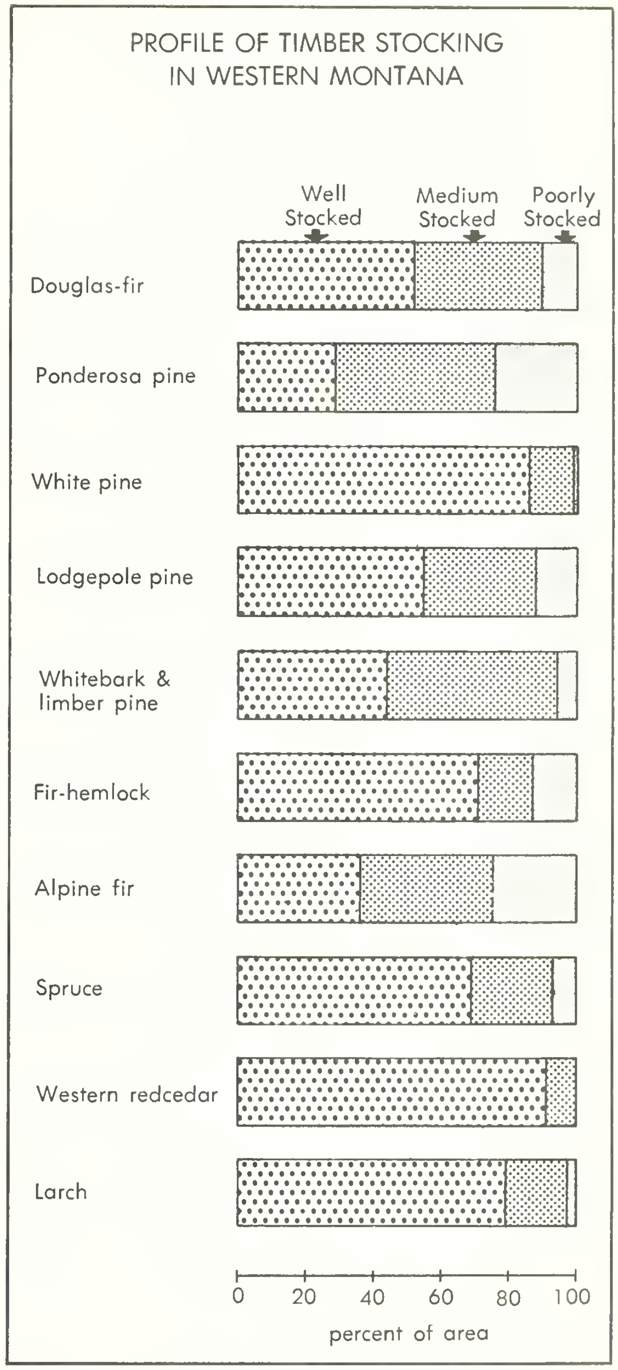
. big as 11 inches in diameter because total owth has been divided among too many stems. r example, in western Montana, fully half of e existing lodgepole pine stands will have to be ritten off insofar as 11-inch and larger trees e concerned, even though the sites they occupy ive the capacity to produce trees of this size.

An even more serious aspect of the lodgepole ne problem is that a substantial part (28 percent) the lodgepole pine seedling-sapling stands in estern Montana are so overcrowded and stagnat- that virtually no trees will ever reach a size rge enough even for pulpwood. Lodgepole pine ands 100 years old with 10,000 or more stems r acre averaging less than 2 inches in diameter e not a rarity. Such stands waste the space they cupy.

The Opportunity for Thinning

One of the big problems in timber inventory i the Northern Rocky Mountain and Intermountain gions today is to develop statistics that ade- uately measure the stocking situation. Until such atistics are available, we shall be handicapped in scribing the management problem involved in aintaining proper space relationships. Neverthe- ss, we can pretty well measure the end effect of erstocking by comparing the volumes in present ell-stocked rotation-age stands with the volumes ese stands theoretically should have. Opportuni- s for improving yields of five important timber es in western Montana[5] are shown graphically figure 4 and table 1. Figure 4 shows, for ex- ple, that on medium sites, well-stocked stands rotation age have from 26 percent to 62 percent the board-foot volume they might reasonably expected to have if tree distribution were con- lled.

Forest managers generally agree that total wood yields cannot be increased by thinning except in stands that will otherwise stagnate. In such stands, thinning will increase both the total yield and the yield of utilizable wood.



Source: Forest Survey data

Figure 3.

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[5]Theoretical yields were calculated by:

1. Discounting normal basal area for that type ond age by 25 percent.

2. Estimating from site tree data average diame- s obtainable at rotation age if stocking were kept under con- .

3. Computing the harvest volume if the discounted al area were made up of trees of the average size obtain- e with stocking control.

These calculations are more completely described in a neographed report, **Forest management objectives in western ntana**, October 14, 1959, Intermountain Forest and Range eriment Station, Ogden, Utah.

The effect of thinning in nonstagnating stands is to concentrate the growth on fewer trees. This produces larger volumes of utilizable wood but does not increase total wood yield.

These comparisons describe both the problem of overstocking and the opportunity for thinning. The opportunity is substantial. For example, to raise medium-site lodgepole pine sawtimber yields at rotation age from 6,000 board feet per acre to 23,000 board feet per acre, or medium-site larch from 24,000 to 39,000 board feet per acre would be an important accomplishment.

The gains to be achieved by thinning are only partially expressed by volume estimates. The larger volumes would be realized through the more rapid growth of the individual tree which is significant in its own right. Table 2 indicates the average-size crop trees that could probably be achieved in stands where proper spacing is maintained throughout a rotation. These estimates appear realistic, as they are based on about 1,200 trees actually measured by the Forest Survey for site determination throughout western Montana and northern Idaho.[6] Site trees generally are chosen from the dominant and codominant trees in the stand, and usually have had a little more room to grow than their associates. It is reasonable to assume then that site trees are a fair indication of sizes that could be attained by all crop trees if they had adequate growing space.[7]

[6]Idaho, north of the Salmon river.

Table 1.—**Sawtimber yields attainable in thinned stands compared with current volume of well stocked rotation-age stands in western Mont**

Species and rotation period (years)	Poor site		Medium site		Good site	
	Thinned stands	Natural stands	Thinned stands	Natural stands	Thinned stands	Nat sta
	Thousand board feet per acre[1]					
Ponderosa pine (140)	13	4	27	10	49	1
Western larch (140)	20	13	39	24	58	4
Spruce (140)	25	15	49	26	73	(
Douglas-fir (140)	18	9	39	13	58	(
Lodgepole pine (120)	11	4	23	6	39	1
White pine (120)	35	(2)	51	22	70	3

[1]Trees 11.0 inches d.b.h. and larger.
[2]Insufficient data to establish average.
Source: Forest Survey

The size objectives shown in table 2 consid ably exceed the actual performance of natu stands. For example, the 140 largest trees per ac in medium-site well-stocked lodgepole pine stan of rotation age in western Montana average abc 10 inches in diameter in comparison with a s potential of 15 inches. The 100 largest trees well-stocked rotation-age spruce stands in that a average 16 inches in comparison with a size pote tial of 22 inches.

[7]This is logical for all types that grow in this area exc lodgepole pine. Overcrowding is so general in this type t site trees do not offer adequate indication of potentialities. that reason, size objectives for lodgepole pine had to be bo on judgment and localized observations in rare stands wh the trees had adequate room to develop.

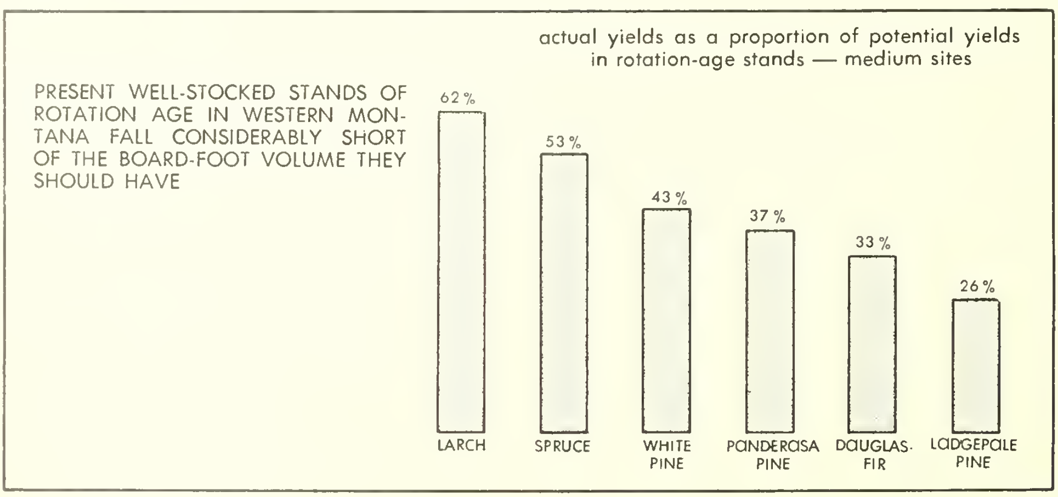

Figure 4.

'able 2.—**Reasonable tree-size objectives if tree numbers are controlled**

Species and otation period (years)	Poor site	Medium site	Good site
		D.b.h. (inches)	
onderosa pine (140)	16	20	23
Vestern larch (140)	14	18	22
pruce (140)	16	22	23
'ouglas-fir (140)	16	19	22
odgepole pine (120)	12	15	17
Vhite pine (120)	15	17	20

[1]Data do not apply to lodgepole pine growing within the /hite pine-cedar-grand fir zone. In this zone, lodgepole pine is hort lived—maturing in about 80 years—and it probably will ot produce crop trees larger than 12-15 inches even on medium nd better sites.

The Value of Thinning

Forestry in this part of the country suffers from psychological handicap because of a reputation or low productivity, not really deserved. The forest f the Northern Rocky Mountain and Intermountain egions covers a wide climatic range—from wet to ery dry, and from cold to hot. At the dry and cold xtremes there is much marginal and submarginal orest from the standpoint of timber production. On ne other hand, the bulk of the commercial forest as a substantial production potential (table 1).)vercrowding has been the principal obstacle tanding in the way of achieving this potential.

Greatly increased harvest values could be reated by thinning, assuming the volume increases nentioned in the preceding pages (fig. 5 and able 3). The opportunity in larch stands is typical. ssuming the present level of stumpage values nd taking account of the effect of tree size on alue, the increase in harvest yields per acre would ange from $166 on poor sites to $514 on the best ites. In other words, by thinning well-stocked arch stands on good sites, we can more than louble their value. On poor sites, thinning would ncrease the harvest value four times.

Wrapped up in the value increases shown ibove are the savings in processing costs that vould result from handling larger trees. Experence in the Lake States Region shows that tree ize greatly affects logging and manufacturing osts (fig. 6). Such data as are available indicate he curve in figure 6 is realistic also for the Northern Rocky Mountain and Intermountain Regions. The average saving in processing costs as a result of thinning, therefore, would range from $5 to $12 per thousand board feet, depending upon species and site.[8]

Any increase in per-acre yields will also tend to reduce development costs per thousand board feet. The bigger harvest yields due to thinning should lower these costs by at least 50 cents per thousand board feet on good sites, $1 on medium sites, and $1.50 on poor sites.

The reductions in the development costs and in processing costs are reflected in higher anticipated stumpage values as shown in table 3.

[8]These calculations were based on the assumptions that:
1. Thinning will increase average crop tree diameters as follows:
Poor site ....2 inches
Medium site ....3 to 4 inches
Good site ....4 to 5 inches
2. The cost of converting stands of 12-inch trees into lumber would average $60 per thousand board feet.

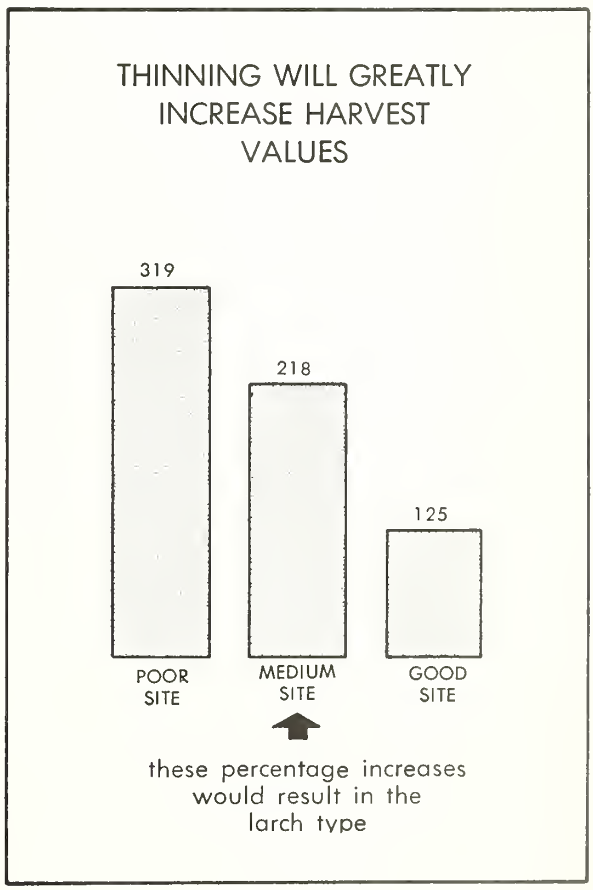

Figure 5.

Table 3. **Stumpage value of well-stocked stands with and without thinning.**

Type and rotation period (years)	Site	Without thinning		With thinning	
		Per M bd. ft.	Per acre	Per M bd. ft.	Per acre[1]
		Dollars			
Ponderosa pine (140)	Good	15.00	285	23.30	1,028
	Medium	10.00	100	17.60	428
	Poor	6.50	26	13.40	157
Larch (140)	Good	10.00	410	17.70	924
	Medium	7.00	168	15.20	534
	Poor	4.00	52	12.10	218
Spruce (140)	Good	11.00	(2)	16.90	1,110
	Medium	7.00	182	15.20	670
	Poor	4.00	60	10.90	245
Douglas-fir (140)	Good	6.00	(2)	13.70	715
	Medium	4.50	58	12.70	446
	Poor	3.00	27	9.90	160
Lodgepole pine (120)	Good	10.00	130	18.30	642
	Medium	6.00	36	13.00	269
	Poor	2.00	8	12.50	124
White pine (120)	Good	20.00	660	31.90	2,010
	Medium	15.00	330	23.80	1,092
	Poor	10.00	(2)	17.50	551

[1]Values discounted 10 percent to allow for mortality.
[2]Insufficient sample.
Source: Developed from Forest Survey data and regional stumpage price information.

Cost of Thinning

Proper stand spacing over a period of 120 or 140 years cannot be accomplished with one or two thinnings. Most stands will have to be thinned four or five times.[9] However, every thinning after the first one, or in some cases the first two, should produce commercial-size stems. It seems safe to assume that the succeeding cuts would each produce enough value to at least cover the cost of thinning and possibly provide a profit as well. There is a certain amount of anticipation in this assumption, as it would be difficult now to market some of the smaller trees that a commercial thinning would produce. However, wood utilization is improving rapidly, and sooner or later any pole- and sawtimber-size material removed in thinnings should be marketable.

From normal yield tables, we estimate the commercial material removed in thinning will range from 2,000 to 15,000 board feet per acre over a rotation. This is 20 percent of the final harvest volume of such stands, and it is 33 to 83 percent (fig. 7) of what the **total harvest yield** would be if no thinning were done.[10]

[9]The term "thinning" is used here in a broader sense than as it is defined in most textbooks on silviculture. It includes weedings and improvement cuttings as well as cuttings made in older stands to reduce stand competition.

[10]At present, there is no information on yields possible from intermediate cuts that could be considered conclusive. In normal stands from which yield tables have been constructed, sawtimber mortality usually amounts to from 20 to 30 percent of the harvest yields. Experience gained on study plots indicates that at least this amount of volume could be captured in intermediate cuts.

The thinning problem centers in the first pr commercial thinning, or for some stands, two thi nings. This precommercial thinning cannot be side stepped because crowding begins at an early ag in these forests. Yet, precommercial thinning pro duces no immediate revenue and is a net co operation at an early stage in a long rotation.

Very little precommercial thinning has bee done in the Northern Rocky Mountain and Inte mountain Regions. For that reason, we have onl limited cost data to draw upon. Figure 8 shows range of thinning costs calculated from data fror other regions. These estimates have been modifie on the basis of judgment and a limited amount o local experience to take account of the more dif ficult terrain and more difficult accessibility in th Mountain States. We estimate costs will range fron $5 to $80 an acre, depending upon number anc size of trees to be removed. However, if the firs thinning is done as early in the life of a stand as i should be, the per acre cost will probably range between $5 and $30.

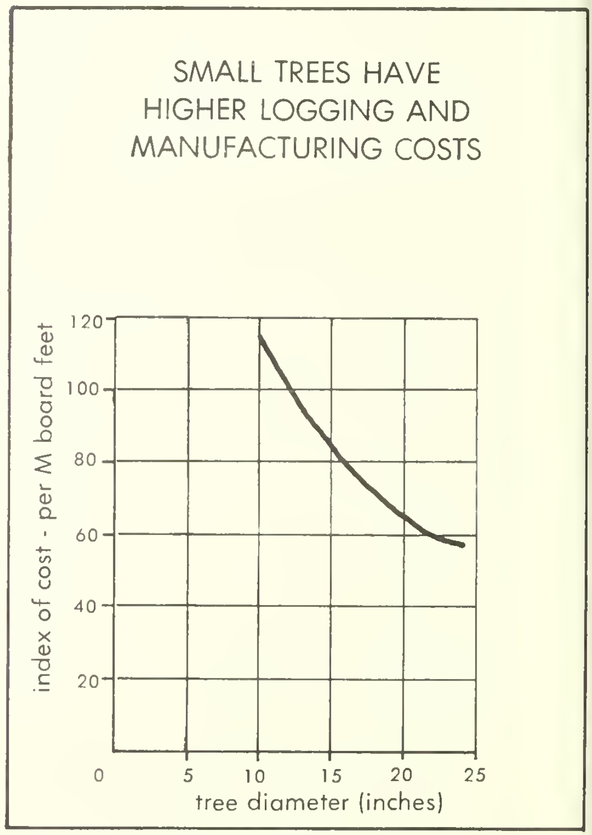

Figure 6.

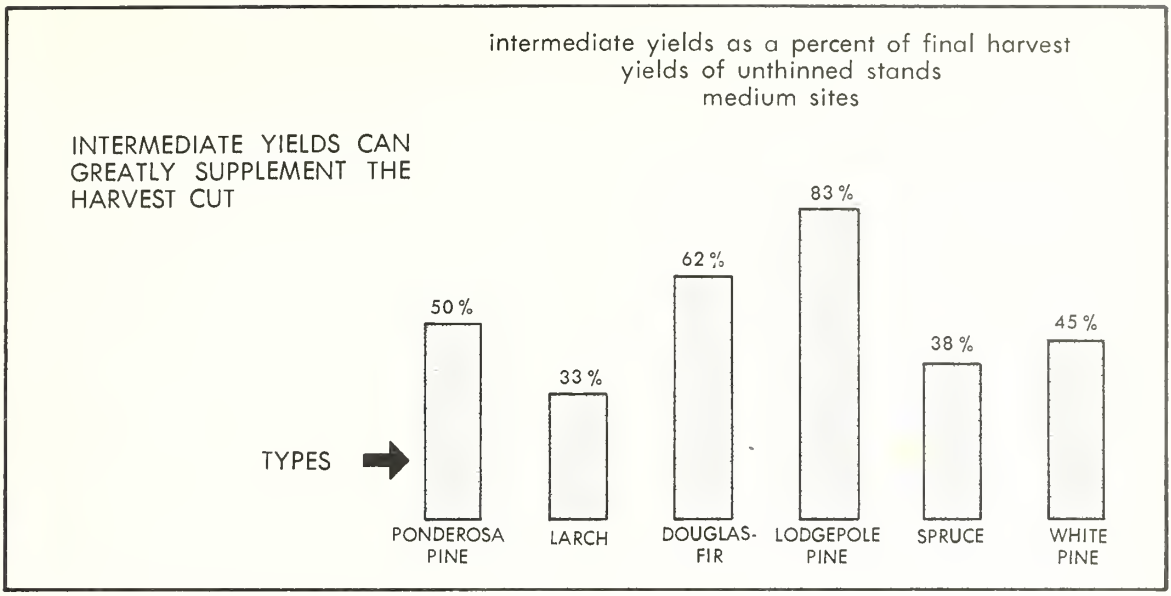

Figure 7.

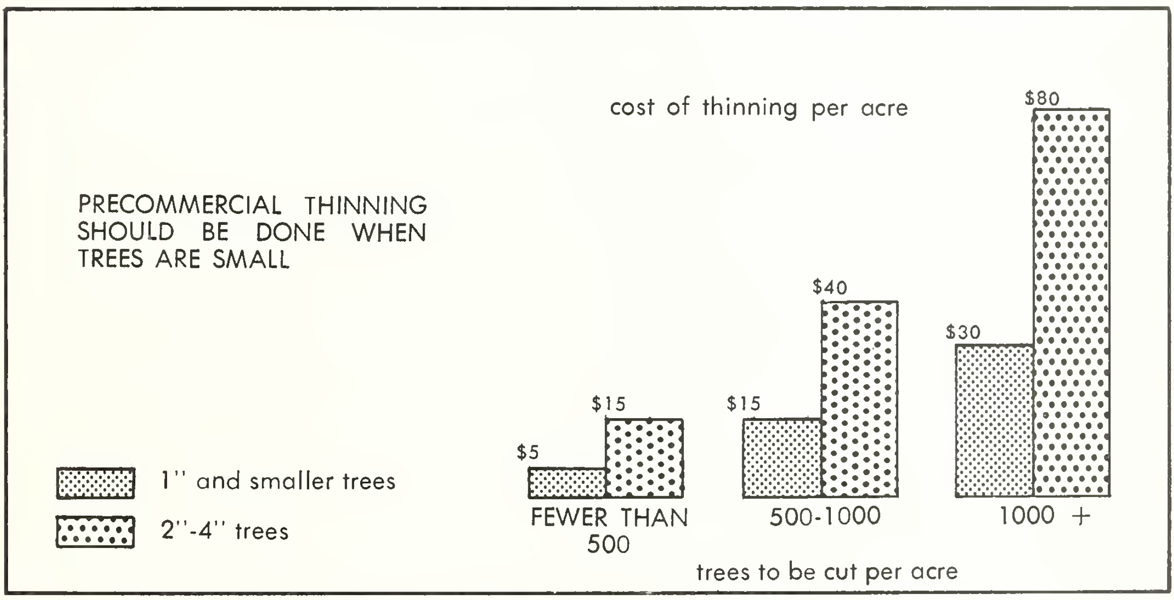

Figure 8.

Summary

If thinning is started early in the life of the stand, the ratio of cost to revenues will be the greatest. For a $5- to $30-per-acre thinning cost, harvest value yield can be increased $100 to $175 per acre on poor sites, $200 to $600 on medium sites, and $500 to more than $1,000 per acre on good sites. In addition, there should be some opportunity for profit in intermediate cuts. These figures represent the maximum opportunity. Thinning in stands that have suffered from overcrowding would, of course, return less.

THE IMPACT OF LIMB PERSISTENCE

One of the more evident contrasts between the coniferous forests of the Mountain States and those of the South is seen in the persistence of dead branches in the Mountain States. Because of a decay-inhibiting climate, this region's timber retains its dead branches long after southern trees have been naturally pruned. In the past, nature has reduced the effect of limb persistence in our virgin stands by long rotations. Even so, the percentage of clear lumber produced from Mountain States logs has been relatively low. In northern Idaho, western Montana, and northeastern Washington, for example, D-select and better boards make up only 2 to 15 percent of the total lumber sold, according to the following tabulation developed from price and sales data from Region 1:

	Percent
Ponderosa pine	15
Spruce	6
Larch and Douglas-fir	10
Lodgepole pine	2
White pine	12

The virgin longleaf pine of the South, by contrast, probably averaged more than 25 percent clear wood.[11]

As rotations are shortened, the problem of limb persistence will become more critical if the emphasis on clear wood is to continue. We can get some idea of the future problem from log grade data. Forest Survey statistics for western Montana show that butt logs of only 25 percent of the **rotation-age** ponderosa pine trees of sawlog size are sufficiently limb- and knot-free to qualify as "clear" (grade number 1).[12] On the other hand, 21 percent of these butt logs are "low common" (grade number 4). Practically no spruce or lodgepole pine logs of rotation age are knot- and limb-free (table 4).

Table 4.—**Quality of butt logs of rotation-age trees of crop-tree size in natural stands, western Montana**

Log grade	Ponderosa pine	Lodgepole pine	Spruce
	Percent		
Number 1—surface clear	25	0	0
Number 2—50 percent surface clear	29	42	60
Number 3—common	25	33	40
Number 4—low common	21	25	0
Total	100	100	100

Source: Forest Survey data.

[11] Bryant, Ralph Clement. Lumber. 539 pp. New York. 1922.

[12] The log grades referred to in this report are the four grades used by the Forest Survey in this area.

Opportunity for Pruning

In this circumstance, pruning becomes an important means of increasing the value yield for those species for which clear wood has or will have a premium value. The four soft-textured softwoods (white pine, ponderosa pine, lodgepole pine, and spruce), which occupy about 60 percent of the commercial forest area in these two regions, certainly are in this category. Clear lumber of these species is currently worth from about $53 to $90 (50

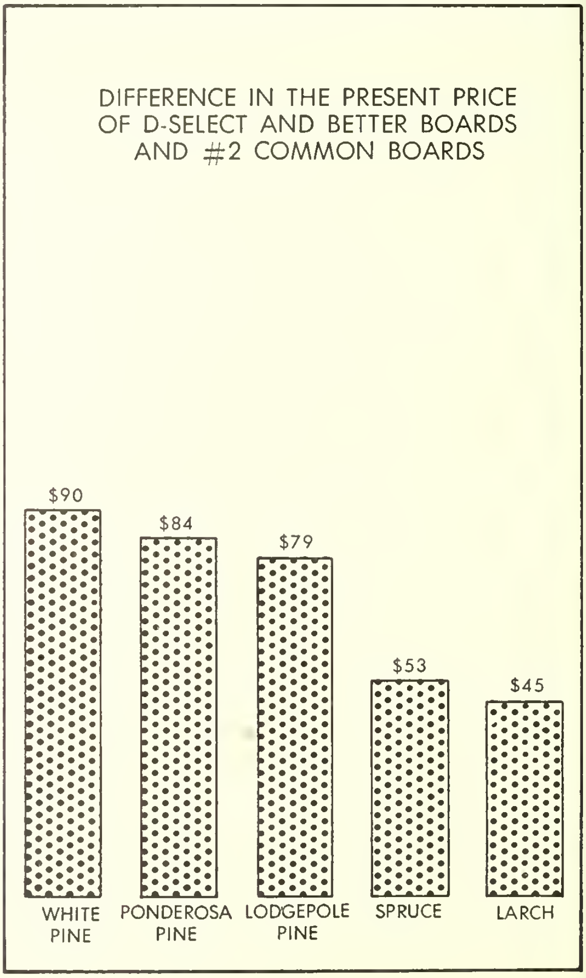

Figure 9.

o 80 percent) more per thousand board feet than umber 2 common lumber (fig. 9).

Larch also can apparently be pruned advan- ıgeously even though it is a hard-textured soft- /ood. This high-strength wood has special value ɔr such structural purposes as laminated beams, ınd it is becoming increasingly popular as a dec- ›rative paneling. The spread in value between)-select and number 2 common larch boards is now nly about $45 per thousand board feet. How- ver, experts in forest utilization believe the quality dvantage of this species is yet to be fully exploit- d.

The physical gains from pruning will depend n three things: how well the pruning is done; ıe size of the tree when pruned; and its size when ut. The potential pruning opportunity is best when rees are young (fig. 10). For example, if a tree is ›runed when it is 4 inches in diameter and logged vhen it is 12 inches, the butt log will produce 50 ıercent clear wood. If it is pruned at 4 inches ınd allowed to grow to 22 inches, the butt log will ave 87 percent clear wood. In any forest where ›runing is done at the appropriate stage in the de- /elopment of each stand, D-select and better lum- ɔer might easily make up the following percentages ıf the final harvest yields in contrast with the 2 to 5 percent recovery in stands now being cut:

	Percent
Ponderosa pine	35
Larch	19
Spruce	34
Lodgepole pine	25
White pine	28

Value of Pruning

How important the improvement in grade recovery will ultimately prove to be will depend largely upon the trend of wood values. These need to be studied in greater detail than they have been heretofore. At present the lumber market is changing because of the impact of competitive materials. The effect clear wood is likely to have on the use and value of plywood in the future is also a factor. If we accept the Forest Service's Timber Resource Review estimates at face value, knot-free or clear wood will be in even shorter supply in the future than it is today.[13] Thus, the value increase from pruning may be greater than present prices indicate.

However, even if it is assumed that the price spread due to difference in quality will never increase, pruning will increase log values by about 50 percent. In other words, the butt log of a pruned tree will be worth about 50 percent more than a comparable unpruned log. Table 5 shows the value increases likely to occur for typical logs of the several species.[14]

[13] U. S. Forest Service. Op. cit. pp. 404-5.

[14] Theoretical pruning yields, like theoretical mink farm yields, should be viewed with a certain amount of caution. It is easy to be carried away by figures. As a hedge against such over-optimism, the data in table 5 include several factors of conservatism. In the first place, fairly large knotty cores were assumed for the larger pruned trees, which tends to discount the clear-wood yield. It was assumed that the knotty core of pruned logs would range from 6 inches in 12-inch trees to 10 inches in 22-inch trees.

In the second place, it was assumed that the composition of the select grade lumber would be about the same as now. Actually, pruned logs should produce relatively more B-select lumber and less D-select lumber than present grade 1 logs. In addition, a discount was applied to allow for losses that will occur between time of pruning and time of harvest.

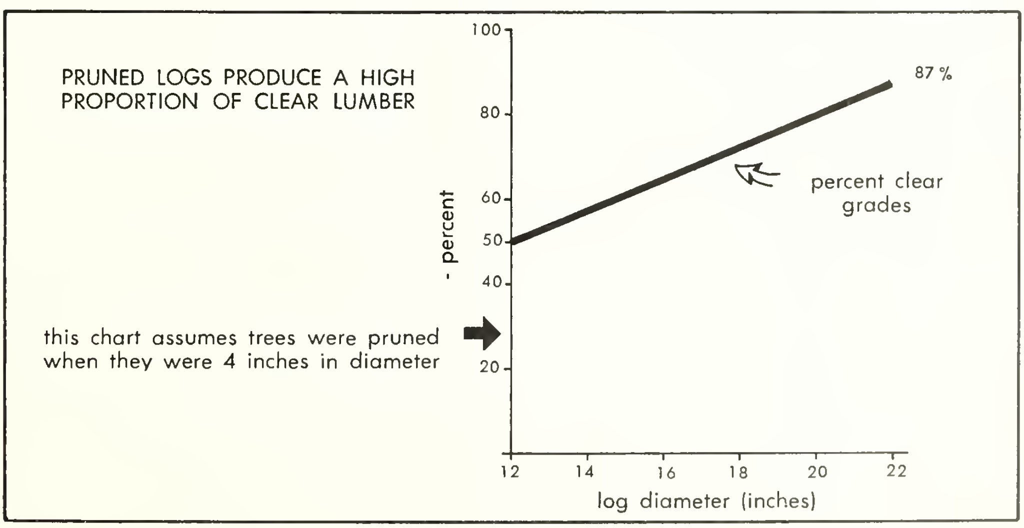

Figure 10.

Table 5.—**Value per thousand board feet of lumber produced from pruned and unpruned logs**

Species	Average log diameter	Conversion value	
		Not pruned	Pruned
	Inches	Dollars	
Ponderosa pine	20	112	166
Larch	19	80	118
Spruce	19	82	127
Lodgepole pine	15	90	140
White pine	18	130	190

Cost of Pruning

Like thinning, pruning is not cheap. It costs about 40 cents to prune the first log of a tree. Assuming that 20 percent of the pruned trees will fall by the wayside before the final harvest, the cost per crop tree harvested will be 50 cents. In current practice, where release cutting is done in conjunction with pruning, the total operation costs from 70 to 75 cents a tree. Assuming a 20-percent allowance for losses and premature harvesting, the cost in this case would be about 90 cents for each harvested tree. These 50- and 90-cent estimates reflect the fact that good pruning involves more than a hurried job of slashing at branches with an ax or club, leaving broken stubs and gouged tree trunks when the aim is poor. Good pruning is an exacting job that takes time.

Pruning is likely to cost from $30 to $92 per acre (table 6), depending primarily upon the number of trees pruned. The low costs are on the best sites where the crop trees would be larger and fewer per acre.

Table 6.—**Estimated cost of pruning, by type and site**

Species	Site	Trees pruned[1] per acre	Pruning cost[2] per acre
		Number	Dollars
Ponderosa pine	Good	59	30
	Medium	66	33
	Poor	83	42
Larch	Good	86	43
	Medium	106	53
Spruce	Good	77	38
	Medium	70	35
	Poor	100	50
Lodgepole pine	Good	110	55
	Medium	104	52
White pine	Good	110	55
	Medium	148	74
	Poor	184	92

[1]Assuming 75 percent of normal stocking at time of harvest.

[2]Pruning cost averages about 40 cents per tree. This cost was increased 25 percent to take account of trees pruned that never reached rotation age.

Summary

Pruning is a more expensive measure than precommercial thinning. However, if the present difference in wood price due to quality continues, pruning offers a substantial opportunity to increase value yield. This is particularly true if the pruning effort is concentrated on the more valuable species growing on the better sites. Less than a dollar spent per tree to prune the first log should result in a $5 to $10 higher conversion value for the tree.

COMPOSITE EFFECT OF THINNING AND PRUNING

To a certain extent, thinning and pruning have a ham-and-eggs relationship. Almost any well-stocked stand that is to be pruned must be thinned for the pruning to be effective. Likewise, pruning is an important adjunct to thinning because the benefit/cost ratio for pruning is usually about 25 percent to 100 percent higher than for thinning. Consequently, the desirability of thinning is enhanced if it is accompanied by pruning.

Figure 11 suggests the value increases that would result from thinning and pruning in five timber types, and from thinning alone in the Douglas-fir type. These data apply to well-stocked stands on medium sites. The actual dollar values used are contained in table 7. To avoid misinterpretation of these data, we repeat the major assumptions that underlie them:

1. It will be possible to achieve 75 percent utilization of the growing space at rotation age on each treated acre that is harvested.
2. Mortality losses will amount to 10 percent of harvest yields.
3. Cost-price relationship will not change.

The most difficult assumption is probably that regarding mortality. Whether the volume yields shown for thinned stands can be maintained over broad areas is subject to question. However, because the mortality data available are totally inadequate for use in predicting yields, it is necessary to rely completely on this assumption, which has no other defense than that it seems reasonable.

In any case, it is apparent that in the lodgepole pine type, and to a lesser extent in the other types, thinning has two important effects:

- It permits the crop trees in productive stands to grow larger.
- It prevents stands from becoming nonproductive through stagnation before the trees reach usable size.

Figure 11 illustrates the contribution that thinning and pruning could make to forest productivity in the Northern Rocky Mountain and Intermountain Regions. Together, they could increase value yields of well-stocked stands by 400 percent or more.

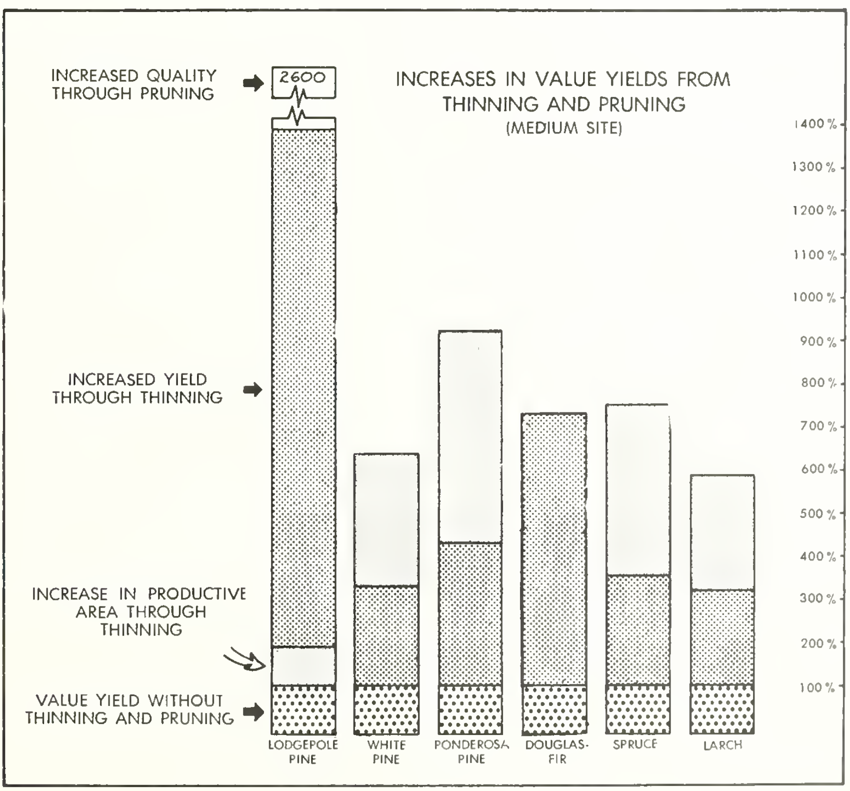

Figure 11.

Table 7.—**Per acre value yields of well-stocked natural stands compared with value yields of thinned and pruned stands**

Species	Site	Average value yields		
		No thinning or pruning	Thinned[1]	Thinned[1] and prune
		Dollars		
Ponderosa pine	Good	285	1,028	1,984
	Medium	100	428	963
	Poor	26	157	456
Western larch	Good	410	924	1,698
	Medium	168	534	1,011
	Poor	52	218	([3])
Spruce	Good	—	1,111	2,151
	Medium	182	670	1,426
	Poor	60	245	605
Douglas-fir	Good	—	715	([3])
	Medium	58	446	([3])
	Poor	27	160	([3])
Lodgepole pine	Good	130	642	1,434
	Medium	18[2]	269	737
	Poor	8	124	([3])
White pine	Good	660	2,010	3,396
	Medium	330	1,092	2,158
	Poor	—	551	1,545

[1]Values have been discounted 10 percent to allow for mortality.
[2]Discounted 50 percent for area that will not grow sawtimber-size trees.
[3]Thinning only.

EVALUATION OF THINNING AND PRUNING

Properly executed programs of thinning and pruning eventually will substantially improve both the volume and quality of timber yields. If present cost and value levels continue, each dollar spent in thinning will produce $4 to $45 in added yields. Under the same circumstances, each dollar spent in pruning would produce $9 to $40 of extra benefit.

The difficulty, of course, lies in the long time span between the pruning of precommercial thinning and the harvest. Just when these operations should be done varies with individual stands. However, with the rotations indicated in the preceding pages, the precommercial thinning will probably be done 80 to 120 years before the end of the rotation. The time span in pruning will probably be 70 to 100 years.

If the justification for thinning and pruning is to be based on a comparison of costs with discounted values stand by stand, the relatively high rate of physical return will be largely nullified by the time factor. Table 8 indicates the rates of return that might be expected in the six most important types in these two regions with this kind of discounting. The significant point is that **only the most valuable species on the best sites would return rates that are currently thought to be reasonable for long-term investment.** There is, of course, relatively little of this top-site area.

Table 8.—**Interest rates thinning and pruning would produce if the value increases on each acre are matched with the costs on that acre**

PONDEROSA PINE

Assuming a 140-year rotation, precommercial thinning at 20 - 40 years, and pruning at 40 - 60 years.

Interest return on investment acre by acre	Percent
Good site	3.2
Medium site	2.6
Poor site	2.0

LARCH

Assuming a 140-year rotation, precommercial thinning at 20 - 40 years, and pruning at 40 - 50 years.

Interest return on investment acre by acre	
Good site	2.7
Medium site	2.4
Poor site	1.7

SPRUCE

Assuming a 140-year rotation, precommercial thinning at 20 - 40 years, and pruning at 40 - 60 years.

Interest return on investment acre by acre	
Good site	([1])
Medium site	3.0
Poor site	2.2

[1]Incomplete data.

DOUGLAS-FIR[2]

Assuming a 140-year rotation, and precommercial thinning at 20 - 40 years. No pruning.

Interest return on investment acre by acre	Percent
Good site	([1])
Medium site	2.3
Poor site	1.5

LODGEPOLE PINE

Assuming a 120-year rotation, precommercial thinning at 20 - 40 years, and pruning at 30 - 50 years, and a 50-percent increase in productive area.

Interest return on investment acre by acre	
Good site	3.0
Medium site	2.6
Poor site	1.7

WHITE PINE

Assuming a 120-year rotation, precommercial thinning at 20 - 30 years, and pruning at 30 - 50 years.

Interest return on investment acre by acre	
Good site	3.8
Medium site	3.3
Poor site	([1])

[2]Thinning only.

The data in table 8 merely emphasize a point that is already generally recognized. **There is virtually no place in long-rotation forestry for the owner with bare ground or a single-age-class property.** This situation is not unique because there is no place in the competitive business atmosphere of today for the enterprise faced with an imbalance between cost and income for a long time. Moreover, even the owner with a reasonably balanced or manageable distribution of age classes will see little opportunity if he weighs the cost of managing each acre against the discounted revenues from that acre.

However, the owner blessed with a manageable distribution of age classes (such as is found in the national forests or on larger industrial acreages) probably will not turn to this type of calculation for a measure of the attractiveness of the business venture or for a means of evaluating alternatives. He will be chiefly interested in the over-all soundness of the total operation, taking account of the costs associated with managing his resource.

His first concern will be to determine what level of costs will be required to achieve the objectives of the enterprise. Presumably, the objective usually will be to increase the productivity of the whole operation and to achieve the best ultimate balance between cost and revenue. The preceding calculations leave no doubt that thinning and pruning offer an excellent way to do this.

His second concern with expenditures will be how much thinning and pruning expense can be borne by current revenues. The answer to th question will vary with each individual owner, de pending upon income and cost prospects and h objectives of management.

The public evaluation of cost-to-revenue re lationships will, of course, be both broader an more involved than for private holdings. It wi be broader because the timber management objec tive of public forest ownerships is essentially t help supply a national wood need and at th same time provide the resource for a substantic expansion of employment. Beyond that there i also the responsibility to accomplish these objec tives as economically as possible.

The case for thinning and pruning on proper ties having a reasonably balanced growing stoc rests on three facts:

- Both measures will greatly increase th quantity and quality of utilizable woo in the long run.
- They will provide the opportunity for ex panded employment in years to come.
- They represent one of the best means a vailable for increasing forestry operatin margins in the Northern Rocky Mountai and Intermountain Regions.

If greater volume and value yields are to b achieved, a substantial effort in thinning and prun ing will be necessary, for these measures are basi to a buildup of productivity and value yield. For tunately, the ultimate payoff from both thinnin and pruning will be large.

Intermountain Forest and Range

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TABLES FOR POINT-SAMPLE CRUISING IN PONDEROSA PINE

By

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TABLES FOR POINT-SAMPLE CRUISING IN PONDEROSA PINE

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The accompanying tables have been compiled to aid foresters in cruising ponderosa pine by the point-sampling method. Volume determination by this method is basically a two-step procedure: first, estimate basal area per acre; and second, convert basal area to volume by using the appropriate ratio of volume/basal area. Point-sampling procedures for accomplishing the first step are now familiar to most foresters. However, proponents of point-sampling recommend a variety of methods for converting estimates of basal area to estimates of volume. The choice of method depends on the precision desired and the character of the timber stands. In even-aged second-growth ponderosa pine stands, the cruiser can take advantage of the uniformity of the stand to select the appropriate ratio based on stand height, or a combination of height and diameter. However, in old-growth or uneven-aged stands, the average ratio must be obtained from a representative sample of trees in the stand.

The following tables are arranged in three classes according to the relative accuracy of the associated techniques for estimating volume. The first table provides "rule of thumb" estimates arrived at quickly with a minimum of observation and calculation. The next set, tables 2, 3, and 4, may well equal the accuracy of the last set in even-aged stands of second-growth, but do not provide the flexibility to fit a variety of stand structures. Accordingly, the last set, tables 5, 6, 7, and 8, requires the most detailed sampling and calculation procedures--but with correspondingly greater potential accuracy.

Conversion of gross to net volume and techniques for calculating timber quality data have been slighted in the literature. A later section of this paper describes a technique using the percentage distribution of tree volume (table 10) which simplifies these calculations.

In the construction of these tables, and in the suggestions for their use, the necessity for complicated weighting factors to allow for the nature of point-sampling probabilities has been largely avoided. Such averages as mean stand diameter, mean stand height, cull deduction, and quality yield are to be computed as simple arithmetic averages of the data collected by point-sampling. This simplification is made possible because the accompanying tables are based on averages so weighted that they correspond to unweighted averages of point-sample data. In fact, the averages obtained by variable plot cruising give better estimates of volume than do averages from sampling on a fixed area basis because the larger trees are given more weight in variable plot sampling than in using the conventional techniques. It is interesting to note that in the stands described in Meyer's normal yield tables, the mean diameter obtained from a direct average of point-sampled trees corresponds very closely to the average diameter of the dominant and codominant trees.

STAND VOLUME RATIOS

Tables 1 and 4 are stand volume tables expressed as the ratio of stand volume to total stand basal area. The basal area of the stand in trees 0.6 inch and larger is multiplied by the ratio from the table for the volume units desired to obtain the stand volume.

The use of total stand basal area to estimate board-foot volume of trees 10 inches d.b.h. and larger may seem strange. However, use of total stand basal area eliminates errors in estimating the minimum diameter to be tallied, simplifies in-growth calculations when determining growth, and provides a common base from which volume in all units--board feet, cubic feet, or cords--can be estimated. Little additional work is entailed to obtain total stand basal area because of the very nature of point sampling.

Ratios Based On Individual Tree Samples

In irregular or mixed-aged stands, the stand volume table approach may not prove flexible enough to give accurate volume estimates. In such stands, the volume/basal area ratio can be determined from a sample of the trees tallied for the basal area estimate. The lower diameter limit of the trees sampled for volume should coincide with that for the basal area estimate, or else the basal area count should be recorded separately for the trees smaller than the minimum size for volume determination. The sample selection should be such that every tree tallied for the basal area count has an equal probability of being selected for the volume estimate. One should measure tree height and diameter either on one out of every n trees or on all the trees at every nth sample point. He should then determine the volume/basal area ratio from table 5, 6, 7, 8, or 9 for each tree sampled. Then, he can multiply the arithmetic average of these ratios by the stand basal area to obtain stand volume.

Tree Volume Ratios According to Height

Volume/basal area ratios for a given tree height are nearly constant over a wide range of diameters. Thus, for rough estimates, table 5, which neglects tree diameters, can be used to obtain the board-foot volume/basal area ratio.

Use of such standard ratios lends itself nicely to making up cumulative volume tally sheets. Carow[1] shows how such a sheet may be designed and used.

The average tree volume/basal area ratio for each height class divided by the height in logs is very nearly a constant. Thus, it is possible to dispense with keeping the field tally by height classes. Instead, the total number of

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1/ Carow, John. Quick cruising with the Bitterlich angle-count method and a cumulative tally sheet. Mich. Forestry Note No. 1, 2 pp., Oct. 1953.

logs in all the trees qualifying at each point is tallied. For second-growth ponderosa pine, the average number of board feet per log per square foot of basal area is 39, and for old-growth, 53 (table 5, last column). These ratios, multiplied by the basal area factor of the angle-gauge, multiplied by the number of logs counted at the point equal the volume per acre represented at that point.

For example, consider three 4-log trees, five 3-log trees, and two 2-log trees counted with a prism having a basal area factor of 10 at a point in a second-growth stand. The volume per acre indicated by this sample is:

$$(3x4) + (5x3) + (2x2) = 31 \text{ logs}$$

$$(31 \text{ logs}) (10 \text{ sq.ft./acre}) (39 \text{ bd.ft./log/sq.ft.}) = 12{,}090 \text{ bd.ft./acre}$$

Tree Volume Ratios by Height and Diameter

Estimating tree diameter further improves the accuracy with which the average volume/basal area ratio can be determined. However, accuracy of the diameter measurement has only a limited effect on the over-all volume estimate, and no effect on the total basal area estimate. Accordingly, ocular estimates of tree diameter in broad diameter classes are adequate for most purposes.

Tables 6, 7, 8, and 9 list the volume per square foot of tree basal area computed directly from volume tables in current use. Tables 6, 7, and 8 apply to second-growth timber, while table 9 applies to old-growth timber with quite different form and top diameters.

FIELD MEASUREMENTS TO ADJUST TABLES FOR LOCAL USE

These tables are based on recognized, widely used stand and volume tables. When large areas are being cruised, local peculiarities of taper and bark thickness should be compensating. As with any other volume table--form-class, composite, or species--measurements of taper and bark thickness must be made in order to use the table with any confidence on small areas, or on areas where peculiarities of form are suspected. The actual volume/basal area ratio determined from stem measurements of the timber being cruised should be plotted over the tabular estimate for each sample tree.[2/] A smooth curve (frequently a straight line) drawn through these points indicates the adjusted values to be used in place of the tabular values given herein.

2/ Plotting is simplified by using log-log graph paper.

DISTRIBUTION OF TREE VOLUME BY LOG POSITION

Cruisers frequently use tables of the proportional distribution of tree volume in the respective logs of that tree as an aid in estimating cull. With point sampling, such tables become indispensable both for cull and log grade determination. Table 10 contains the proportion of tree volume in each log position for ponderosa pine.

PROCEDURES FOR QUALITY AND CULL ESTIMATION

Consider a cruise design on which height, quality, and defect have been tallied on each tree at every nth sample point. In order to summarize these data on a per-acre basis, one needs to calculate the volume/basal area ratio for each kind of volume--gross and net, in each quality category. Then, when the total stand basal area as estimated by the variable plot cruise is multiplied by the volume/basal area ratio for each category, the stand volume per acre in that category is obtained.

Table 11 illustrates and explains the compilation of such data summarized from a field tally. In this example the effect of diameter on the volume/basal area ratio has been disregarded. If the diameter were to be considered, a similar summary would be prepared for each diameter class. Then the entries in line 1 of table 11 would be taken from table 6, 7, 8, 9, or their equivalent. By using taper tables for each diameter and height class, upper log diameters could also be estimated and their volumes collated and totaled by diameter classes.

The compilation technique outlined here utilizes the full power of the variable plot survey design. The data can be readily compiled on desk calculators, although on large scale surveys, electronic computers could be advantageously programmed following the same procedure.

SLOPE CORRECTION

Sloping plots can be tallied in two ways: (1) by modifying the critical angle so that a constant basal area factor is maintained, or (2) by keeping the angle gauge constant and changing the basal area factor for the sloping plot. The former method is very convenient for tree-by-tree correction when a wedge-prism is the angle gauge. The procedure is clearly explained by Bell and Alexander.[3] The latter method is simple to apply in gently rolling terrain where abrupt changes in slope are unlikely within the "plot" area.

3/ Bell, J. F., and L. B. Alexander. Application of the variable plot method of sampling forest stands. Oreg. State Board of Forestry Res. Note 30, 22 pp. 1957.

Table 12 lists the correction factors by which the basal area factor of the angle gauge is multiplied to correct for the slope at that point when the angle gauge is not adjusted for slope compensation. This table is taken from Grosenbaugh.[4/] It is reproduced here so as to be readily available for use in conjunction with the other tables in this publication.

DERIVATION OF RATIO TABLES

Table 1

Cubic feet ratios were taken from table 6 according to a height/diameter curve for Inland Empire second-growth ponderosa pine prepared by D. W. Lynch. Suitable converting factors from cubic feet to cords were then applied to obtain the cords/square foot basal area ratios.

Table 2

This table is based on data from 207 plots of second-growth (25-125 years of age) ponderosa pine in the Inland Empire measured by D. W. Lynch. Individual tree volumes were estimated from table 32, U.S.D.A. Technical Bulletin 630. The original plots consisted of a complete enumeration of all trees on a fixed area. Calculation of $\Sigma dbh^3/\Sigma dbh^2$ gave the variable plot mean diameter. From the height/diameter curve for each plot the height corresponding to this mean diameter was determined. The equation

$$\log {}^{V}/BA = -0.48089+1.07326 \log H - 0.08795 \log D$$

accounted for 96.7 percent of the variation in the volume/basal area ratio. The standard error of estimate of the volume/basal area ratio is 0.4 percent.

Table 3

This table is derived from table 2 by applying a conversion from cubic feet to board feet-International 1/4-inch rule of the form:

$$\log \left(\frac{100 \text{ bd.ft.}}{}/\text{cu.ft.}\right) = a + {}^{b}/D^2 + c\frac{H}{D^2}$$

This equation is based on that given by Lynch (1958) with constants adjusted for the transformed variables, D and H.

4/ Grosenbaugh, L. R. Better diagnosis and prescription in southern forest management. U.S. Forest Serv. South. Forest Expt. Sta. Occas. Paper 145, 1955.

Table 4

This table was derived from Meyer's ponderosa pine yield tables. Variable plot mean diameters were calculated from Meyer's stand tables as described for table 2.

Table 5

The most probable diameters for each log height were estimated from height diameter curves and the corresponding ratios taken from tables 8 and 9. It is recognized that this entails an interchange of the dependent and independent variables. However, the change in ratios is gradual enough that little error is introduced thereby.

Tables 6, 7, 8, and 9

These tables were derived from the original tables referred to in their respective footnotes. They were derived by dividing each entry by the basal area in square feet corresponding to the d.b.h. This process can be used to adapt any suitable volume table to variable plot cruising. Ultimately, it will be more desirable to construct ratio equations directly from the original tree measurement data. For small-scale cruises, tables based on these equations would be used for compilation, while on large-scale cruises the equations themselves would be incorporated into the electronic computer program for analysis of the data.

Table 1.--Stand volume/total stand basal area for cubic feet and cords

Volume measures	Stand height[1/] (feet)											
	30	40	50	60	70	80	90	100	110	120	130	140
Cubic feet[2/]	11.0	14.6	18.3	21.8	25.4	29.0	32.6	36.2	39.7	43.3	46.0	48.0
Cords:												
Site II[3/]	--	.06	.14	.25	.30	.34	.38	.42	.46	.50	.54	.58
Site III, IV, V[4/]	.05	.14	.21	.27	.31	.35	.39	.43	.48	.52	.55	.59
Site VI[5/]	.10	.17	.24	.29	.33	.37	.42	.46	.51	.55	.59	.63

1/ Height of tree of mean diameter of trees selected by angle gauge.
2/ Cubic feet inside bark, including stump and tip.
3/ Sticks straight and smooth.
4/ Sticks straight and slightly rough.
5/ Sticks slightly crooked and rough.

Table 2.--Stand volume/total stand basal area for cubic feet[1/]

Stand diameter (inches)[2/]	Stand height[3/] (feet)										
	20	30	40	50	60	70	80	90	100	110	120
2	7.74	12.0	16.3	20.7	25.1						
4	7.29	11.3	15.3	19.5	23.7	27.9					
6	7.03	10.9	14.8	18.8	22.8	27.0	31.1	35.3			
8	6.86	10.6	14.4	18.3	22.3	26.3	30.3	34.4	38.6	42.7	46.9
10	6.72	10.4	14.1	18.0	21.8	25.8	29.8	33.7	37.8	41.8	46.0
12		10.2	13.9	17.7	21.5	25.4	29.3	33.2	37.2	41.2	45.2
14			13.7	17.4	21.2	25.0	28.9	32.8	36.7	40.6	44.6
16				17.2	20.9	24.8	28.5	32.4	36.3	40.1	44.1
18					20.7	24.5	28.3	32.1	35.9	39.7	43.7
20						24.3	28.0	31.7	35.6	39.4	43.2
22							27.8	31.5	35.3	39.0	42.9
Mean[4/]	7.40	11.0	14.6	18.3	21.8	25.4	29.0	32.6	36.2	39.7	43.3

1/ Cubic feet inside bark, including stump and tip of all trees 0.6" and larger d.b.h. (Individual tree volumes taken from table 32, U.S.D.A. Tech. Bul. 630.)
2/ Mean diameter of trees selected by angle gauge.
3/ Height of tree of mean diameter determined as above.
4/ Calculated from:

$$\log V/BA = -0.4133+0.9858 \log H.$$

Table 3.--Stand volume/total stand basal area for board feet, International 1/4-inch rule1/

Stand diameter (inches)2/	Stand height3/ (feet)										
	20	30	40	50	60	70	80	90	100	110	120
6	0.36	1.02	2.58	6.08	13.69	29.95	64.05				
8	2.84	6.16	11.8	21.0	35.8	59.2	95.8	152.5			
10	7.15	13.7	23.1	36.3	54.6	79.7	113.9	159.9	221.8		
12		20.8	32.8	48.3	68.0	92.9	124.2	163.2	211.7	271.3	
14			40.3	57.1	77.2	101.4	130.2	164.4	205.0	252.6	308.7
16				63.3	83.5	106.9	133.9	164.8	200.3	240.5	286.6
18					88.4	111.2	136.9	165.6	197.8	233.5	273.5
20						113.1	137.4	164.2	193.7	225.8	261.2
22							138.2	163.6	191.3	221.0	253.3

1/ For trees 10" and larger d.b.h. to a variable top. (Individual tree volumes taken from a table developed for use by the Forest Survey in the Intermountain Region.)

2/ Mean diameter of trees selected by angle gauge.

3/ Height of tree of mean diameter determined as above.

Table 4.--Stand volume/total stand basal area for board feet Scribner rule[1]

Stand diameter (inches)[2]	Stand height[3]									
	50	60	70	80	90	100	110	120	130	140
8	15									
10		40	40							
12		68	70	73						
14			100	105	113					
16			130	132	138	147	158			
18				158	158	167	182	200		
20					172	183	198	216	235	
22						200	213	230	248	267
24								245	262	281

1/ Volume of trees 12" and larger d.b.h. to an 8" top. (Individual tree volumes taken from table 34, U.S.D.A. Tech. Bul. 630.)

2/ Mean diameter of trees selected by angle gauge.

3/ Height of tree of the mean diameter determined as above.

Table 5.--Board foot/basal area ratios of ponderosa pine trees by height in 16' logs. Scribner rule

Timber age	Logs per tree								Mean per log
	1	2	3	4	5	6	7	8	
Second growth[1]	37	75	110	152	195	240	285	335	39
Old growth[2]	60	102	150	212	270	330	385	440	53

1/ Top diameter 6" to 9". Most probable ratios taken from table 8 below.

2/ Top diameter 8" to 25". Most probable ratios taken from table 9 below.

Table 6.--Second-growth ponderosa pine cu.ft./B.A. ratios[1/]

D.b.h. (inches)	Total height (feet)													
	20	30	40	50	60	70	80	90	100	110	120	130	140	150
4	9.2	13.8	17.2	21.8	25.3									
6	8.7	11.7	14.8	18.4	21.4	24.5	28.1							
8		10.6	14.0	17.2	20.3	23.8	27.2	31.5	34.4					
10		10.6	14.1	17.4	21.1	22.9	28.4	32.1	36.7	40.4	44.0			
12			14.0	17.8	21.7	25.5	29.3	33.1	36.9	40.8	44.6			
14			14.0	17.8	21.5	26.2	29.9	33.7	37.4	41.2	44.9	48.6	52.4	
16			14.3	18.6	22.2	25.8	30.1	33.7	37.2	41.5	45.1	48.7	51.6	54.4
18			14.7	18.7	22.6	26.0	30.0	34.0	37.3	41.9	45.3	48.7	52.1	55.5
20			14.7	18.8	22.9	26.6	30.3	33.9	38.1	41.7	45.4	49.1	52.3	55.5
22				18.6	22.7	26.5	30.3	34.1	37.9	41.7	45.1	48.9	51.9	55.3
24				18.8	22.6	26.4	30.6	34.1	37.9	41.4	44.9	48.1	51.6	54.4
26				19.0	22.8	26.6	30.4	33.9	37.7	41.2	44.4	48.0	50.4	53.9
28					22.9	26.6	30.4	33.6	37.4	40.9	44.2	47.4	50.5	53.5
30					22.8	26.5	30.1	33.6	37.1	40.3	43.6	46.9	49.7	52.8
32					22.5	26.1	29.9	33.3	36.5	39.7	42.8	46.0	48.7	51.5
34					22.2	26.2	29.5	33.0	35.9	39.0	42.1	45.1	47.6	50.1
36						25.7	29.1	32.5	35.4	38.3	41.0	44.0	46.4	48.6
38						25.4	28.8	32.0	34.8	37.6	40.0	42.8	45.2	47.5
40						25.2	28.4	31.4	34.1	36.8	39.0	41.7	44.0	46.3
42							28.0	30.8	33.5	36.0	38.1	40.6	42.8	45.0
44							27.5	30.1	32.8	35.1	37.2	39.6	41.7	43.8
46								29.5	32.1	34.3	36.3	38.6	40.6	42.6
48								28.8	31.3	33.5	35.4	37.5	39.5	41.4
50								28.2	30.6	32.7	34.5	36.6	38.4	40.3

1/ Total volume inside bark including stump. Basis: table 32, U.S.D.A. Tech. Bul. 630.

Table 7.--Second-growth ponderosa pine, bd.ft. (Scribner)/B.A. ratios[1/]

D.b.h. (inches)	Total height (feet)											
	40	50	60	70	80	90	100	110	120	130	140	150
10	18	18	37	37	55	55	73	73	92			
12	26	51	64	76	102	127	140	153	178	191		
14	37	56	75	103	122	140	168	187	206	225	243	
16	43	72	86	115	129	150	172	193	215	244	258	287
18	51	74	96	119	136	164	192	209	232	260	283	306
20	55	78	101	124	147	170	202	220	243	266	293	316
22		80	102	129	155	178	205	227	254	280	307	337
24		83	105	134	159	185	210	236	264	290	318	347
26			111	138	163	187	214	244	271	295	322	350
28			112	138	164	192	220	248	273	297	322	346
30			114	141	165	196	222	249	273	295	320	340
32			114	143	170	197	222	247	270	292	313	333
34			117	144	173	197	222	244	267	287	308	327
36				147	174	195	221	242	262	281	301	320
38				148	174	193	218	239	258	277	294	313
40				149	172	191	215	234	253	271	289	307
42					170	189	211	230	248	266	284	301
44					167	187	206	225	243	260	277	293
46						183	203	221	238	255	271	285
48						179	198	217	233	249	265	279
50						176	194	212	228	243	259	272

1/ Volume to 8" top. Basis: table 34, U.S.D.A. Tech. Bul. 630.

Table 8.--Second-growth ponderosa pine (Site IV), bd.ft. (Scribner)/B.A. ratios[1]

D.b.h. (inches)	Number of 16' logs									
	1	2	3	4	5	6	7	8	9	10
8	57.3	143	229							
10	36.7	101	165							
12	31.8	76.4	134	185						
14	23.4	65.5	112	168	215					
16	17.9	60.9	104	158	204	258				
18	17.0	56.6	99	147	201	252	306			
20	13.8	52.7	99	144	195	245	296			
22	11.4	51.1	97	140	193	241	288	348		
24	11.1	50.9	95	140	191	237	286	342		
26	9.5	51.5	95	141	188	234	282	337	396	
28	9.3	51.4	93	140	187	234	281	334	388	
30	9.2	51.9	94	140	187	232	282	333	381	436
32		52.8	92	139	186	231	282	330	376	428
34			91	138	185	229	280	328	374	422
36			89	137	183	226	277	323	369	415
38			88	135	181	223	273	318	364	409
40			86	133	179	220	269	312	358	404
42			84	131	177	216	265	307	352	401

1/ 1.5' stump, 6"-9" top. Basis: table 35, U.S.D.A. Tech. Bul. 407.

Table 9.--Old-growth ponderosa pine tree volume (Scribner)/B.A. ratios

D.b.h. (inches)	Logs per tree								Top d.i.b.
	1	2	3	4	5	6	7	8	
12	64	115	153						7
14	56	103	140	206					8
16	57	100	143	186					8
18	62	108	142	187	226				9
20	69	124	156	193	243				10
22	80	136	174	208	250	288			11
24	83	146	191	223	258	293			11
26	87	152	203	233	266	298	342		12
28	89	159	210	243	271	308	343		12
30	92	163	220	255	283	314	346	383	13
32	93	163	224	265	293	326	352	385	14
34	94	167	232	273	303	333	363	387	14
36	96	168	238	283	312	344	373	396	15
38	96	169	242	286	322	354	382	405	17
40	96	171	245	292	330	362	389	412	20
42	97	171	248	296	336	371	397	426	25
44	98	175	248	299	341	379	407	436	28

Basis: RE-NRM
FOREST SURVEY
Ponderosa pine multiple volume table 1931 applicable to Region 1.
(Anderson-Ibenthal)
(Girard 1938)

Table 10.--Volume distribution in ponderosa pine trees[1/]

Log position in tree	Logs per tree						
	2	3	4	5	6	7	8
	Proportion[2/]						
Butt	0.62	0.47	0.38	0.32	0.28	0.25	0.23
2	.38	.34	.30	.27	.24	.22	.20
3		.19	.21	.20	.19	.19	.18
4			.11	.14	.15	.15	.15
5				.07	.09	.10	.11
6					.05	.06	.07
7						.03	.04
8							.02

1/ From C. A. Wellner and R. Hansen. Volume distribution in ponderosa pine trees. U.S. Forest Serv. North. Rocky Mtn. Expt. Sta. Res. Note 17, 1941.

2/ Proportion of gross merchantable volume (Scribner) by log position for ponderosa pine trees of indicated number of 16-foot logs per tree.

Table 11.--Explanation

Line 1. Volume/sq.ft. basal area ratios taken from table 5 (second-growth) or its equivalent.

Line 2. Ratio in line 1 multiplied by the proportions given in table 10.

Line 3. Represents a tally of the ratio of sound wood in each log of each tree tallied, recorded under their respective tree height, log position, and log grade. Thus, a perfectly sound log is recorded by the entry 1.00; a total cull, by 0.00; etc.

Line 4. Records the count of trees represented in each column. Note that the entry in the total column counts each tree only once, irrespective of its number of logs. Hence, the eight 3-log trees contribute only 8 to the total of 25 trees tallied.

Line 5. Equals the sums of data in line 3.

Line 6. Equals line 2 multiplied by line 4.

Line 7. Equals line 2 multiplied by line 5.

Line 8. Equals $100\left(1-\frac{\text{line 7}}{\text{line 6}}\right)$.

Line 9. Comprises the data in line 7 sorted by log grade.

Line 10. Equals the sums of data in line 9.

Line 11. Equals line 10 $\div$ total number of <u>trees</u> counted.

Table 11.--Calculation of quality and cull sample data

Line	Item																															Total
	Tree height (logs)	1			2						3									4												
1	Tree volume ratio	37			75						110									152												
	Log position	1			1			2			1			2			3			1			2			3			4			
2	Log volume ratio	37			46.5			28.5			51.7			37.4			20.9			57.8			45.6			31.9			16.7			
	Log grade	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
3	Ratio of sound wood in each log tallied			0.90 .75 1.00 .50 .00		1.00 .95	0.90 1.00 .80 1.00 .15			1.00 1.00 .90 .70 .20 .90 .75	1.00	0.90 1.00 .95	0.50 .30 .80 .60		1.00 1.00 .95 .80	0.60 .50 .80 .90			1.00 .80 1.00 1.00 .90 .95 1.00 .75	1.00 1.00	1.00 .95 .85			1.00 .95 .85	0.90 1.00			0.85 1.00 1.00 .90 1.00			1.00 1.00 .80 1.00 .90	
4	No. of trees tallied			5		2	5			7	1	3	4		4	4			8	2	3			3	2			5			5	25
5	Total ratios sound wood			3.15		1.95	3.85			5.45	1.00	2.85	2.20		3.75	2.80			7.40	2.00	2.80			2.80	1.90			4.75			4.70	
6	Gross volume extension			185.0		93.0	232.5			199.5	51.7	155.1	206.8		149.6	149.6			167.2	115.6	173.4			136.8	91.2			159.5			83.5	2350.0
7	Net volume extension			116.6		90.7	179.0			155.3	51.7	147.3	113.7		140.2	104.7			154.7	115.6	161.8			127.7	86.6			151.5			78.5	1975.6
8	Cull percentage			37.0		2.5	23.0			22.2	0.0	5.0	46.0		6.3	30.0			7.5	0.0	6.7			6.7	5.0			5.0			6.0	15.9

$$\text{Net volume/sq.ft. basal area} = \frac{\text{Net volume extension}}{\text{Total no. of trees}} = \frac{1975.6}{25} = 79.02$$

$$\text{Gross volume/sq.ft. basal area} = \frac{\text{Gross volume extension}}{\text{Total no. of trees}} = \frac{2350.0}{25} = 94.0$$

Line		Grade 1	Grade 2	Grade 3	All grades
9	Net volume extension in each grade by log position	51.7 115.6	90.7 147.3 140.2 161.8 127.7	116.6 179.0 155.3 113.7 104.7 154.7 86.6 151.5 78.5	
10	Total grade out-turn	167.3	667.7	1140.6	1975.6
11	Net volume in grade/sq.ft. basal area	6.69	26.71	45.62	79.02

Table 12.--Appropriate correction factors for basal area or volume per acre calculated from unadjusted angle-gauge tallies taken on a slope, where slope percent is measured at right angles to contour

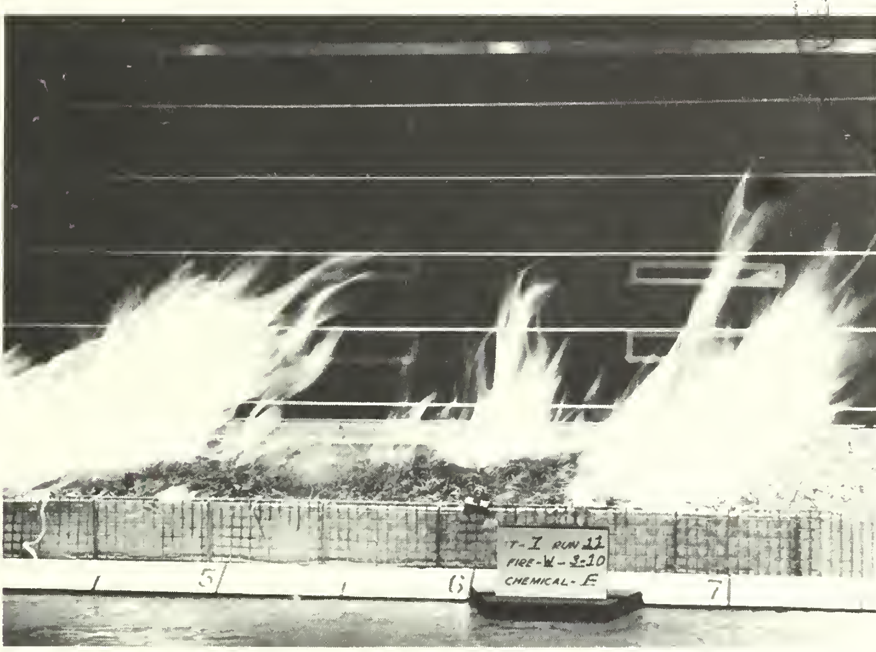
Limits of percent slope	Slope correction factor	Limits of percent slope	Slope correction factor	Limits of percent slope	Slope correction factor
10.0		55.8		80.7	
	1.01		1.15		1.29
17.4		57.8		82.3	
	1.02		1.16		1.30
22.5		59.8		83.9	
	1.03		1.17		1.31
26.7		61.7		85.4	
	1.04		1.18		1.32
30.4		63.6		86.9	
	1.05		1.19		1.33
33.6		65.4		88.4	
	1.06		1.20		1.34
36.6		67.2		89.9	
	1.07		1.21		1.35
39.5		69.0		91.4	
	1.08		1.22		1.36
42.1		70.8		92.9	
	1.09		1.23		1.37
44.6		72.5		94.3	
	1.10		1.24		1.38
47.0		74.2		95.8	
	1.11		1.25		1.39
49.3		75.8		97.2	
	1.12		1.26		1.40
51.5		77.5		98.7	
	1.13		1.27		1.41
53.7		79.1		100.1	
	1.14		1.28		1.42
55.8		80.7		101.5	

Correction factor for steeper slopes is:

$$\sqrt{1 + \left(\frac{\text{Slope percent}}{100}\right)^2}$$

Source: Grosenbaugh, L. R. Better diagnosis and prescription in southern forest management. U.S. Forest Serv. South. Forest Expt. Sta. Occas. Paper 145, 1955.

EVALUATION OF FOREST FIRE RETARDANTS---
A TEST OF CHEMICALS ON LABORATORY FIRES



BY

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2325 Vista Del Mar
Ventura, California
Ammonium poly-pectate

U.S. Borax and Chemical Corporation
630 Shatto Place
Los Angeles 5, California
Sodium Calcium Borate
(Firebrake and Borate XPI-113)

Arizona Agrichemical Corporation
734 East S.P. Drive
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Fire-Trol

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Shell Building
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and

Monsanto Chemical Company
Inorganic Chemicals Division
Research Department
St. Louis 66, Missouri
Diammonium phosphate

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EVALUATION OF FOREST FIRE RETARDANTS--

A TEST OF CHEMICALS ON LABORATORY FIRES

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PURPOSE

The purpose of the research program reported here is to evaluate the ability of selected chemical fire retardants to slow down or stop the advance of a fire in forest fuels. Many factors enter into final selection of chemical fire retardants including effectiveness in various fuel and fire situations; aerial application characteristics; problems of corrosion, abrasion, and toxicity; cost; and ease of mixing, pumping, and storing. The tests covered in this report are concerned only with the relative effectiveness of seven different chemicals in slowing or stopping fire advance when each chemical is applied on a forest fuel in the same amount and manner. The fuel bed itself does not duplicate any specific natural fuel. It is merely an easily reproducible medium upon which various chemicals can be applied and the relative rates of fire spread compared.

THE PROGRAM IN BRIEF

Facilities of the Northern Forest Fire Laboratory were used in conducting the first controlled atmosphere tests of the relative fire retardant effectiveness of several chemicals. Seven of the chemicals that had been proposed to the U.S. Forest Service as being effective fire retardants suitable for aerial delivery had already passed certain previous laboratory and field tests and were considered appropriate for further testing under uniform controlled conditions. The chemicals tested were: algin-diammonium phosphate (algin-DAP), algin-calcium chloride (algin-gel), bentonite, sodium calcium borate (Firebrake), sodium calcium borate (Borate XPI-113--a new, experimental formula), ammonium sulphate-attapulgite clay (Fire-Trol), and pectin-diammonium phosphate (pectin-DAP).1/

Some chemicals were thought to be more effective within a shorter period of time after application than others, but others were considered to be more effective after longer intervals. The speed and duration of wind is known to affect rate of fire spread and perhaps also to affect the relative retardant abilities of the various chemicals. Perhaps a change of wind velocity might transpose the relative effectiveness of two or more chemicals. To test these parameters, the following variables were established:

1/ In reporting experimental work it is sometimes desirable to mention trade or brand names in the interest of brevity and clarity. Such mention does not imply endorsement of the products mentioned, nor does it imply nonendorsement of unnamed products.

7 chemicals
2 periods of drying after chemical application--1 hour and 3 hours
2 wind conditions: 0 m.p.h. and 3 m.p.h.
1 repetition of each of the above parameters
56 fires plus reruns, or possibly 75 fires in all

The three measurements of retarding ability of each chemical and the methods of measurement were:

1. Rate of fire spread, measured visually in the combustion laboratory and by thermocouples in the wind tunnel.

2. Radiation, measured by a radiometer in both the combustion laboratory and wind tunnel.

3. Convection column temperature, measured by thermocouples in both the combustion laboratory and wind tunnel.

Analysis of the data recorded from test fires was made on the basis of percentage reduction of the rate of spread, radiation, and convection column temperatures from the magnitude registered on similar untreated fuel-bed sections. The results are shown in figures 14, 15, and 16, and in table 2.

DEVELOPMENT OF CHEMICAL FIRE RETARDANTS

Chemical fire retardants and their systematic investigation are not new to foresters. The U.S. Forest Service began testing chemical additives for forest fire control in 1931 (Barrett, 1931). A paper titled "Chemical Methoc of Combating Forest Fires" (Serebrennikov, 1934) reported on Russian studies in forest fire control during 1932 and 1933. Many of these early studies showed a very decided advantage for chemicals over plain water. For example, in experiments conducted in northern California 10-percent solutions of mono-ammonium phosphate extinguished from 50 to 80 percent more fire than an equal quantity of plain water (Truax, 1939). Experiments in Montana evaluated the possibility of bombing forest fires with water and chemicals (Barrows and Keilman, 1947).

Despite these apparent successes, chemicals were little used for forest fire control until 1955, when several factors combined to start the air tanke program. Chief among these factors were the interest of a group of northern California pilots skilled in agricultural aviation, the availability of surplus military aircraft with the power and maneuverability needed to fly in mountainous terrain, the development of sodium calcium borate, and the concep of applying the chemical as a retardant rather than as a suppressant.[2] The

---

2/ A retardant is used to treat the fuels at or ahead of the flame fro so that the combustion process is modified when fire reaches the treated fue while a suppressant is used to cool or extinguish the flaming or glowing phases of combustion by direct application to the burning fuel (Wilson, 1960) retardant concept allowed the pilot to fly outside of the smoke and flame to apply the chemical to unburned vegetation just ahead of the fire.

In 1961, 6 years after the start of the air tanker program, almost 6 million gallons of retardant--mostly Firebrake and bentonite--were cascaded on forest fires in national forests alone.

Many tank trucks are now equipped to use fire-fighting chemicals, and fire agencies are planning a large investment in additional similar equipment (Davis, Dibble, and Phillips, 1961). Both bentonite and Firebrake have proved to be useful as fire retardants. They have constituted by far the largest percentage of retardant material used. However, both materials have serious limitations: bentonite depends almost entirely on its water-retaining ability for effectiveness; Firebrake is effective much longer after application, but is toxic to vegetation and is relatively expensive. As a result, most air drops, particularly of bentonite, are being made as close as possible to the fire line rather than at predetermined locations that might give a tactical advantage.

FIRE RETARDANT EVALUATION SYSTEM

The U.S. Forest Service and several cooperating forest fire control agencies in the United States have established a standard system for evaluation and development of fire-fighting chemicals. This system consists of the following eight phases:

1. Performance requirements.--Describes the characteristics desired in fire retardants and fire suppressants and indicates to industrial producers the general types of chemicals needed. These specifications are prepared jointly by fire research groups and fire control agencies.

2. Initial screening of chemicals.--Normally performed by the chemical companies on chemicals which appear to meet the general requirements of phase 1. Some screening of other chemicals is done by fire research groups.

3. Laboratory tests of chemicals.--Determines which chemicals offer promise for further research and development. Tests will be similar to those outlined by Dibble, Richards, and Steck (1961). Experience to date shows that about 95 percent of the proposed chemicals are eliminated by this step.

4. Laboratory fire tests.--Evaluates the performance of chemicals on fires in forest fuels under standard conditions of fuel moisture, temperature, relative humidity, and wind speed. Chemical performance is tested at the Northern Forest Fire Laboratory, using the combustion laboratory, fuels lab, and wind tunnels. (This phase of retardant testing is reported in detail in this paper.)

5. Field tests.--Evaluates drop patterns, pumping and mixing requirements, application requirements in various fuel and vegetative types, and other operational problems. Tests are conducted jointly by the fire agencies and fire research groups using standardized procedures.

6. Operational tests.--Fire control personnel, pilots, and airport managers evaluate the performance of the mixing, handling, and effectiveness of the retardant on wild fires. Standard evaluation forms are used.

7. Engineering.--This phase deals with the design, development, testing, and evaluation of equipment required in handling, mixing, pumping, storage, and application of chemicals. Equipment-development groups study these problems in close cooperation with various equipment manufacturers. Fire research groups assist in providing required data on chemicals and their performance as fire retardants and suppressants.

8. Application guides.--The final phase consists of preparation of guides for storing, mixing, pumping, and application of various approved chemicals. These guides include information on when, where, and how to apply chemicals for both fire prevention and fire suppression. The guides are prepared jointly by fire research groups and the fire control agencies.

CHEMICALS

Recent Tests of Fire Retardants

Within the past 2 years the Pacific Southwest Forest and Range Experiment Station has screened more than 70 proposed fire-retardant chemicals and combinations of chemicals in accordance with phases 2 and 3 of the evaluation system shown above.

Several materials showing the most promise were field tested under phase 5 conditions before the standardized procedures were adopted. These tests included mixing and pumping trials by the Arcadia Equipment Development Center, and air drops and fire tests by the California Air Attack Coordinating Committee (CALAIRCO).[3/]

3/ The California Air Attack Coordinating Committee represents the following five agencies: California Division of Forestry; Los Angeles County Fire Department; and Pacific Southwest Forest and Range Experiment Station, Region 5, and Arcadia Equipment Development Center of the U.S. Forest Service.

Firebrake and bentonite were also tested so that comparisons could be made between them and the new chemicals. The five new chemicals are briefly described below:

1. Algin-gel.--Algin-calcium chloride gel is produced by adding a small quantity of calcium chloride solution to water thickened with sodium alginate--a viscosity agent manufactured from the giant kelp.

   Addition of the calcium chloride immediately forms a thick, water-holding gel that has been applied with good results from ground and air at several locations in the West. The gel initially holds large quantities of water but slowly dries to a tough, impervious film. Air drop tests of the gel show that as much as three times more material may reach the vegetation than from a similar drop of bentonite or the borates. An additional advantage is that very little material, other than water, is required; consequently, algin-gel requires little warehousing or handling and the gel is easily mixed by portable facilities. The viscosity and gel characteristics depend on the mix ratio of the algin and calcium chloride. The calcium chloride solution has been combined with algin water in several ways. Most commonly, the two solutions are pumped from separate tanks through a metering arrangement into a mixing chamber in the nozzle of the aircraft-loading device.

   Algin-gel costs two or three times as much as bentonite, but at about 6 cents per gallon is still comparatively inexpensive. It is noncorrosive and nontoxic. The solution can spoil by bacterial or enzymatic action if stored for a few summer days without a preservative.

2. The diammonium phosphates.--In previous tests, diammonium phosphate (DAP) has consistently ranked near the top of most lists of forest fire retardants. Although used successfully in forest fire control in several parts of the United States, it has not proved entirely effective in plain water solutions under severe burning conditions and in heavy fuels in the West. Probably the chief reason is that the larger fuel surfaces retain insufficient chemical. However, recent tests with thickened DAP have been very promising (U.S. Forest Service, 1960).

   a. Algin-diammonium phosphate.--DAP solutions, thickened with sodium alginate to about the consistency of motor oil, cling to vegetation in a thick layer. The chemicals can be mixed rapidly in batch-type mixing equipment. DAP is almost noncorrosive to mild steel, and corrosion of aluminum can be effectively controlled by an inhibitor. However, DAP corrodes copper, brass, and bronze under laboratory conditions if parts are alternately exposed to the DAP solution and to oxygen. The cost of algin-DAP should be about 20 cents per gallon.

b. Pectin-diammonium phosphate.--Ammonium pectate is a viscosity agent or thickener produced by the citrus industry. Although it forms a viscous solution with water, it quickly progresses to the consistency of mayonnaise when combined with diammonium phosphate. The resulting gel clings to vegetation; initially, it retains a large quantity of water, but later dries to a fire-retardant coating. In addition, pectin-DAP intumesces, or swells up, when heated and produces a valuable insulating layer.

Powdered pectin and DAP can be preblended and bagged together. The blend mixes readily in a batch-type mixer equipped with high-shear impellers. The cost of pectin-DAP should be 12 to 15 cents per gallon. Corrosive properties of pectin-DAP are similar to those of algin-DAP.

3. Fire-Trol.--This proprietary chemical is formulated and blended by the manufacturers. It is primarily a combination of ammonium sulphate and attapulgite clay. Ammonium sulphate, like DAP, is widely used as a fertilizer and ranks high as a fire retardant. Attapulgite clay is similar to bentonite in that it forms a stable gel-like slurry with water. Unlike bentonite, it is salt-tolerant and is compatible with such fire-retardant salt as ammonium sulphate. This substance initially retains a large quantity of water, and the 15-percent ammonium sulphate content remains an effective fire retardant when dry.

High-shear impellers are required to mix this material. Without an inhibitor, Fire-Trol corrodes copper, brass, and mild steel. The cost should be 12 to 15 cents per gallon.

4. Borate XPI-113.--This newly developed retardant is mixed at the rate of 1.5 pounds per gallon, compared to 4 pounds per gallon for Firebrake. The B_2O_3 content is about 10 to 12 percent, compared to about 30 percent in Firebrake. The two advantages (less bulk and greatly reduced toxicity) minimize two of the primary objections to the use of Firebrake. Borate XPI-113 mixes readily in equipment commonly used for Firebrake or bentonite. It is nontoxic to animals and noncorrosive to most metals used in fire-fighting equipment. Its cost should be 8 to 10 cents per gallon.

Letter Symbols for Chemical Names

Each chemical was assigned a code letter symbol to represent it during e burning tests at the Northern Forest Fire Laboratory. Two reasons prompted e assigning of letter symbols: (1) simplicity of identification and reference, d (2) an attempt to eliminate bias. The letters were drawn from a box in ndom fashion by the man in charge of mixing the chemicals. No identifying mes were divulged until preliminary analysis of the data was completed. The tter symbols were:

A - Algin-gel
B - Bentonite
C - Pectin-DAP
D - Fire-Trol
E - Borate XPI-113
F - Firebrake
G - Algin-DAP

Mixing Chemicals

All chemicals were mixed by a uniform procedure. Three gallons of each tardant solution were prepared at the beginning of the program to eliminate ed for remixing before the burning program was completed. All proportions re in accord with manufacturers' recommendations. A special high-shear peller, developed by the Pacific Southwest Station, was driven by a heavy ty drill press at 2,000 r.p.m.

The proportions of chemicals to water were as follows (11,356.2 grams water equals 3 gallons):

Table 1.--Chemical Mixing Data

Code	Common name	Material: Water	Material: Chemical		Ratio to: Water	Ratio to: Total Wt.	Viscosity[1]
		Grams	Grams		Percent	Percent	c.p.s.
A	Algin-gel	10,800	96	Keltex (FF1000	0.89		4,230
			6	$CaCl_2$[2]	.06	0.94	
B	Bentonite	11,356.2	952.7	bentonite	8.39	7.74	4,600
C	Pectin-DAP	11,356.2	715.4	pectate (spp)	6.30		470
			79.5	versene	.70		
			1,703.4	diammonium phosphate	15.00	18.03	
D	Fire-Trol	11,356.2	3,810.1	Fire-Trol	33.55	25.12	490
E	Borate XPI-113	11,356.2	2,041.2	Borate XPI-113	17.97	15.24	923
F	Firebrake	11,356.2	5,443.1	Firebrake	48.93	32.40	450
G	Algin-DAP	11,356.2	170.3	Keltex (FF1000)	1.50		290
			1,703.4	diammonium phosphate[3]	15.00	14.16	

1/ Data obtained with Brookfield viscometer, spindle 4, 60 r.p.m. and liquid temperature 74.5° F.
2/ 6 grams $CaCl_2$ is first added to 1,200 grams H_2O; then this mixture is added to the 9,600 grams of H_2O-Keltex solution.
3/ Added to Keltex solution.

Selection of Chemical for Each Fire

Selection of the chemical for each of the six fires to be burned daily was done on a random scheme. No repetition of any chemical and drying time was made on the same day.

Application of Chemical to Fuel Bed

Amount

Two criteria determined the amount of chemical to be applied to each fuel bed:

1. The amount should be sufficient to slow fires down, but not to the point where rates of spread become too erratic for reproducible measurements.

2. The amount should conform somewhat to the actual quantity measured on the ground from aerial drops.

An application rate of 2 gallons per 100 square feet satisfied both requirements (Davis, 1960; Storey, Wendel , and Altobellis, 1959). An equivalent amount for the area to be covered in the present experiments is 473 cc. One-third, or 158 cc., was applied to each of the three layers of the fuel bed.

Method

All chemicals were applied in the same manner. A Brown "Speedy" model paint spray gun, with an 0.072-inch diameter round-orifice nozzle, was used with 17 p.s.i. air pressure at the service outlet.

A large syringe was used to transfer 158 cc. of the retardant to the spray gun. The retardant was sprayed uniformly over a 1-inch thick layer of ponderosa pine needles. (Refer to FUELS section below for description of fuel bed.) The spray gun was held approximately 18 inches above the needles and a pattern was followed to assure even distribution of retardant on the needles. The needles in the first 4 feet of the fuel bed were shielded to prevent any mist from settling on them. Second and third layers of needles were added, and each layer was sprayed with 158 cc. of retardant. This system assured that needles on the bottom and middle of the fuel bed were treated similarly to those on top.

The method of application just described may or may not have given each chemical equal advantage in respect to the manner in which it settled on the fuel particles. Two chemicals, bentonite and algin-gel, had much higher viscosity than the other five (see table 1). Application of bentonite was relatively easy since its thixotropic nature permitted its momentary thinnin during ejection from the spray gun. However, since algin-gel is not as thix- tropic, some difficulty of application was experienced. Much has yet to be learned about the effect of application method on the possible change in characteristics of a chemical, both when applied on a small scale for xperimental purposes and when applied from aircraft or pumpers, on an perational basis. Without this specific knowledge, the method developed nd described here appeared to give as uniform an application as is presntly possible.

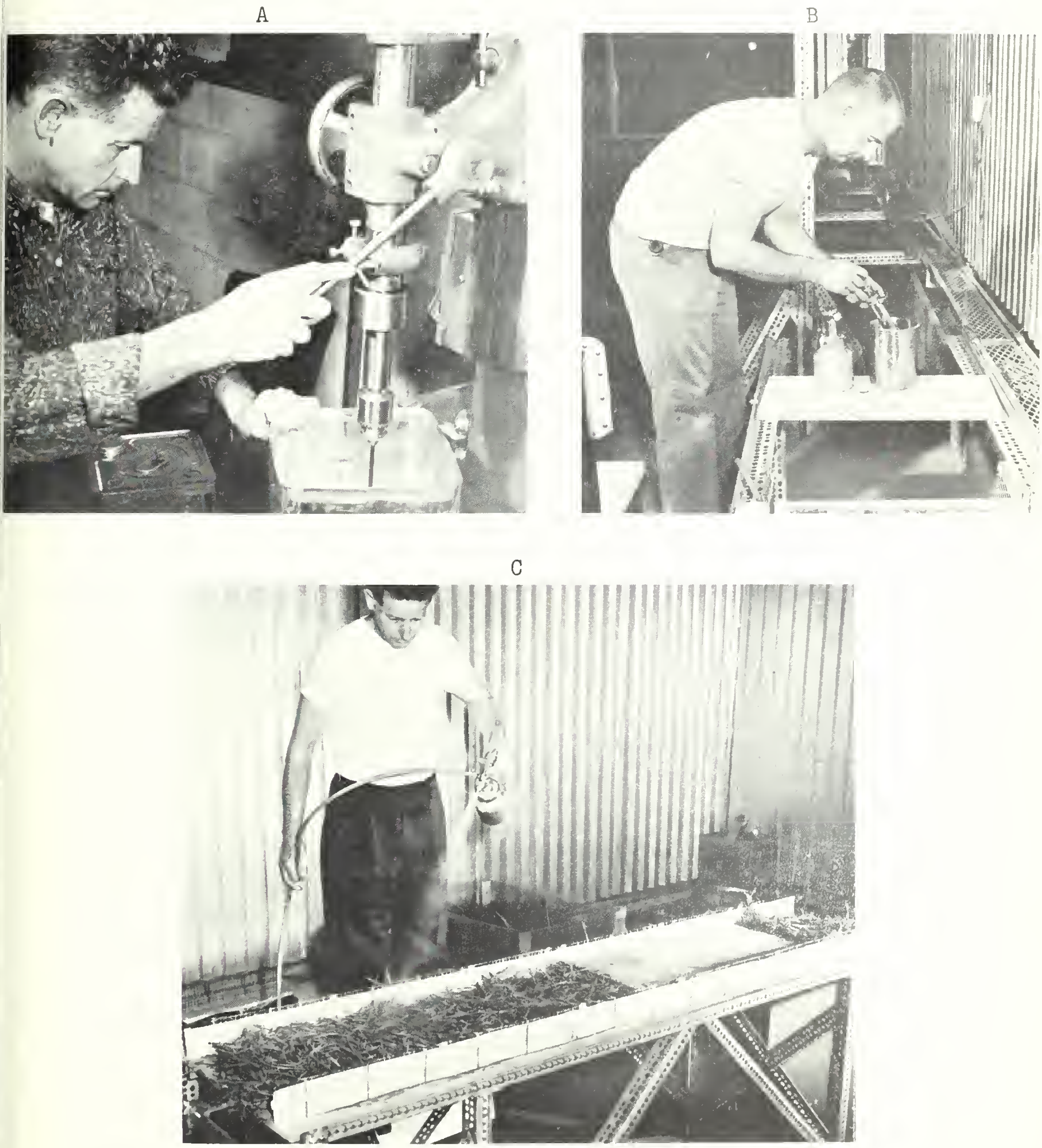

Figure 1.--Chemicals: A., Mixing; B, Filling syringe; C, Spraying a fuel bed.

FUELS

The ideal fuel for use in evaluating fire retardants would represent the major fuel types that carry forest fires: grass, brush, leaves, and branch wood. This ideal fuel would receive chemicals in a manner similar to the way that natural fuels would receive aircraft-dropped chemicals; and, finally, this fuel should be one that could be exactly duplicated for many tests under uniform conditions.

No completely satisfactory fuel complex for use in studies of fire retardants has yet been developed. However, the fire physics research project at the Northern Forest Fire Laboratory has shown that a fuel bed of ponderosa pine needles can yield data of the type needed for experiments with fire retardants. This type of fuel bed was selected because it can be reproduced with reasonable accuracy, the needles are hygroscopic, and they are readily available.

Collecting and Mixing

Six hundred pounds of ponderosa pine needles were thoroughly mixed and cleaned of foreign material. After the cleaning and mixing, large wire baskets were filled with 10 pounds (dry weight) of needles.

Conditioning

The atmospheric conditions selected for the combustion laboratory and wind tunnel during the days of burning were temperatures of 90° to 95° F., and relative humidity of 15 to 20 percent. Moisture content of the fuels was brought to equilibrium with these atmospheric conditions. The fuel conditioning was accomplished in three steps:

1. The fuel was placed on the storage racks for several days; there its moisture content decreased to 1 to 2 percent above the equilibrium moisture content desired.

2. Enough fuel for 1 day's operation was placed in a forced-air drying oven at 110°-120° F. for 1 to 3 hours.

3. This fuel was then transferred immediately to one of two conditioning cabinets and held for 2 days at 95° to 100° F., and 12 to 14 percent relative humidity.[4/]

Moisture content of the fuels in the storage rack, oven, and conditioning cabinets was sampled periodically for control purposes. At the time each fuel bed was built up, a separate small basket was filled with needles and placed with the fuel bed during its final conditioning period. This

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4/ The conditioning cabinets operate on the saturated salt-solution principle; lithium chloride salt was used to hold the relative humidity to this level.

sample was taken from the fuel bed conditioning location within 5 minutes of ignition time.

The atmospheric conditions were nearly the same in the combustion laboratory as in the conditioning cabinets. Thus, there were no appreciable differences in the fuel moisture content between the two, as determined by the xylene distillation method. At the time of ignition, moisture content of the untreated sections of the fuel beds averaged 4.3 percent, plus or minus 0.5 percent.

Fuel Beds

Trays

The filled burning tray was designed to approximate as closely as possible a narrow section of an infinite fuel bed. Prior experiments showed that a bed width of 18 inches and a fuel depth of 3 inches would satisfy the major requirements. A length of 8 feet is necessary. The first 4 feet is needed to build up rate of spread and radiation from fire in untreated fuel to a steady state. The other 4 feet is used for measuring the rate of spread, radiant flux, and convection column temperatures of the chemically treated fuels. Sides of the trays used in the combustion laboratory (0 m.p.h. wind) were lined with strips of paper to prevent indrafts from the sides and more closely simulate an infinitely wide fuel bed. The paper was treated with monoammonium phosphate to prevent it from burning but to allow it to char and crumble after the fire passed. The sides of the trays used in the wind tunnel (3 m.p.h. wind) had permanent strips of asbestos sheets 3 inches high to prevent indrafts from the sides.

Fuel Bed Buildup

Six pounds of carefully arranged fuel is required for a tray 3 by 18 inches by 8 feet. The fuel was transferred from the conditioning cabinet directly into the combustion lab, which was circulating air at the predetermined temperature and humidity. Enough fuel for one tray was weighed and set aside in six 1-pound increments. Each pound was spread uniformly over a 4-foot length 1 inch thick by 18 inches wide. After the first layer was spread, one-third of the retardant was sprayed over the last 4 feet of the bed. Then the other two 1-inch layers were successively spread and sprayed. This fuel bed preparation and retardant application complied with the objectives of the test; that is, applying a known amount of retardant over a specified area of fuel and coating each piece of fuel.

After application was completed, stray needles sticking up above the general fuel bed level were cut off with scissors. Strings were then tied across the tray at 1-foot, 4-foot, and 7-foot marks and along the center line to facilitate accurate measurements during burning. The strings had previously been dipped in a monoammonium phosphate solution and dried to prevent them from carrying fire faster than the needles.

Identification

A card system was used to maintain control of the fuel as it moved through the various processes. Each fire, as represented by a burning tray, was identified as follows, using a 3-unit system:

1. Location of experiment. (C = Combustion lab; W = Wind tunnel)
2. Drying period. (1 = 1 hour; 3 = 3 hours)
3. Sequence number of the fire, either in the combustion lab or in the wind tunnel series. (3 = third fire; 11 = eleventh fire)

Examples: C-1-10 = Combustion lab, 1-hour drying time, tenth fire.
W-3- 7 = Wind tunnel, 3-hour drying time, seventh fire.

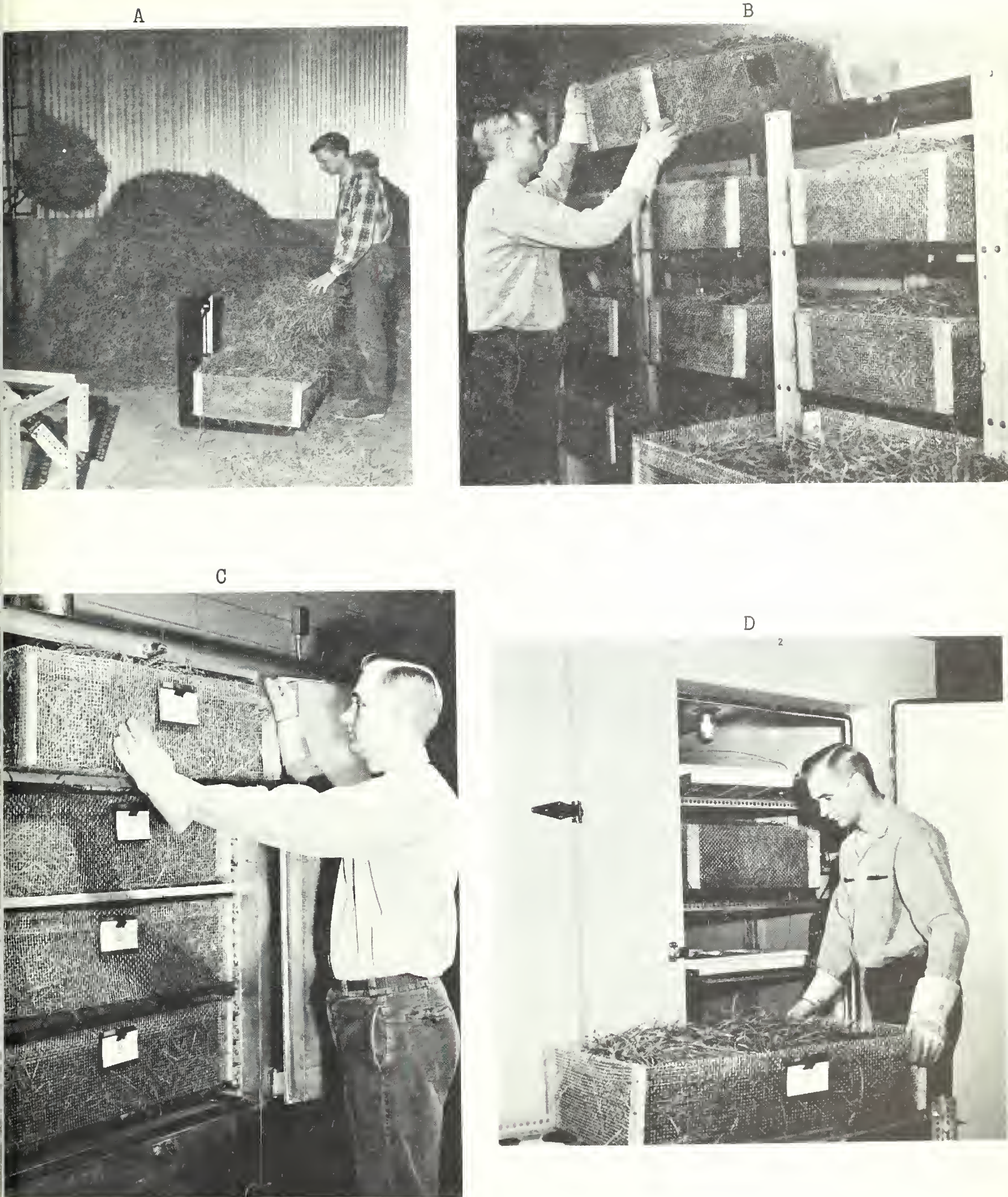


Figure 2.--Fuels: A, Mixing and weighing needles; B, Fuel storage rack; C, Drying oven; D, Conditioning cabinet.

Figure 3.--Fuels: A, Measuring out 1-pound increments; B, Building up a fuel bed; C, Hoisting tray into wind tunnel throat; D, Photographing burned fuel bed.

INSTRUMENTATION

The method of instrumentation was essentially the same in both the combustion laboratory and the wind tunnel. The placement and use of the instrumentation was designed to provide comparisions between untreated and treated fuels. Fire progress in the combustion laboratory was slow enough that rate of spread could be measured visually with sufficient accuracy. In the wind tunnel, however, rate of spread was so rapid that it had to be measured by thermocouples and oscillographs. Following is a summary of the instrumentation used in both burning areas (see also fig. 4):

Combustion Laboratory Instrumentation

Parameter	Sensor	Readout
Pressure drop across orifice	Pressure taps	Δ P controller
Convection column temperature	5 thermocouples in parallel	Recorder
Radiant energy	1 radiometer	Recorder
Dew point	Dew cell	Recorder
Air temperature	Thermistor	Recorder
Rate of spread	Stop watch	Clip board

Wind Tunnel Instrumentation

Rate of spread in untreated fuel	6 thermocouples	Oscillograph
Rate of spread in retardant-treated fuel	6 thermocouples	Oscillograph
Convection column temperature	5 thermocouples in parallel	Recorder
Radiant energy	1 radiometer	Recorder
Air velocity	Pitot static probe	Transducer and recorder
Dew point	Dew cell	Recorder
Air temperature	Thermistor	Recorder

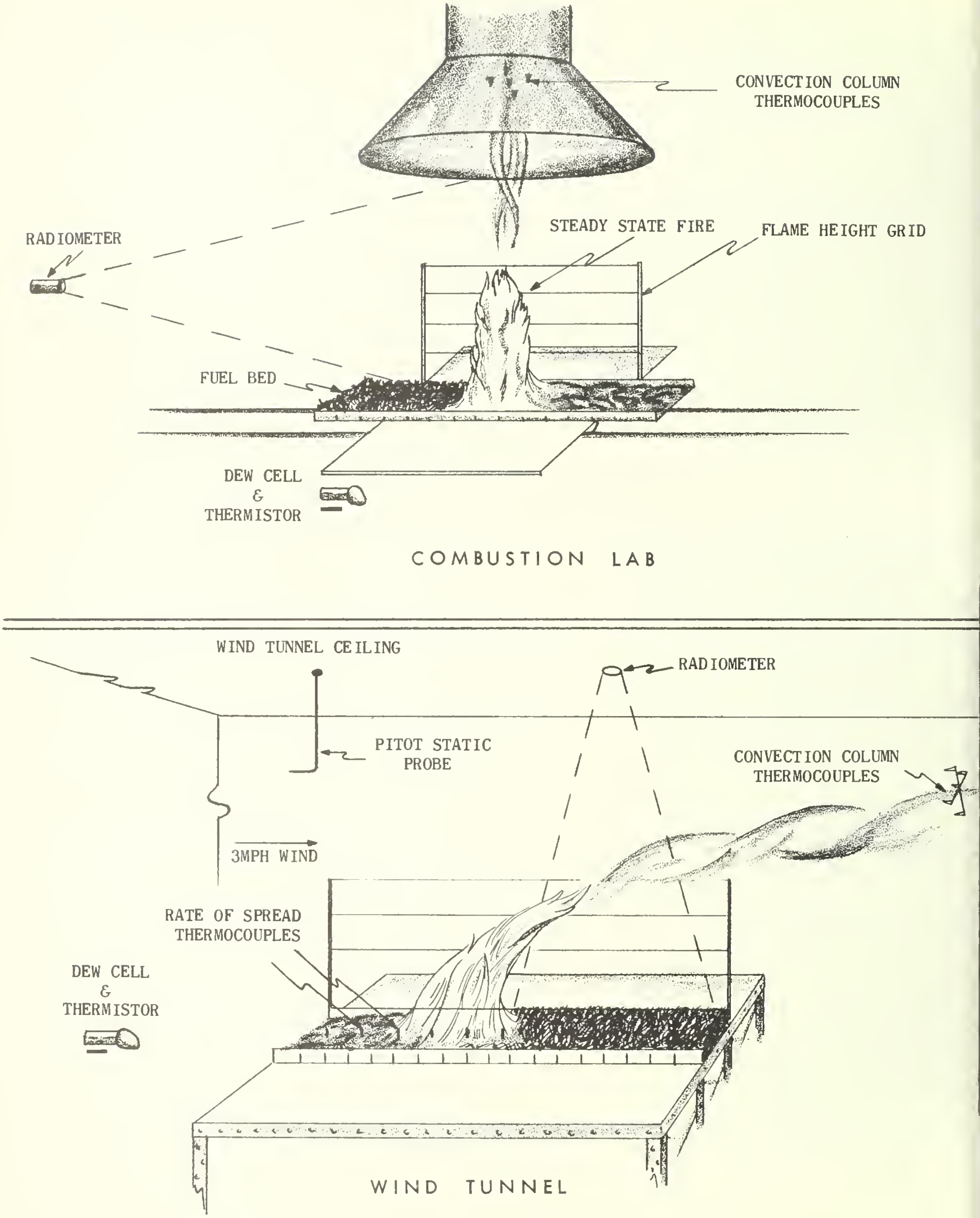


Figure 4.--Scheme of combustion lab and wind tunnel instrumentation.

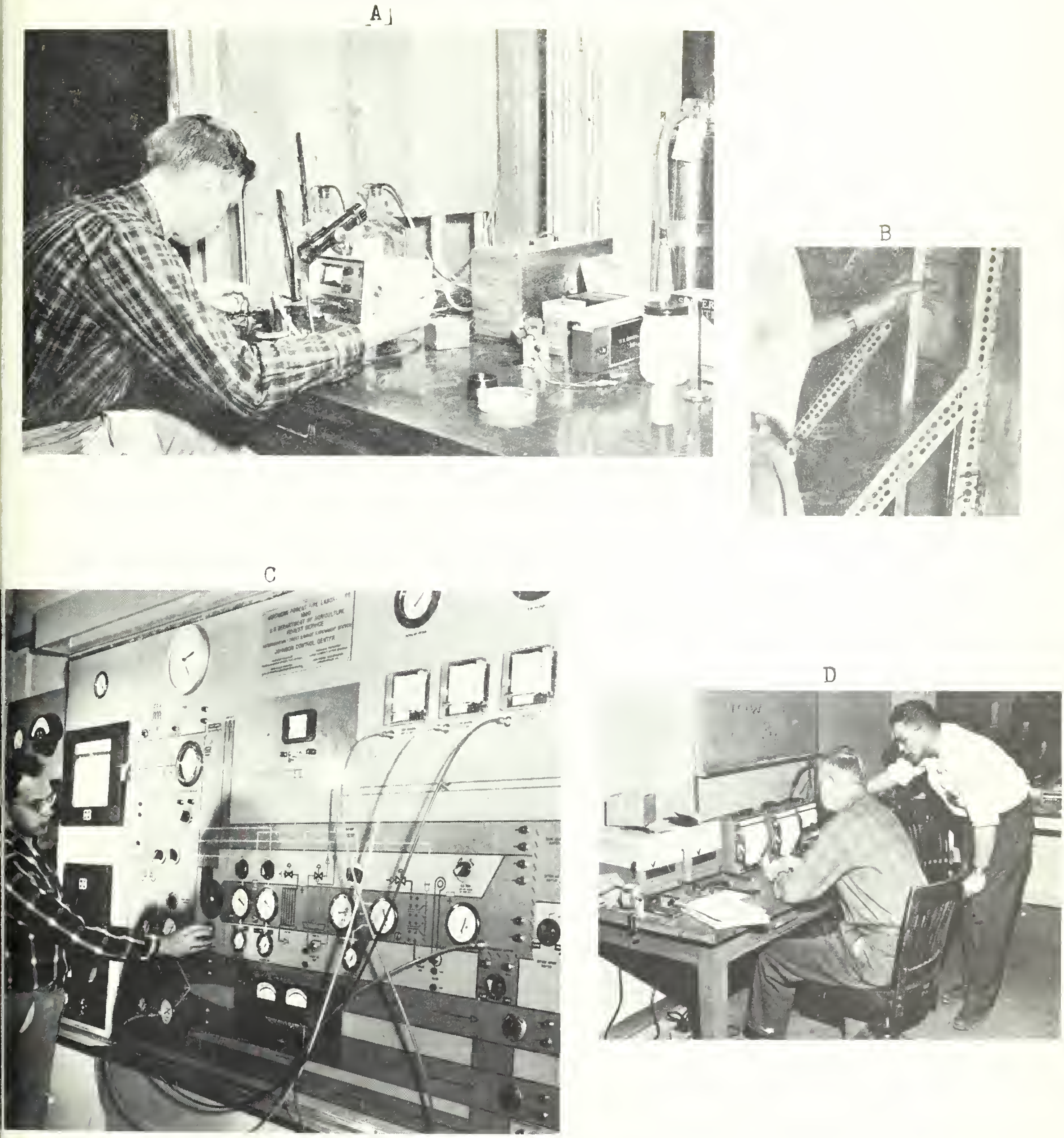


Figure 5.--Instrumentation: A, Calibration of wind tunnel air velocity; B, Installing thermocouples into burning tray in wind tunnel; C, Operating control panel; D, Monitoring recorders.

BURNING PROCEDURES

A sequence of burning was established that was compatible with several factors. Fuel bed buildup began by midmorning when proper atmospheric conditions were established in the combustion laboratory. Six fuel beds were burned each day, three with 1-hour drying times, and three with 3-hour drying times. Adequate time was allotted between fires to permit burning and removal of one tray, and placing and instrumenting the next. Adhering to the daily operation schedule shown in figure 6 permitted six fires to be burned each day.

Combustion Laboratory

Near the end of the drying period the fuel bed was transferred to a movable burning table. Five minutes before ignition, the fuel sample was removed to determine its moisture content, and all personnel not on the burning crew left the room. Upon signal from the control panel operator at ignition time, the fuel bed was ignited across its entire width by means of an 18-inch long alcohol tray, and simultaneously the rate-of-spread observer started his stop watch. The front of the fire was timed as it reached each one-half foot increment. As the fire advanced, the table operator moved the fuel bed so as to keep the flame centered under the exhaust hood and thereby maintain a constant distance from the radiometer. The elapsed-time observer timed the fastest rate of spread between the 1- and 4-foot marks and between the 4- and 7-foot marks. Flame height at the 5- and 7-foot marks was recorded by photographs of 1-second exposure time. The exhaust stack air velocity was held constant during the burn. An oral description of the fire was recorded on tape. After the fire, an overhead photograph recorded the fuel bed residue.

Wind Tunnel

Procedures in the wind tunnel were essentially the same as those in the combustion laboratory except that the fuel bed remained stationary. The increment rate of spread was measured by thermocouples, equally spaced in the fuel bed, rather than by a stop watch. The thermocouples were read out on two light-beam oscillographs. The wind speed was maintained as closely as possible to 3 m.p.h.

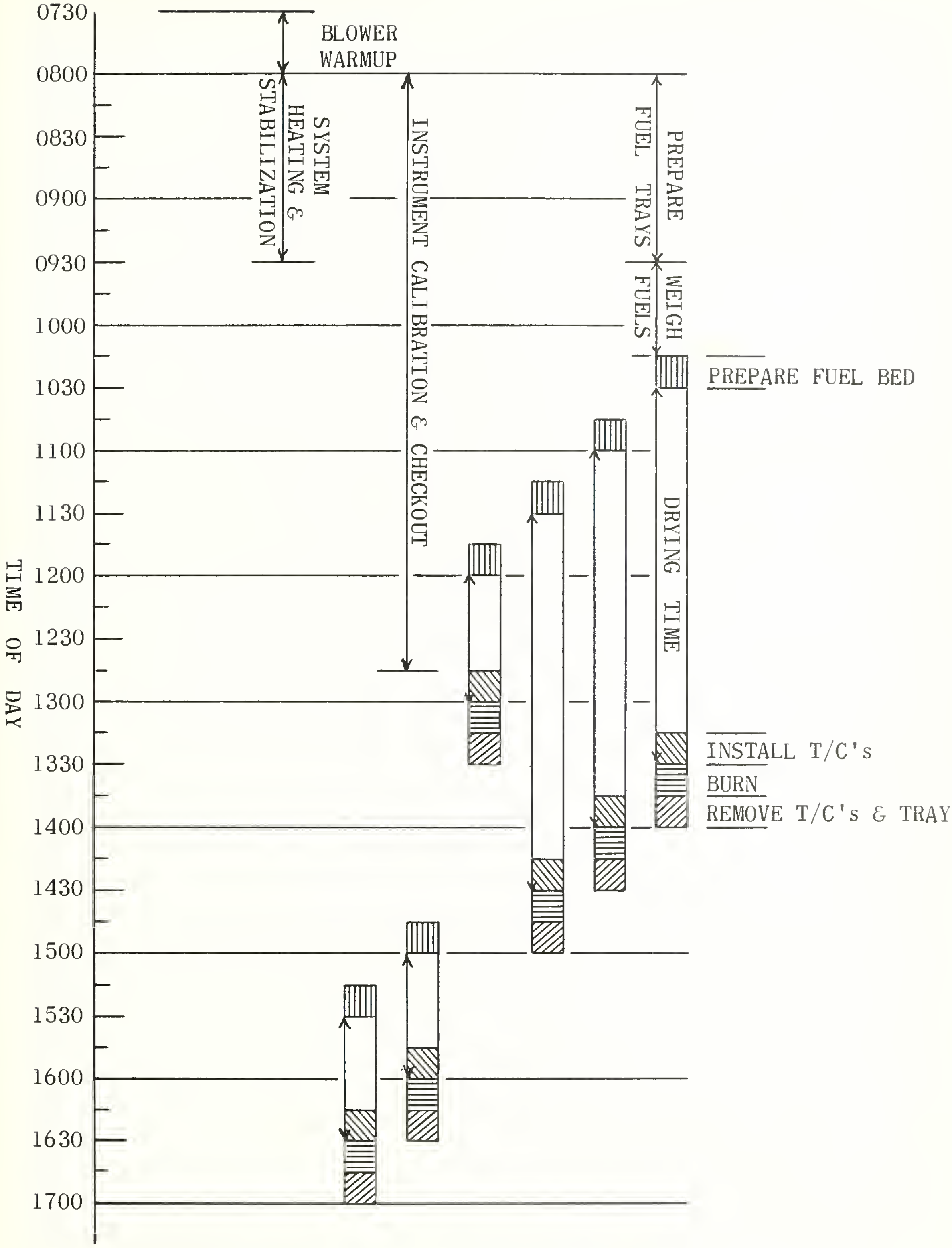
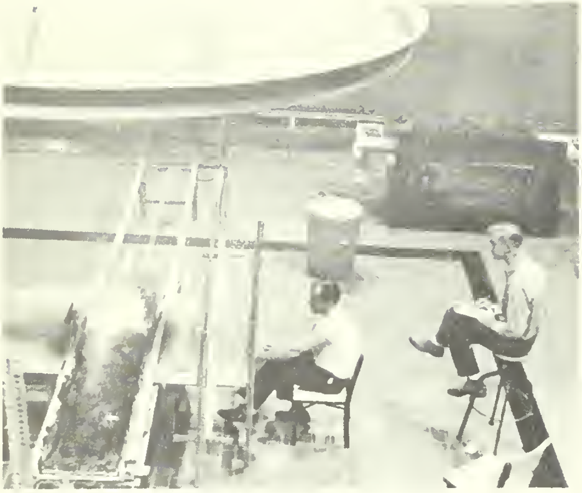


Figure 6.--Daily operating schedule.

A



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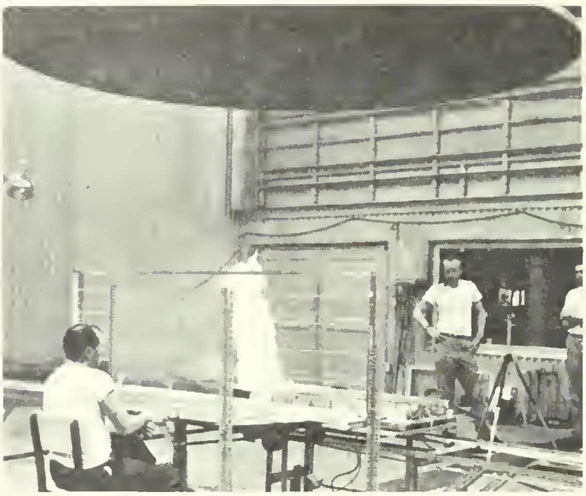


C

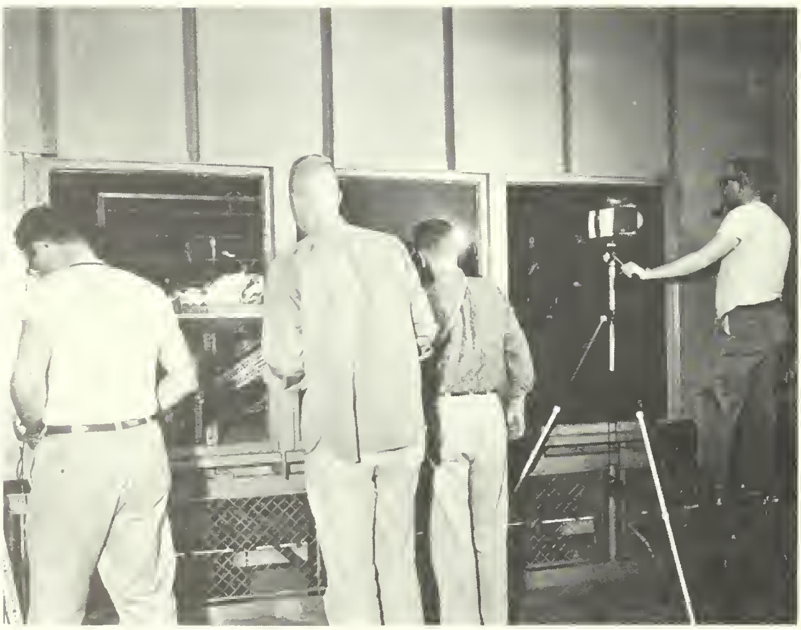


Figure 7.--Burning retardant test fires. A and B, Recording crew observing combustion laboratory fire; C, Recording crew observing wind tunnel fire.

AMBIENT CONDITIONS

Combustion research facilities at the Northern Forest Fire Laboratory :an hold ambient conditions of air temperature, relative humidity, and wind ;peed within prescribed limits.

Limits imposed on the air temperature were 90°-95° F. The planned .imits on relative humidity were 15 to 20 percent; however, the conditioning :abinets maintained relative humidity closer to 14 percent. Therefore, the .ower limit on the relative humidity in the burning environment was reduced :o 14 percent. The established wind speed of 3 m.p.h. at the fuel bed, or 'ground level," corresponds to a measured speed of approximately 8 m.p.h. in :he field, as measured by an anemometer 20 feet above the ground. The varia-:ion of these parameters is shown in the normal distribution curves of :igure 8.

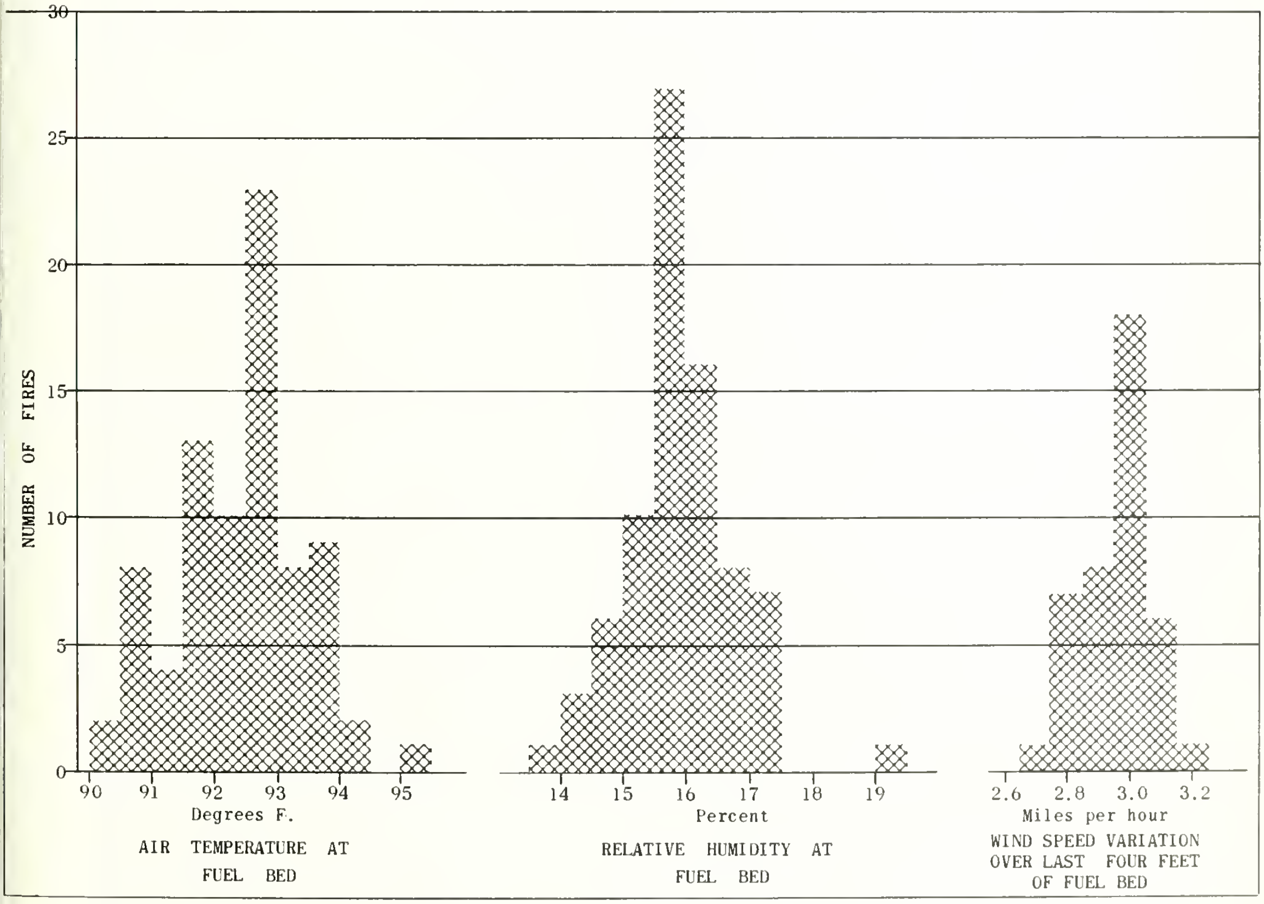


Figure 8.--Ambient condition distribution.

METHOD OF COMPARISON

Combustion Laboratory

Rate of spread, radiant energy flux, and convection column temperature from the 4-foot treated section of the fuel bed were compared to the same parameters as measured in the first (untreated) 4 feet of the same fuel bed.

Wind Tunnel

Each parameter was compared to the average value of the same parameter as measured in the last 4 feet of three untreated fuel beds.

Photographic Comparison

Photographic record of the flame characteristics at the 5-foot and 7-foot marks indicated in general the flame height, depth, and vigor. A photograph of the burned-out fuel bed from directly overhead illustrated again the intensity of the fire and the degree of total fuel consumption. The photographs in figures 9 to 12 compare for each chemical, drying time, and wind speed group, the characteristics of a representative fire in a treated and an untreated fuel bed. In the postburn views, the left half of the fuel bed was untreated, while the right half was treated with the designated chemical. A splotchy or light color indicates ash and thus rather complete consumption. Needles in sections showing a black or very dark color still held their shape and body, indicating arrested combustion. In the wind tunnel tests, the bottom layer of the darkest sections often contained patches or entire layers of completely unburned needles.

RESULTS

The data spread in each pair of fires used for computing the average rate-of-spread reduction and the average radiant energy flux reduction can best be described by referring to figure 13. The better the retardant, the farther the point is from zero. The better the repetition, the closer together is each pair of symbols. If the first two fires for each retardant, after the same drying time and wind speed, did not agree within approximately 10 percent on all three parameters (rate-of-spread reduction, radiant energy flux reduction, and convection column temperature reduction), burning was repeated until two fires gave similar results. For most tests, two fires were sufficient; for a few others, three or four fires were necessary.[5]

---

[5] After the burning program had been terminated, closer observation of the data revealed a 24-percent variation in the rate of spread of pectin-DAP after 3 hours' drying time at 3 m.p.h. This is not believed to be serious, however, since the other comparisons made on pectin-DAP are consistent and define its relative standing with the other retardants.

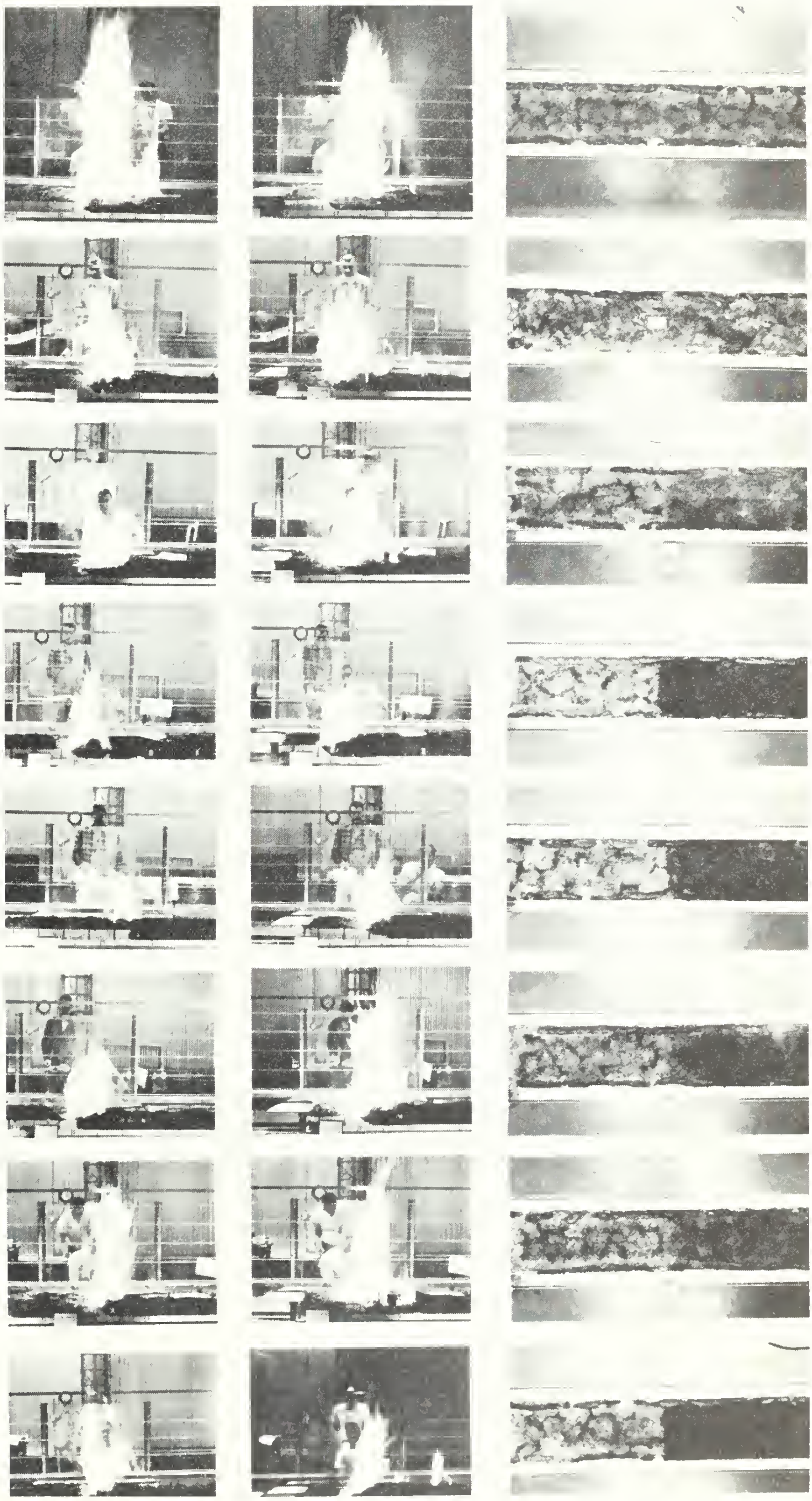


Figure 9.--Fire characteristics, under no-wind and 1-hour drying time conditions.

Chemical | 5-foot mark | 7-foot mark | Postburn view

None

Algin-gel

Bentonite

Pectin-DAP

Fire-Trol

Borate (XPI-113)

Firebrake

Algin-DAP

Figure 10.--Fire characteristics, under no-wind and 3-hour drying time conditions.

Chemical | 5-foot mark | 7-foot mark | Postburn view

None

Algin-gel

Bentonite

Pectin-DAP

Fire-Trol

Borate (XPI-113)

Firebrake

Algin-DAP

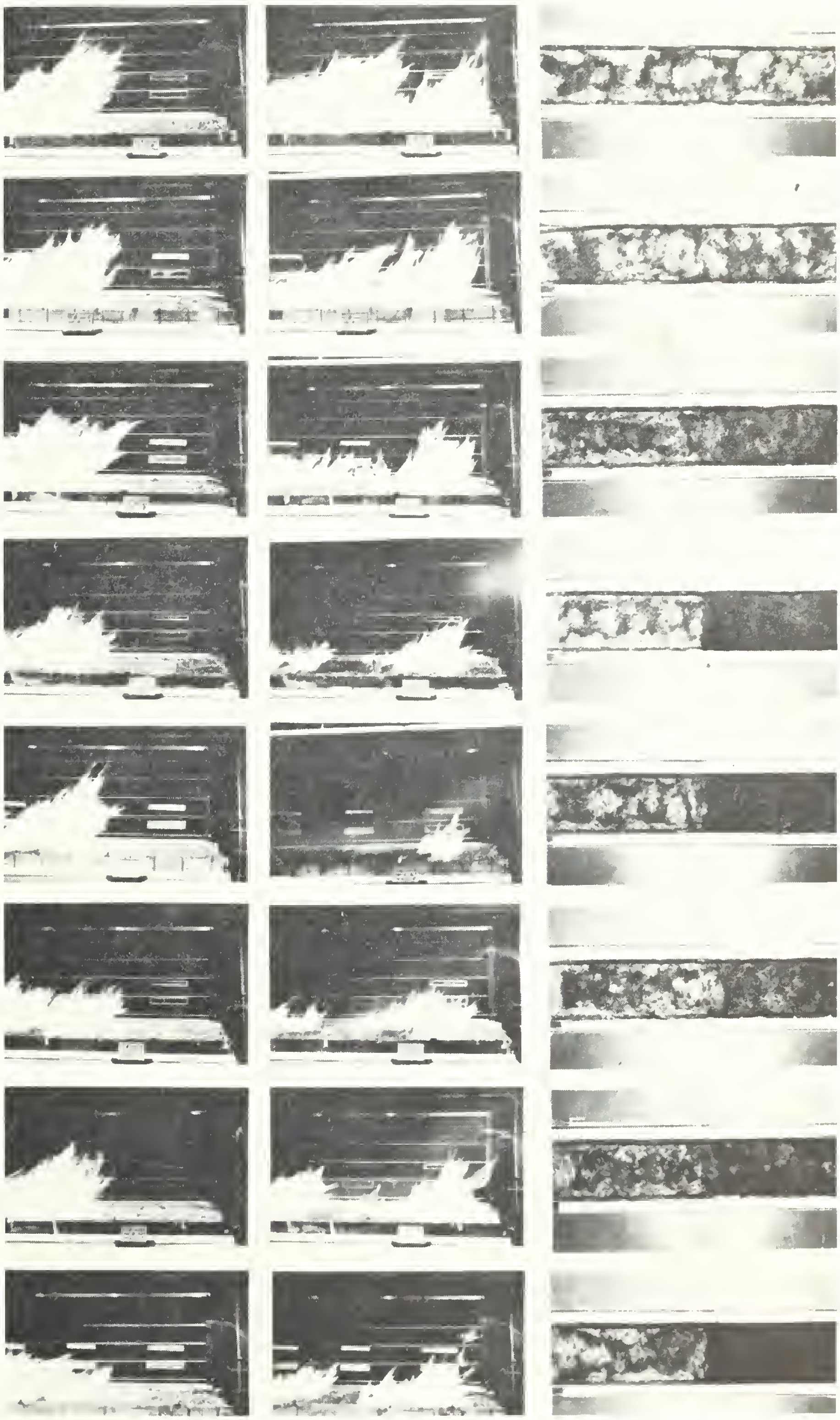


Figure 11.--Fire characteristics, under 3 m.p.h. of wind and 1-hour drying time conditions.

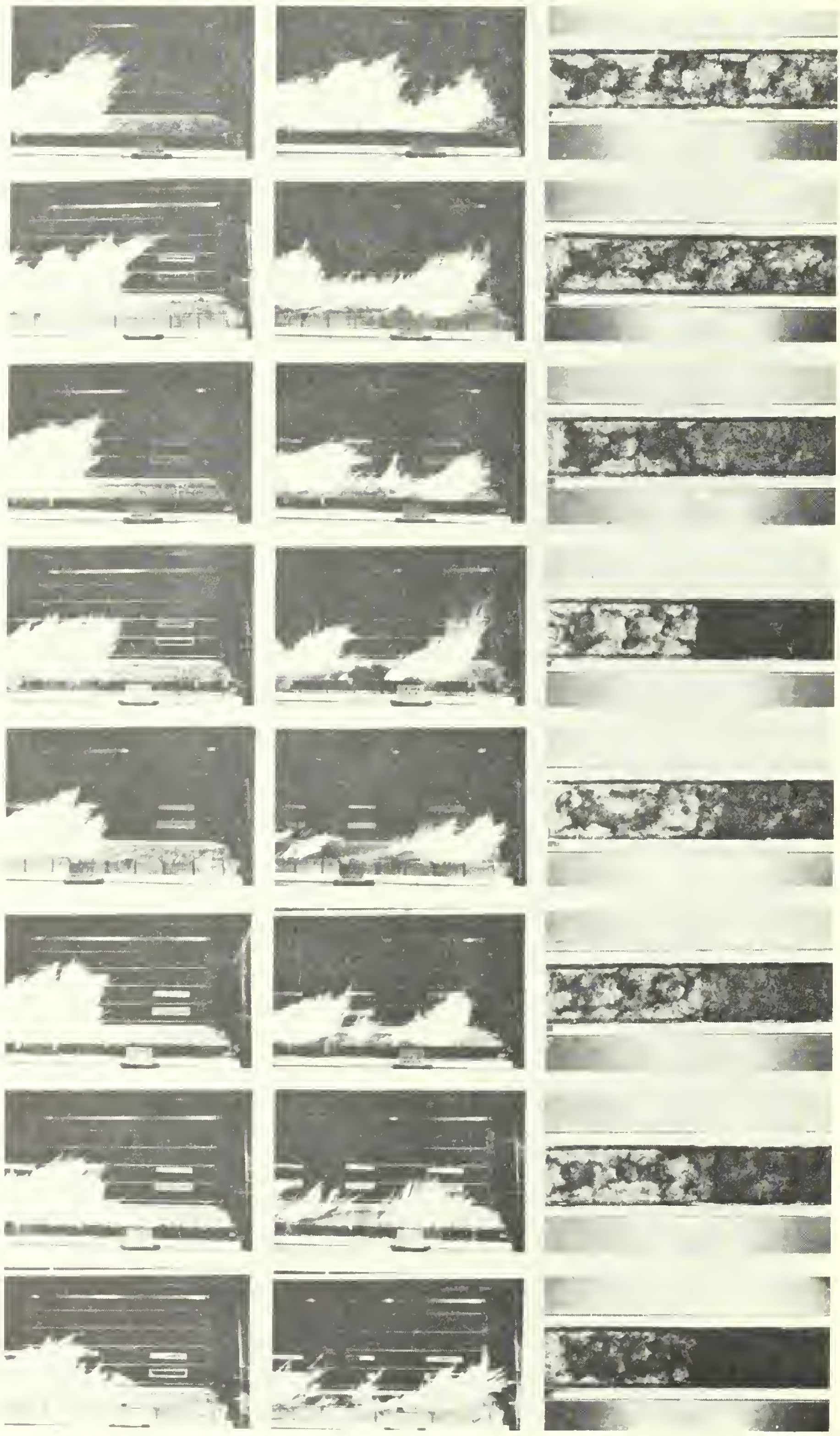
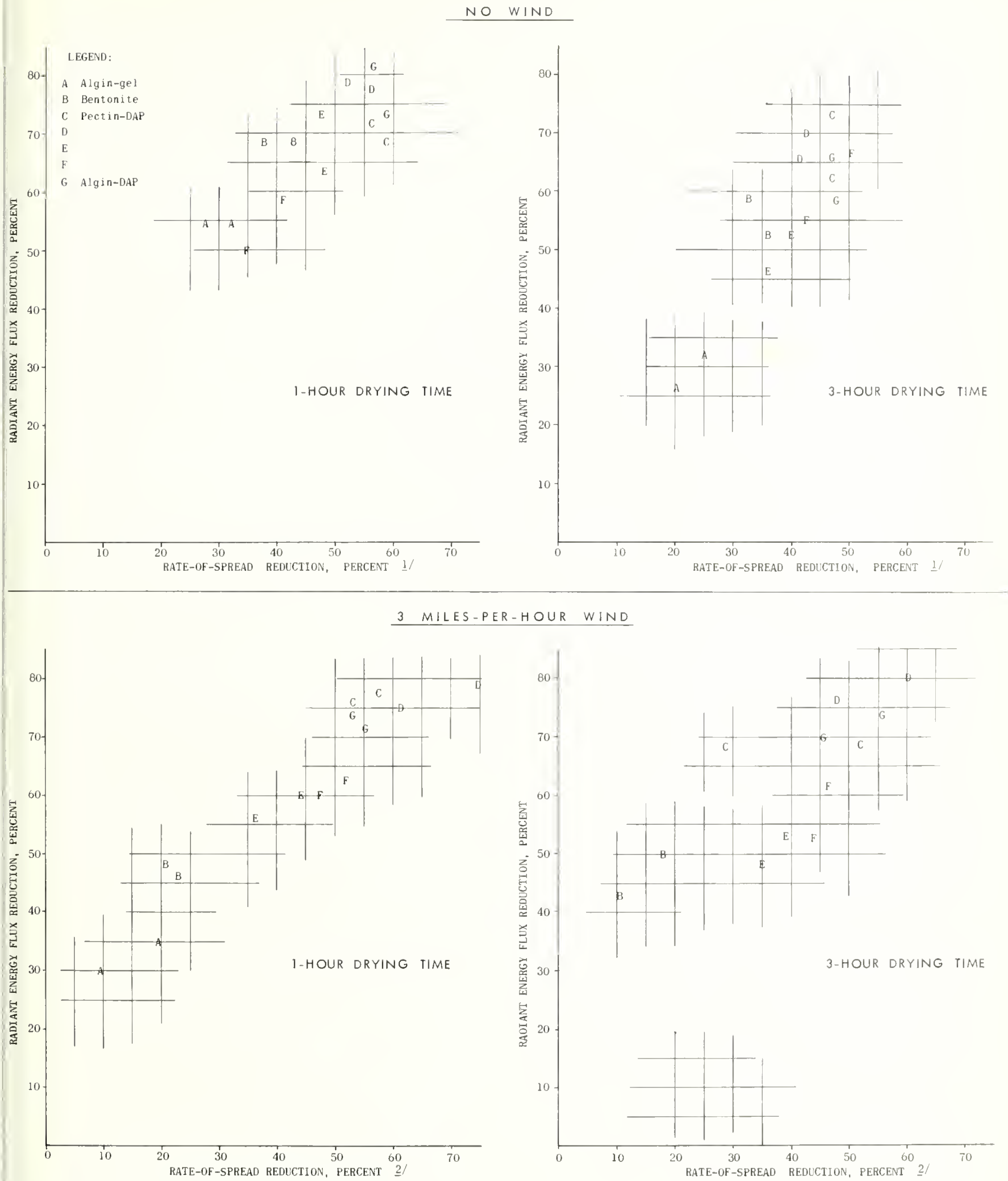


Figure 12.--Fire characteristics, under 3 m.p.h. of wind and 3-hour drying time conditions.



1/ Reduction based on untreated first four feet of each fuel bed.

2/ Reduction based on average values in the last four feet of three untreated fuel beds.

Figure 13.--Data spread in each pair of fires used for computing the average rate-of-spread reduction and average radiant energy flux reduction.

The differences between effectiveness shown by plotting these data seemed sufficiently obvious for selection of retardant chemicals for field testing. Hence, the data were not subjected to any rigorous type of statistical analysis.

Rate of Spread

Relative effectiveness of the retardants in reducing rate of spread is shown in figure 14. Under no-wind conditions, algin-DAP and pectin-DAP effected the best reductions after 3 hours' drying, along with Firebrake. In the presence of wind, Fire-Trol gave the best results after both 1 hour and 3 hours' drying. The contrast between Firebrake and bentonite should be noted. After 1 hour with no wind, bentonite was slightly more effective than Firebrake, but after drying for either 3 hours with no wind or 1 hour in the presence of wind, Firebrake was considerably more effective than bentonite. Bentonite was least effective after 3 hours of drying in the presence of wind. Borate XPI-113 usually ranked between bentonite and Firebrake. As a retardant, algin-gel did not perform as effectively in these tests as it had in some preliminary field experiments.

Radiant Energy Flux

Fire-Trol and the diammonium phosphates caused the greatest reduction of radiant energy in all burns. Bentonite was more effective after 1 hour drying time in the absence of wind, and Firebrake increased its effectiveness with a certain amount of drying. Borate XPI-113 usually ranked between them, and algin-gel was the least effective retardant (figure 15).

Convection Column Temperature

This parameter is probably less significant than rate-of-spread reduction and radiant energy flux reduction; however, the same general relation between the chemicals was maintained by this means of evaluation (figure 16).

Significance

It is necessary to remember that these results indicate only the relative effectiveness of the chemicals in reducing the intensity of fires burned under consistent conditions. No other qualities of the retardants were considered in this phase of the evaluation system.

A fire retardant chemical, successful from laboratory and field-testing standpoints, may still not be ready for operational testing or general field use. Chemicals containing ammonium phosphate and ammonium sulphate are corrosive to many metals. Solution to this problem may be through addition of corrosion inhibitors, protection of exposed aircraft parts, development of rigid inspection and maintenance guidelines, or some combination of these.

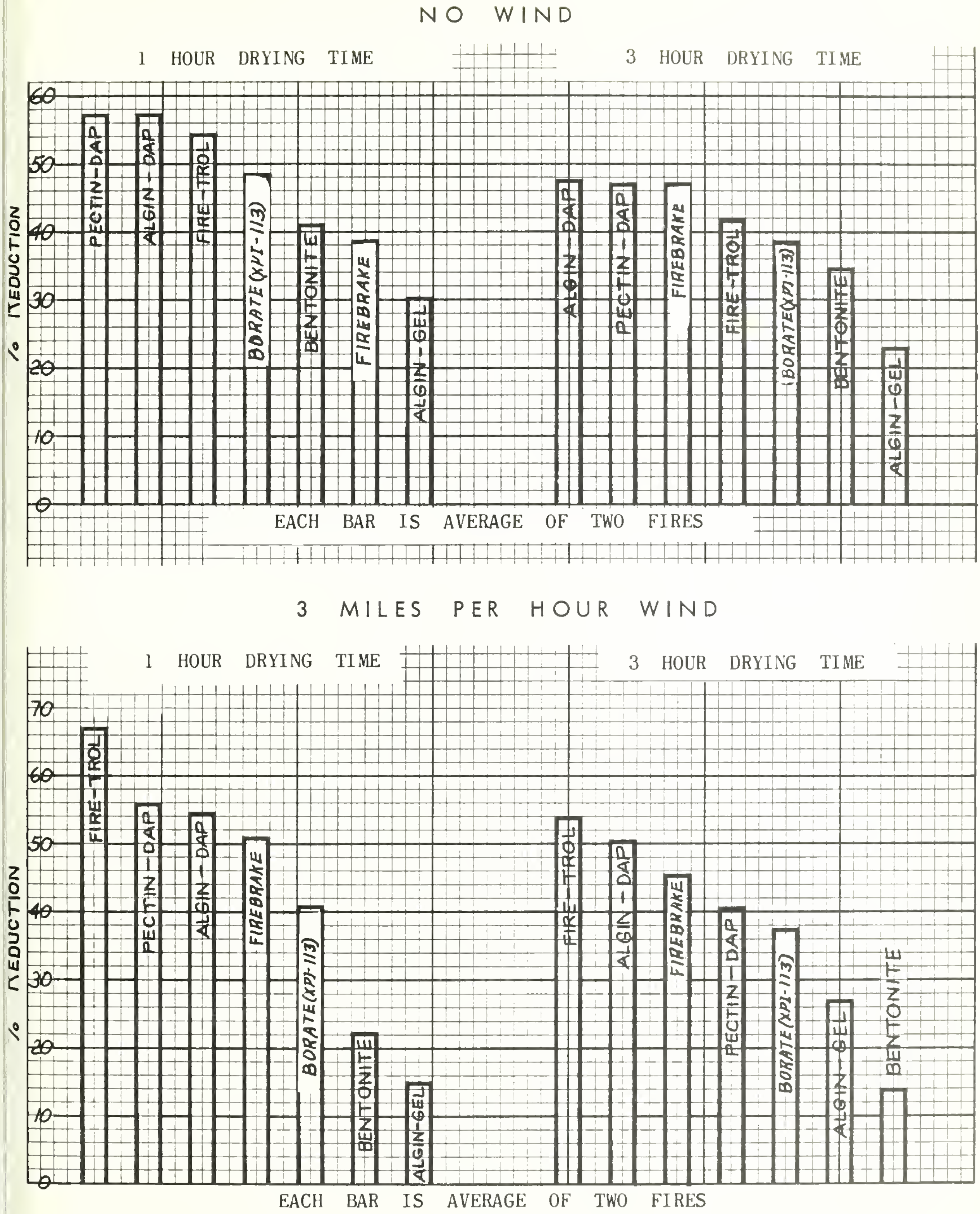


Figure 14.--Percent reduction in rate of spread of flame front.

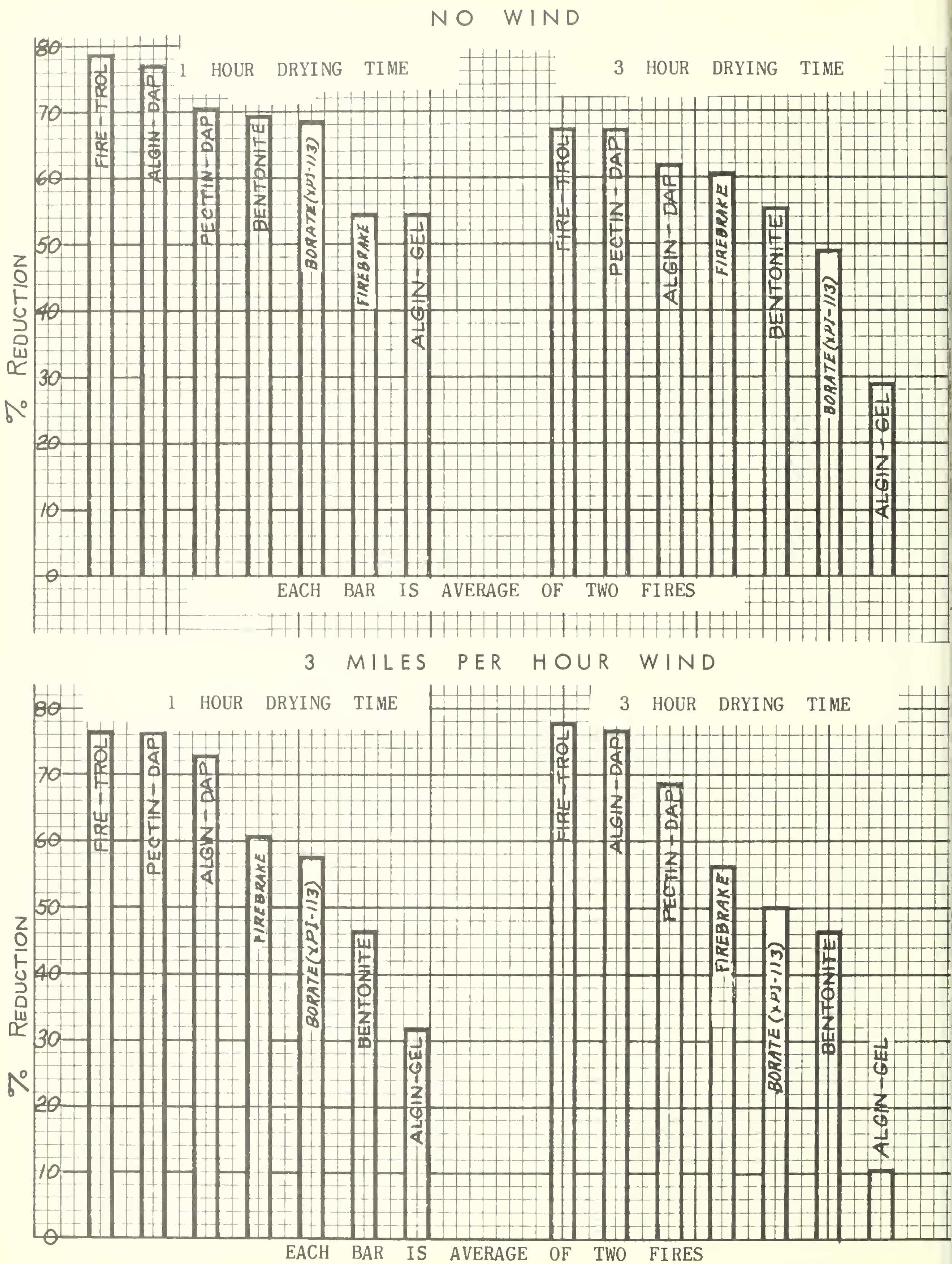
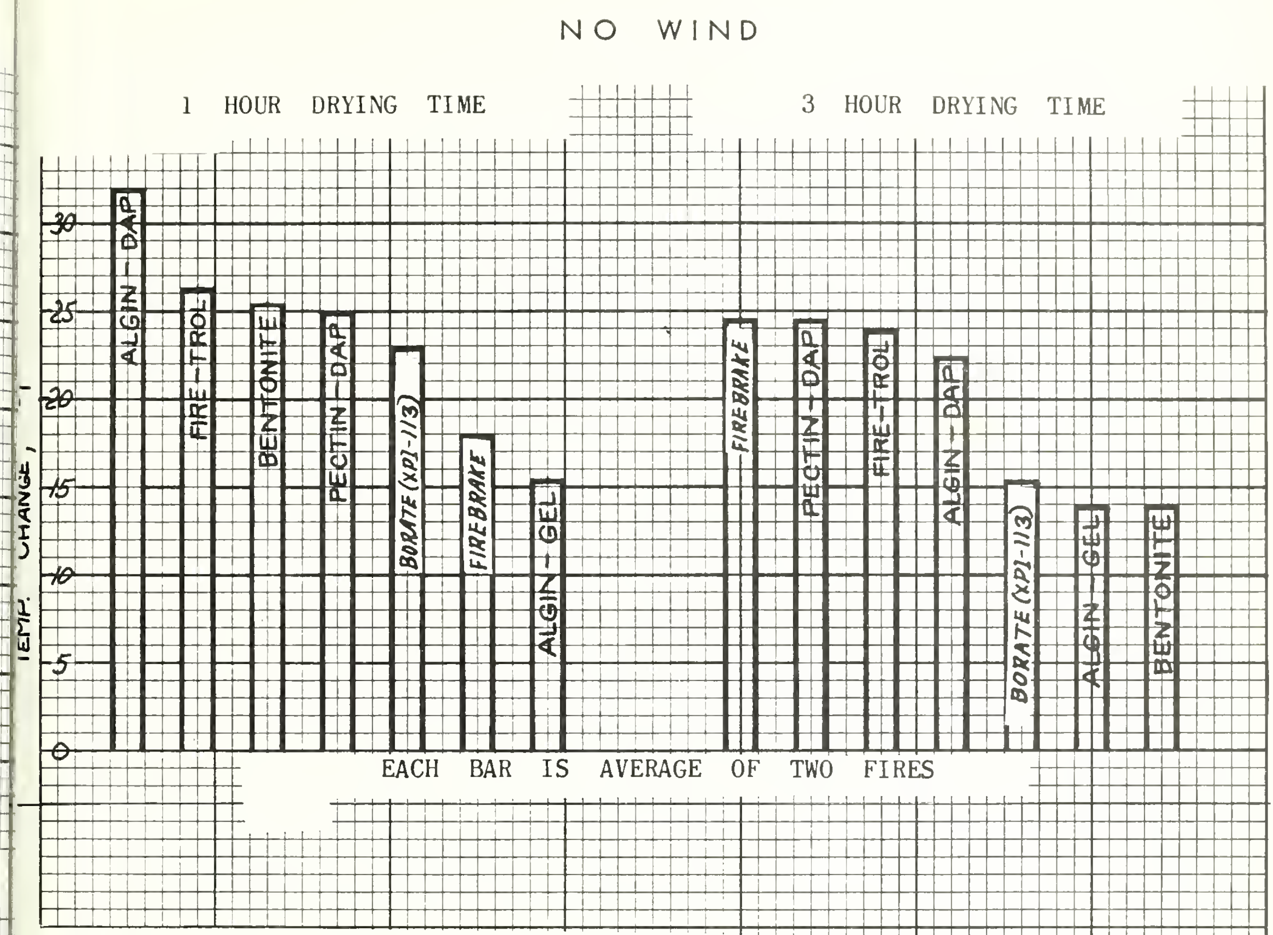
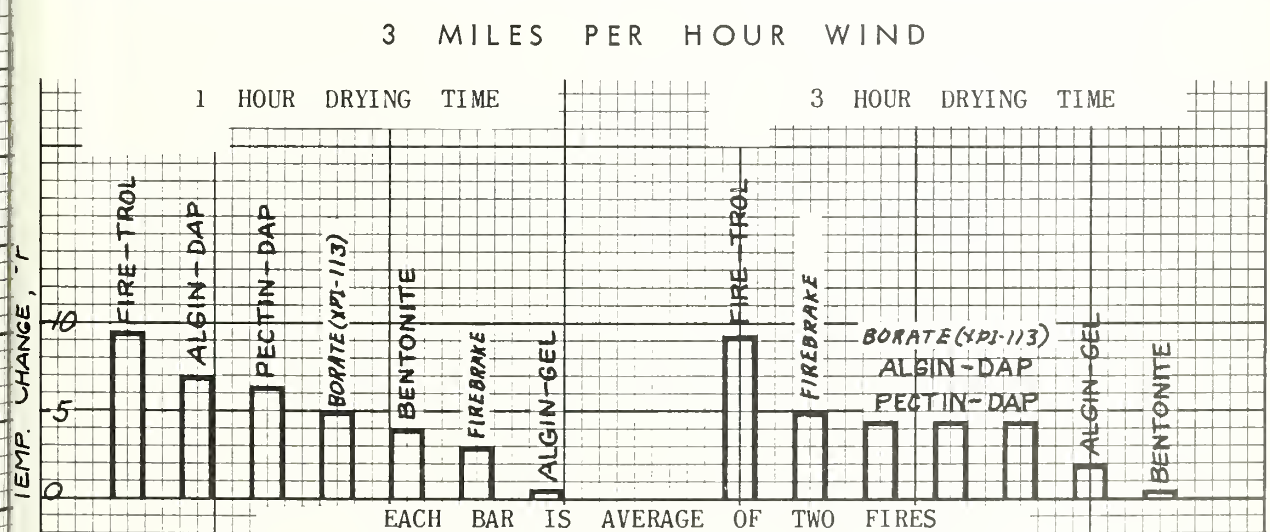


Figure 15.--Percent reduction in radiant energy flux.





Figu .--Reduction of convection column temperature.

WHERE DO WE GO FROM HERE?

Field-testing of the most promising chemicals is the next logical step to follow this laboratory evaluation. The field tests will be followed by operational tests and evaluations, which in turn will result in the development of application guides, as outlined in phases 5 through 8 under the FIRE RETARDANT EVALUATION SYSTEM section above (pp. 3-4).

Keeping performance requirements realistic and up to date is a continuing task. Also, the screening and laboratory testing phases of this system must continue to be active. A specific program of field evaluation is described in the following paragraphs.

Air drops will be made over prepared plots of standing brush. The retardant materials will be allowed to dry on the vegetation for a specified length of time following the drop. Later the brush plots will be ignited and the fire allowed to spread into the retardant-treated portion of the plot The plan is to burn each plot under similar weather and fuel conditions. The length of each retardant line that successfully stops the fire will be measured. Each experimental burn will be photographed to record results given by each chemical applied. This series of field tests should yield quantitative data that will permit comparisons of retardant effectiveness under field conditions.

Plans are being developed by CALAIRCO for further testing of the material that shows the greatest promise in these field tests by using it at six or more air tanker facilities in California and possibly elsewhere in the West. Besides using the new materials, each base will continue to use the already field-proved bentonite or Firebrake. Alternating drops of new and old material are planned so that a direct fire-line comparison can be measured. Information on drop effectiveness will be obtained from a standard reporting system.

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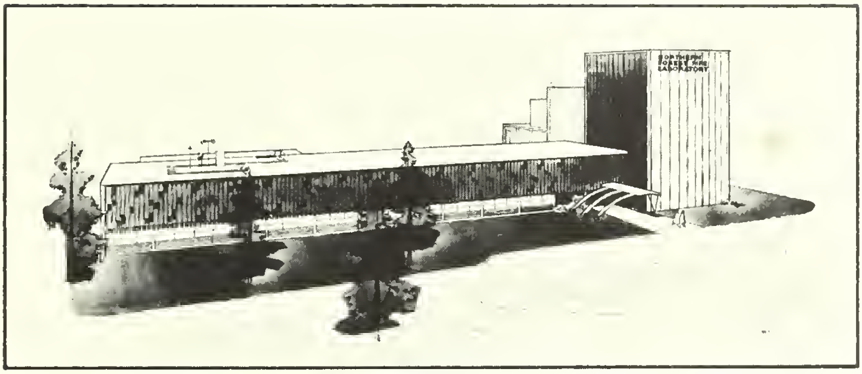

The research reported in this publication was performed at the Northern Forest Fire Laboratory, Missoula, Montana, a unit of the Intermountain Forest and Range Experiment Station.

UNITED STATES DEPARTMENT OF AGRICULTURE

1862 1962

RESEARCH PAPER 65 1962

MANAGEMENT FOR COMMERCIAL TIMBER
CLARK FORK UNIT, MONTANA

S. BLAIR HUTCHISON
ARTHUR L. ROE

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
OGDEN, UTAH
REED W. BAILEY, DIRECTOR

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
NORTHERN REGION

FEDERAL BUILDING
MISSOULA, MONTANA

ADDRESS REPLY TO
REGIONAL FORESTER
AND REFER TO
1630 (1000)

Dear Sir:

A Regional Forester doesn't ordinarily send a letter along with an Experiment Station publication. However, this is a special report and the study behind it was made at the request of my predecessor, Charles Tebbe.

The management of commercial forest land of the Northern Region, both public and private, is a difficult job. We have made great progress in protecting this forest, making it accessible, and administering it. However, the art and practice of tree growing has not advanced as rapidly or as far.

This situation, as you may know, has been of great concern to public and private foresters alike. We asked for this study to get a better understanding of the nature and extent of present deficiencies in forest silviculture. My purpose in writing this letter is twofold: first, to publicly commend the authors for a factual, straightforward discussion of the subject; second, to urge you to take time to read the report. If we can get public understanding of this problem, we will be able to move more rapidly toward building up the truly large timber productivity of the National Forests in this Region.

Sincerely yours,

Boyd L Rasmussen

BOYD L. RASMUSSEN
Regional Forester

Enclosure

WATER · FORAGE · RECREATION · LIFE
FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

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Cover picture by Marge Dodge

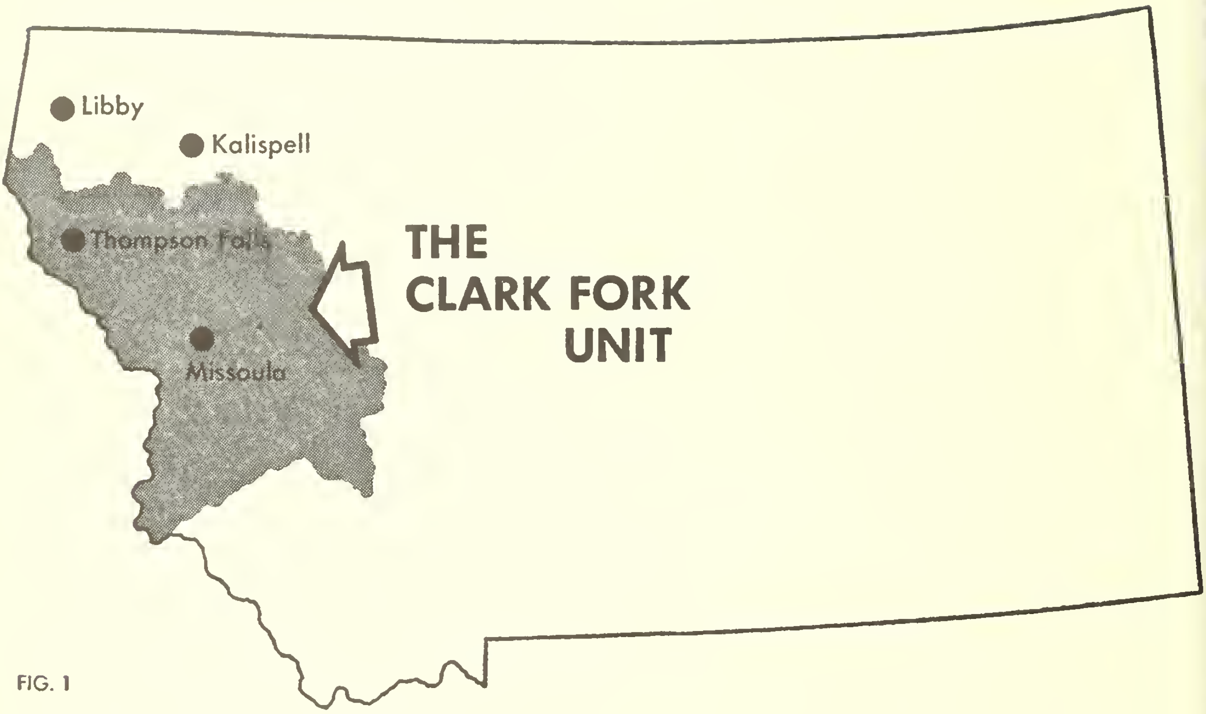


FIG. 1

The Clark Fork Unit includes all of the Clark Fork River Drainage west of the Continental Divide in Montana. Flathead and Lincoln Counties are the only two western counties not included. The total area in the unit is 10.4 million acres. About three-quarters of that area, or 7.6 million acres, is forested, of which 6.5 million acres are suitable for commercial timber production. This commercial area annually produces about 600 million board feet of logs which, when converted to timber products, are worth approximately $50 million.

INTRODUCTION

Up to now, the inadequacy of forestry financing has made it necessary to assign low priority to silviculture such as planting and thinning in the Mountain States. In relation to the total job, little of this work has been done. In the past few years, however, a growing public sense of urgency about resource management has brought the silvicultural issues to the forefront. More than ever before we are looking beyond present values in the forests to the contributions that should be expected from them in the long run.

For years conservationists have been preaching this doctrine of providing adequately for the future. Now it is getting serious consideration in the public mind and we are able to consider the plans and finances necessary to achieve long-range resource goals.

In the study reported in the following pages we have attempted to appraise the timber management job involved in increasing production on a fairly representative area of the U.S. Forest Service's Northern Region.[1] The area involved is the 10.4-million-acre Clark Fork Unit described in figure 1. It will, of course, be a long time before all the silvicultural and economic questions relating to the details of management of the Clark Fork Unit will be solved. However, it is necessary at this stage to bring the problems and potentials of the area into focus and to describe the broad programs required to cash in on the opportunities the timber presents.

* * * *

Timber has furnished a substantial annual income to the Clark Fork Unit for more than half a century and can continue to do so in the future. This fact is evident even to the casual observer who sees only the general forest landscape. The forest, which occupies a big part of the total area, is green and obviously is producing a lot of wood.

Not so evident is the amount of effort that will be required to achieve specific levels of timber growth in years to come. Although the prevailing public mood seems to be one of implicit faith that the forest will provide, a close examination of the situation indicates that unless this faith is supported with some good works, timber yields in the future will fall far short of what the land can produce and what the Nation is expected to need from this area. No one really knows how much effort will be required to get the forest land of the Clark Fork to provide in adequate amounts. The Forest Service has set a production goal for the national forests of its Northern Region of 2.4 billion board feet (International ¼-inch rule) by the year 2000. This amounts to a big jump from the 1959 cut of 1.1 billion board feet. Nevertheless, only a start has been made in the complex task of judging the characteristics and capacities of hundreds of thousands of individual stands and determining the nature and cost of the silviculture required to produce a desirable sequence of yields from these stands.

The task of developing a program to increase forest production in this area is complex not only because of the number of stands involved but also because some very stubborn problems must be solved in managing the growing stock nature has provided. Timberland in this part of the United States has a much higher productive capacity than most foresters realize, but on the other hand, the natural unmanaged forest, on the whole, is a

[1]Montana, Idaho north of the Salmon River, and the three northeastern counties in Washington.

surprisingly inefficient timber producing unit. **UNLESS SUBSTANTIAL EFFORT IS PUT INTO CULTURAL WORK, FUTURE TIMBER YIELDS ARE LIKELY TO BE DISAPPOINTINGLY SMALL AND OF DISAPPOINTINGLY LOW QUALITY.** Disappointments will be greatest in terms of larger premium-quality trees, but even for fibre the productivity of "natural" stands leaves a great deal to be desired.

* * * *

Considering that few people knew the meaning of the word "forestry" 50 years ago, land managers have made enormous progress. Nevertheless, there has been considerable uncertainty in the past half century as to where this region fits into the total forestry picture. That being the case, it has been hard to focus efforts.

Fortunately, the haze has lifted somewhat in recent years. We are now beginning to get a clearer picture of what future goals should be. In this analysis, we have taken a new look at the forestry job. Specifically, this report considers what a mounting need for wood, the qualities of the local species, and the economics of management seem to point to in the way of a forestry program for the Clark Fork Unit.

Many persons have helped provide the data used in this analysis and have reviewed the statements herein. Special thanks are due G. M. DeJarnette and Henry C. Jacobs, Division of Timber Management, U.S. Forest Service, Missoula, Montana, for assistance in estimating forestry costs.

THE MANAGEMENT PROBLEM

In 1958 about 600 million board feet of sawtimber were logged in the Clark Fork Unit. As in the rest of the Northern Rocky Mountain Region, that level of cut is below the potential capacity of the forests to produce wood. For example, the Forest Service has set its sights on raising the sawtimber output of the Clark Fork Unit national forests from 202 million board feet in 1960 to something like 620 million board feet in the year 2000.[2] There is reason to believe that such a rapid buildup of cut cannot be achieved without seriously depleting growing stock because much of the present growing stock is not all it should be. Nevertheless, 620 million board feet is certainly a reasonable longe-range goal considering the capacity of the land to produce wood. We estimate that it should eventually be physically feasible to sustain an annual sawtimber cut of 1.1 billion board feet from the lands of all owners in the unit. This is about twice the present cut.

The fact that 620 million board feet can be produced annually on the national forests, and 1.1 billion board feet on all lands, should not, however, be regarded as a promise of what will happen. The forest of the Clark Fork Unit now produces far less than this, and there is no certainty these yields will be achieved. We realize this statement is contrary to the impression one gets from traveling through the forest and from watching

[2]Actually, the Forest Service has as yet only established a production goal for the region as a whole. The objective for the Northern Region is 2.4 billion board feet (International 1/4-inch rule). The above estimate for the Clark Fork Unit was derived from this figure on the assumption that about 26 percent of the production capacity of Northern Region national forests is in the Unit.

truckloads and trainloads of logs pouring out of the hills. However, the procession of logging vehicles has been tapping timber reserves built up by nature over many decades. This facade of abundance masks a timber growing situation that is not satisfactory.

WHEN ALL THE PLUSES AND MINUSES OF TIMBER RESERVES AND GROWING STOCK CONDITIONS ARE ADDED TOGETHER, THE COMMERCIAL FOREST OF THE CLARK FORK UNIT CURRENTLY APPEARS TO BE JUST ABOUT ONE-THIRD AS PRODUCTIVE AS IT SHOULD BE. In other words, the current effective productivity of the 6.5 million acres of commercial forest in the Clark Fork Unit is just about what could be achieved by 2 to 2.5 million acres stocked with high vigor trees and managed intensively (fig. 2).

However, that is only one side of the coin. It is equally important to appreciate how much the productivity of this forest can be increased by thinning and other forestry practices. Of course, the forest cannot be transformed overnight because the land manager will have to work with some low vigor growing stock during the present rotation. Also, it will take time to do all the stand treatment work that is needed and more time for this treatment to produce the desired effects. Nevertheless, a well-directed silvicultural effort in the Clark Fork Unit should achieve fairly high timber production. John H. Wikstrom and Charles A. Wellner have shown that the volume and value of utilizable timber can be greatly increased by thinning and pruning (*9*).[3] We shall discuss that opportunity in more detail later in this report. It is sufficient here to raise three points in anticipation of that discussion:

- The forest as a whole is not in a highly productive condition today.
- Efforts to regenerate new stands on cutover areas are considerably less than 100 percent successful.
- The growing stock in this unit is undergoing a subtle, unnecessary, and undesirable deterioration. As a result, the timber we are growing is poorer than the timber we are cutting.

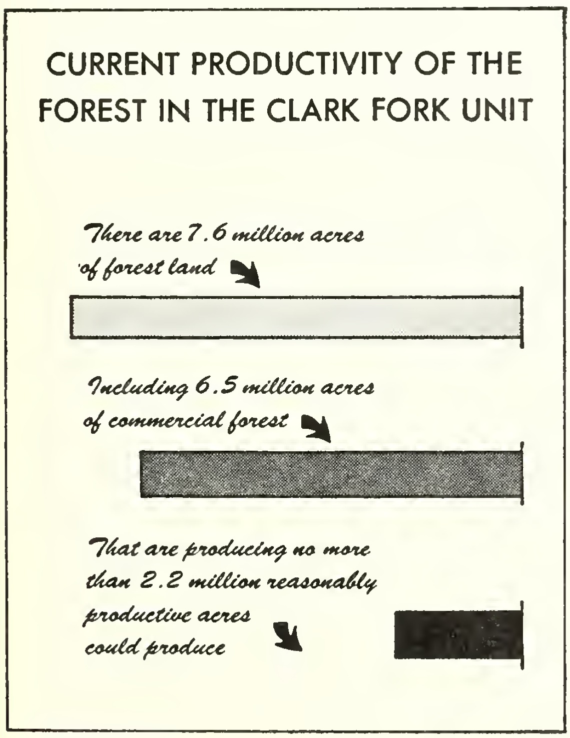


FIG 2

As long as these circumstances prevail, it is unlikely that a sawtimber cut much larger than the present can be sustained in the Clark Fork Unit. On the other hand, as we have already stated, the potential is there for a much larger production if the silvicultural effort is expanded (fig. 3).

THE TWO BIG PROBLEMS THAT MUST BE FACED IN TIMBER MANAGEMENT ARE THAT THERE ARE TOO MANY TREES IN MOST STANDS AND NOT ENOUGH IN SOME OF THE REST. The task ahead has been aggravated by diseases, insects, poor distribution of ages and sizes of trees, and inadequate regeneration of new stands in cutover areas.

Poorly stocked stands

Forest Survey records show that 15 percent of the commercial forest in the Clark Fork

[3]Italicized numbers in parentheses indicate numbered items in Literature Cited.

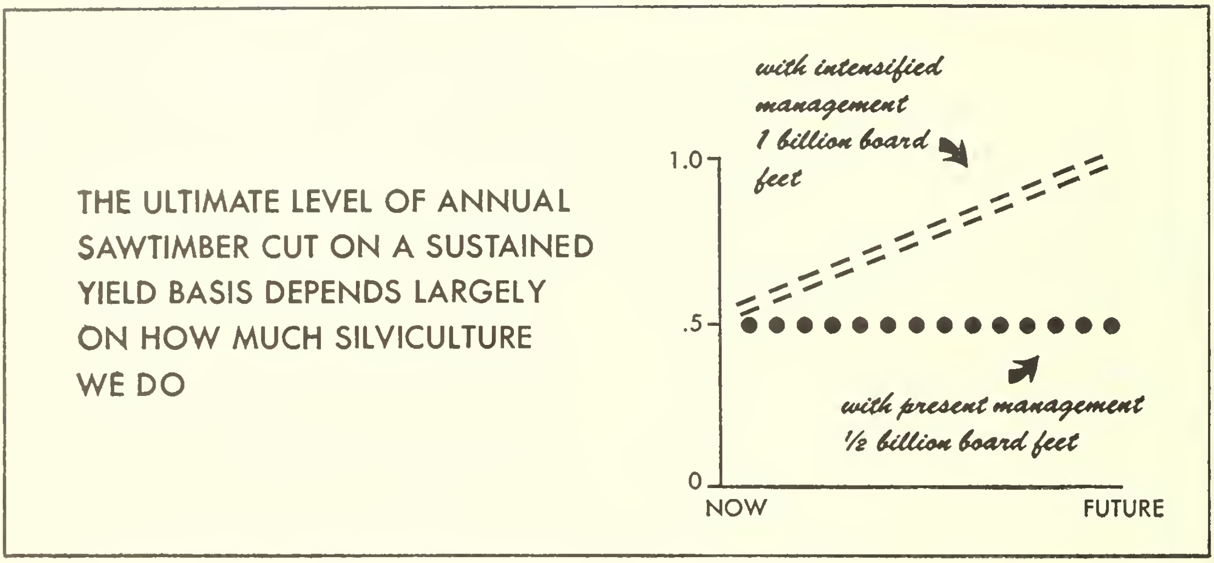


FIG. 3

Unit is understocked. This situation prevails to some extent in all types, but is particularly important in the ponderosa pine type. Ponderosa pine is characteristically an open-grown species, and on the thinner soils poor stocking may represent full use of the growing space. However, even when appropriate allowance is made for that fact, most of the present stands fall short of desirable stocking.

Figure 4 depicts the situation in national forest ponderosa pine stands. In terms of area equivalents the stand of all trees 4 inches and larger appears to be about two-thirds of what it should be for capacity production. The stand of ponderosa pine trees alone is at only one-third of the desired level. Actually, the data in this chart minimize the problem, as no distinction was made in inventory tallies avail-

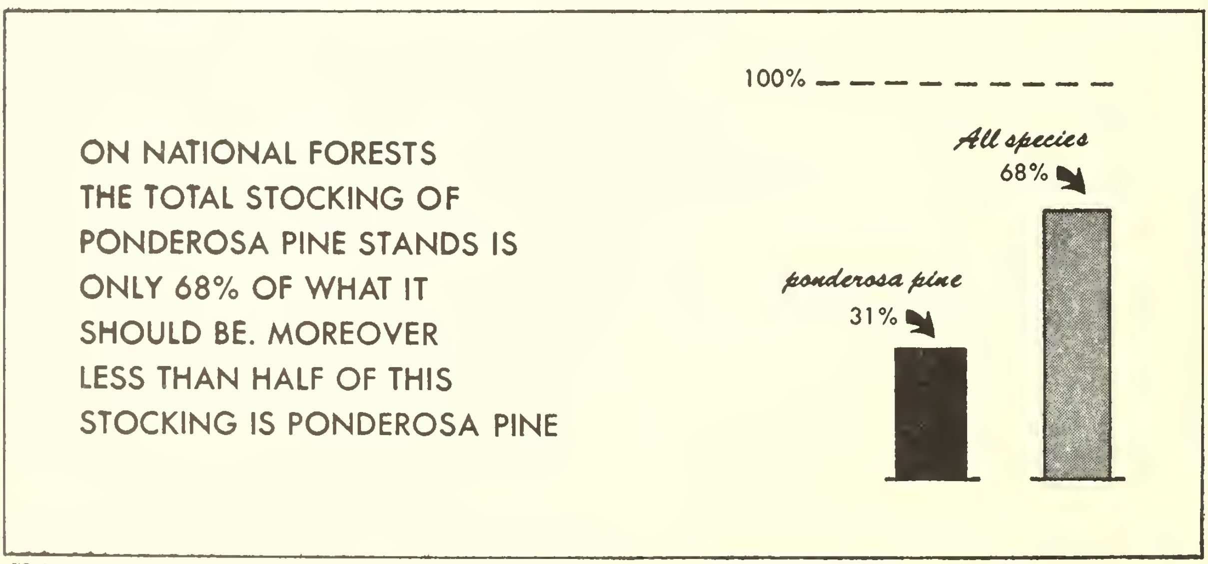


FIG 4

able to us between trees that by virtue of position and quality will be featured in management and those which from that point of view are excess. If it were possible to separate the "sheep" from the "goats," we probably would find that the ponderosa pine trees we can reasonably expect to carry through to maturity occupy even less of the growing space than indicated.

Overstocked stands

The area with not enough trees is considerably exceeded by the area with too many. Figure 5 shows the composite picture of the stand on a 132,000-acre area near St. Regis. In the critical younger years of the stands the proportion of excess or surplus trees competing for light and moisture is often large, and they are a massive drag upon the productivity of the commercial forest. Overstocking is, in fact, the most important single roadblock in the way of higher production.

The problem of too many trees is most severe in the lodgepole pine type wherein some stands have completely bogged down like the one pictured in figure 6. Facts and figures on stagnation are skimpy, but it seems likely that at least one-third of the present seedling, sapling, and pole stands in this type should be "written off" so far as future growth is concerned because they cannot recover from suppression (table 1). Some of these young stands in various stages of arrested development contain trees that may eventually be utilizable. However, at least 80,000 acres support stands worth little or nothing for timber production, and on most of the remainder of the 1.9 million acres of lodgepole pine type the yields will be low because trees have lost vigor due to overcrowding.

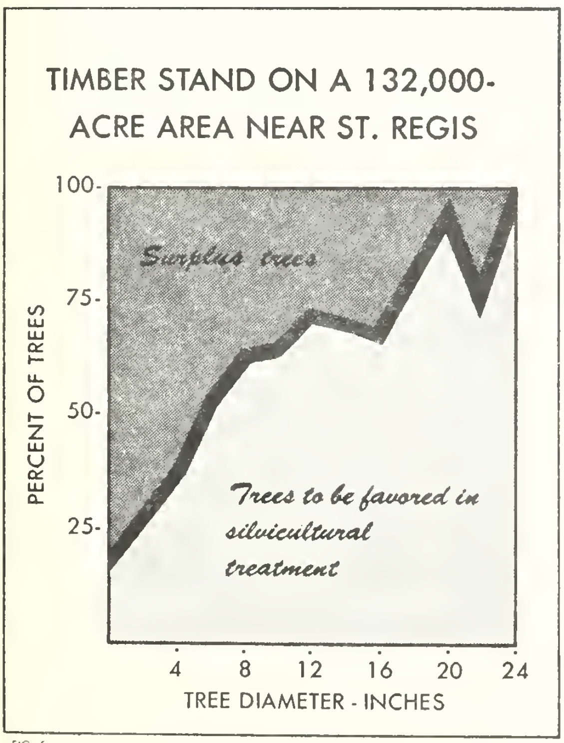


FIG 5

Table 1. — *Estimated condition of lodgepole pine seedling, sapling, and pole stands in the Clark Fork Unit*

	Acres	*Percent*
Growing stands	1,071,000	65
Stagnated stands		
Large poles[1] probably utilizable	363,000	
Small poles[1] may eventually be utilizable	132,000	35
Seedling and sapling[2] stands, no present or future value	82,000	
Total stagnated	577,000	
Total pole, seedling, and sapling area	1,648,000	100

[1]Pole stands in which the majority of the dominant trees are 7.0 to 10.9 inches d.b.h. are classed as large poles. Small poles include trees 5.0 to 6.9 inches d.b.h.

[2]This is strictly a size category. Actually, some of the stagnated seedling and sapling stands are old.

Overcrowding exerts its depressing effect upon diameter growth in other types also. For example, in the larch type, which occupies three-quarters of a million acres, the problem is but slightly less serious than in the lodgepole pine type. Relatively few acres in

A STAGNATED STAND OF LODGEPOLE PINE ABOUT 40 YEARS OLD IN THE SEELEY LAKE AREA.

CHART SHOWS THE RELATION OF DIAMETER GROWTH TO STAND DENSITY IN GOOD SITE LODGEPOLE STANDS IN THE ST. REGIS AREA.

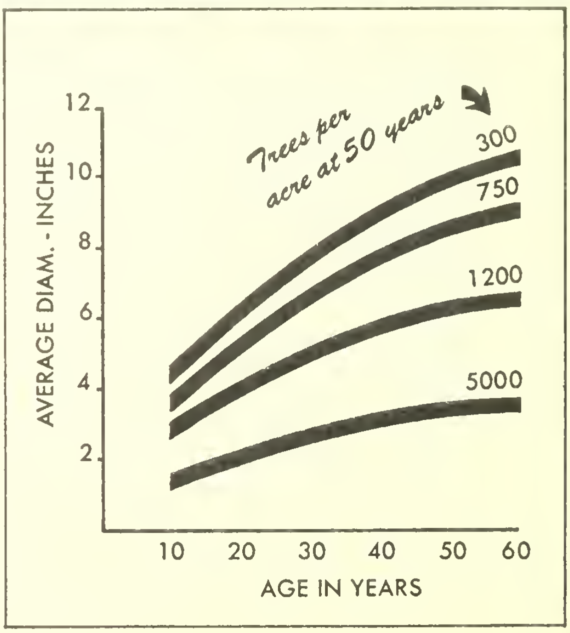


FIG. 6

this type are completely stagnated, but we estimate that in two-thirds of the young stands, overstocking will require lengthening the rotations or settling for smaller size trees. Larch has a reputation for being slow growing; yet, given room, it will grow quite rapidly. For example, it should be possible to grow crop trees averaging 19 inches in diameter in 140 years on medium sites. *In most unthinned natural stands, 200 years or more will be needed to produce crop trees of this size.*

The story in the spruce type is different only in detail. In rotation-age spruce stands of western Montana the area of stem cross sections per acre (basal area) is about what it should be. However, the volume of sawtimber in rotation-age stands is only about half the volume expected from stands stocked with uniformly distributed trees,[4] thus indicating that the trees are growing in thickets interspersed with openings and that when distribution is taken into account the basal area is divided among too many stems.

The surplus trees in some stands do not represent serious enough competition to warrant their removal. Indications are, however, that the competition of these extra trees is a critical problem in most young stands. In the previously mentioned area near St. Regis, for example, a survey of management needs shows that serious competition occurs on 7 out of 10 acres of pole size or smaller timber (fig. 7). Surprising as it may seem, it is already too late to do anything about the overcrowding on 3 of these 7 acres. Although the stands are relatively young, the trees in many of them have such short crowns they will not respond satisfactorily if released by thinning.[5]

[4]The objectives in this case are based on 75 percent of normal yield table values.

[5]Much of the seriously retarded timber is lodgepole pine, a short-lived species in the white pine country. Unless it grows rapidly during the first 40 years of its life, this lodgepole is still small at 80 to 100 years when the stands become mature and begin to decay.

For the longer lived species, the situation can be at least partially retrieved in stands not too seriously retarded. The years lost cannot be regained, but with thinning and extension of rotations, substantial timber yields are still possible. For example, as figure 8 shows, larch can come back after being suppressed, and ponderosa pine likewise responds to release. However, while trees of the longer lived species can respond to release at older ages, they do not respond significantly unless freed of competition while they still retain good crowns and vigor.

The fine sawtimber trees and stands that have been and are supplying industrial needs probably grew under such conditions of overstocking as we have described here. However, as indicated earlier, it took considerably longer than 120 or 140 years to grow most of the logs being cut today. Moreover, for every acre that produced merchantable sawlogs, some fraction of an acre spent a whole rotation producing little or nothing.

Mistletoe damage

Destructive agents have played havoc with the productivity of many acres. The part that fire and insects have had in timber losses has been sufficiently well documented that there is no need to discuss it here. On the other hand, the damage by dwarfmistletoe is less well known. This relatively inconspicuous plant parasite is no newcomer to the forest. A quarter of a century ago Boyce pointed out that "Dwarfmistletoes cause extensive damage in western coniferous forests ranking next to heart rots in the losses caused. In the future, when the overmature, virgin forests have been largely cutover, these parasites, if not controlled, will be far more damaging than fungi (*1*)." Nevertheless, only in the past few years have surveys been made to determine the extent of occurrence.

The case against mistletoe is well summarized in a recent publication by William R. Pierce (*5*). His studies of western Montana

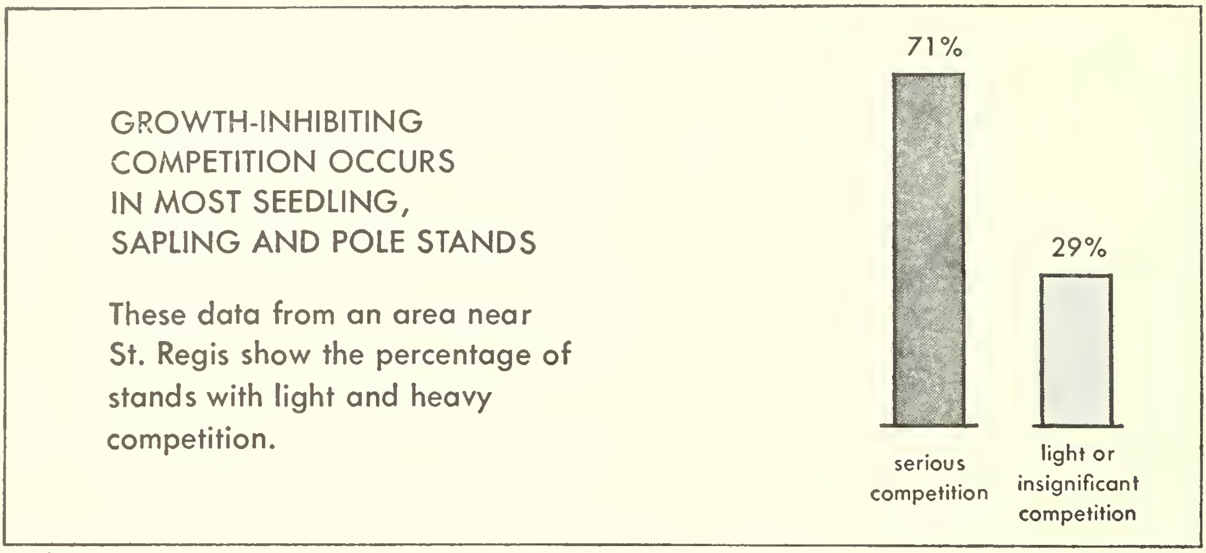


FIG 7

larch and Douglas-fir show that a heavy infection reduces basal area growth of individual trees about 69 percent; a moderate infection reduces it 41 percent; and a light infection 14 percent. Since mistletoe infection reduces height growth as well as diameter growth, it is not surprising that other studies show cubic-foot growth reduced from 41 to 89 percent, depending upon how heavily the stands have been hit (*3*).

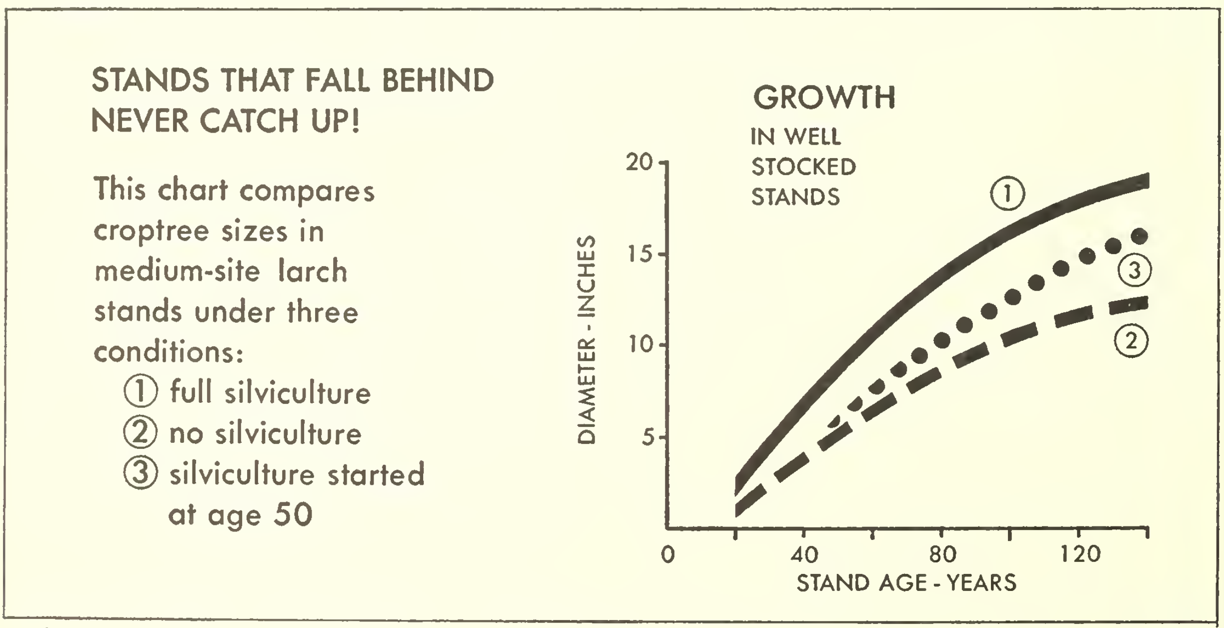


FIG. 8

A survey by Donald P. Graham[6] shows that dwarfmistletoe has a foothold in all parts of the Clark Fork Unit. Figure 9 presents some of the highlights from his survey. One-third of the commercial forest (2.3 million acres) has infected trees, and three-quarters of a million acres are heavily infected. This parasite saps about 40 percent of the timber growth on the land where it occurs. It is probably causing the Clark Fork Unit to lose 70 to 80 million board feet of sawtimber growth annually.

Mistletoe takes on added significance because there is as yet no way to deal effectively with this pest once it has become established in a stand. It is highly desirable, therefore, to find some chemical means for cleaning up existing infections. Until some such mass attack method is developed, mistletoe control procedures will be at cross purposes with other silvicultural practice. The thinning so desperately needed to increase tree growth would in many stands speed the development and spread of mistletoe. Pending a mass control procedure, five facts are important:

- We will have to live with existing infection in older stands until they can be harvested. Some heavily damaged older stands should have a high priority for logging.
- There is a limited opportunity to clean up some of the lightly attacked younger stands by cutting infected trees.
- Where thinning is being considered and mistletoe is present, the advantages of improved growth may have to be weighed against the disadvantages of increasing the mistletoe problem.
- More than one-quarter million acres of pole, seedling, and sapling stands are so heavily infected that they can never produce usable wood in any quantity. Some of these stands are stagnated as well as diseased.
- New stands will have be established in such a way that infection will be held to the minimum.

[6]Dwarfmistletoe survey in western Montana. (In process).

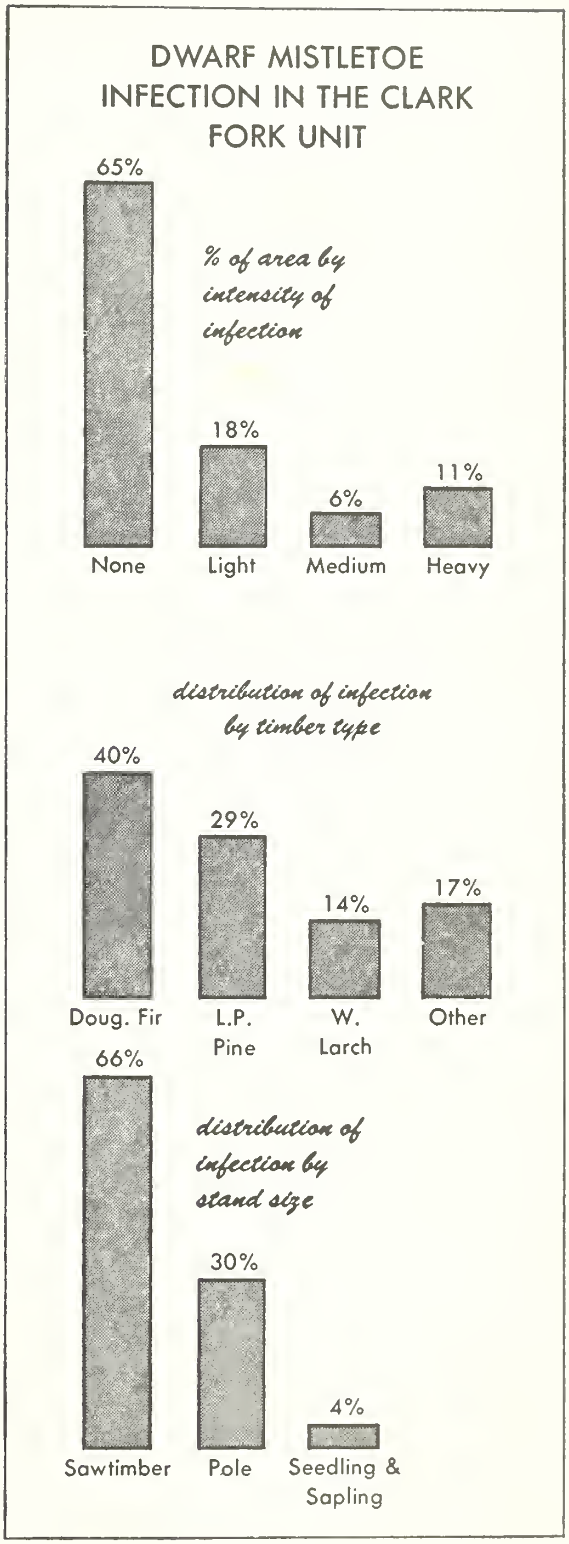


FIG. 9

For many years, mistletoe was virtually ignored. Now that it has been "discovered" it will likely receive a great deal of attention. However, the list of destructive agents is long. Others, including the heart rots, comandra rust, and western gall rust, also damage many trees and must be studied and evaluated before we can completely comprehend the protection problem.

The disorganization of the forest

Timber has been harvested in the Clark Fork Unit for more than a century, but so little cultural work has been done that the forest still retains the general characteristics of a natural forest. That is, it is a jumbled collection of stands. It must be molded into an orderly arrangement of sizes and ages if an even flow of products is to be achieved.

Fortunately, the Clark Fork Unit contains enough mature timber to keep industry supplied for many years while younger stands are being shaped into a managed forest. However, a sizable portion of the volume is in old stands vulnerable to insects and disease and cannot be held for a long period. Past cutting has tended to complicate this problem, for timber has been logged without sufficient regard for its vitality or for the need to maintain an even flow of products by species. Thus, cutting has contributed in its own way to an imbalance in the growing stock.

The problem of unbalanced inventory is most acute in the ponderosa pine type. This is not surprising, as ponderosa pine practically carried the lumber industry for many decades. Today there is little or no cushion or surplus of merchantable timber and the shortages of smaller size trees are particularly striking. Figure 10 compares the average stand per acre in the ponderosa pine type on national forest land with the stand required to sustain the production of this type at 75 percent of yield table levels. There are apparently plenty of 4-, 6-, and 8-inch trees but not enough larger

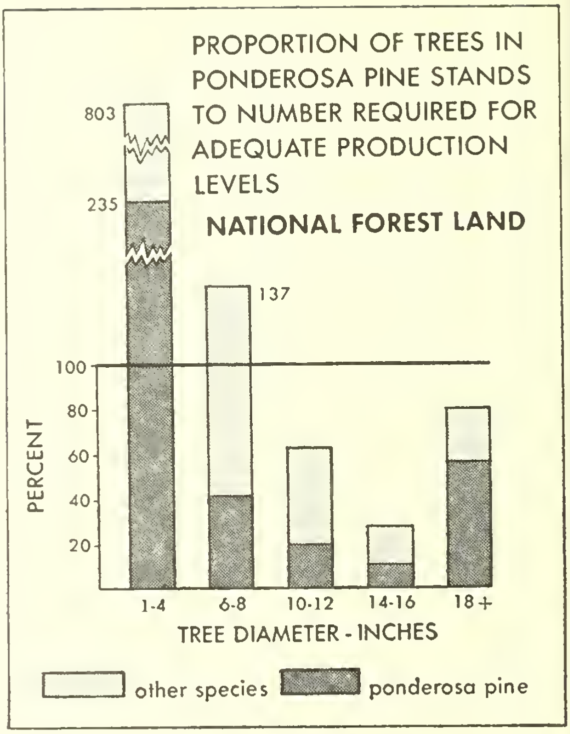


FIG 10

trees.[7] The amount of ponderosa pine is especially inadequate and the other species that occur in the type make up only part of the deficiency. The size of the management problem is best indicated by the fact that the number of 14- and 16-inch pines should be increased tenfold or more to achieve an even flow of products from this type.

The proportion of ponderosa pine in ponderosa pine stands is higher on private lands than on the national forests. Otherwise, the inventory picture on these lands is about the same as on the national forests.

We pointed out earlier that loggers have made heavy inroads in the ponderosa pine type because of the high value of this species. Prior to World War II, roughly 40 percent of

[7]One difficulty in this comparison is that it does not distinguish between trees that have a place in the future development of the stand and those that are excess. Because of this, the situation is probably even less satisfactory than we have indicated.

the lumber cut in the Clark Fork Unit was ponderosa pine. In the 1950's, the cut of other species rose substantially and ponderosa pine production declined. Today, ponderosa pine is only one-fourth of the total cut. Nevertheless, the 120 million board feet or so of ponderosa pine sawtimber cut from the lands of all owners in 1958 appears to be twice as much as can be sustained by the present growing stock.

Overcutting of ponderosa pine today is a problem, chiefly on private lands. However, the very unsatisfactory tree-size pattern on the national forest (fig. 10) indicates the need to take a serious look at the allowable cut that has been established for these lands also. The cut of ponderosa pine on the national forests may have to be reduced below present levels for some years before it can be increased, in order to build up the growing stock and overcome the serious deficiency of trees 10 inches and larger shown in figure 10.

There are three ways future curtailment of ponderosa pine production can be minimized:

1. Spread out the merchantable reserve of ponderosa pine as far as possible by logging decadent trees first, leaving those sawtimber trees that are growing well.
2. Discourage "premature" cutting of 10-, 12-, and 14-inch trees. These are the fast-growing trees that will help fill the gap 40 to 50 years from now. This will be difficult because much of the young ponderosa pine grows on the lands of so-called "small private owners."
3. Reclaim some of the area that was once ponderosa pine but has since been taken over by other species following logging of the pine. There is a problem of restoration of ponderosa pine on these sites through type conversion. In some of these stands, other species have gotten such a start we may have to raise and harvest them first. However, a good part of the original ponderosa pine area probably should be restored to ponderosa pine because this tree is so much more valuable than the species that are replacing it. This will have to be done largely through planting.

The bright spot in the timber inventory is in the forests of larch, Douglas-fir, and associated species, that occupy slightly more than half of the commercial area. There is not enough young timber in these types but the surplus of older timber both accounts for and offsets this deficiency (fig. 11). The annual cut of larch, Douglas-fir, and spruce is rising; so the problem will be to avoid consuming the surplus too rapidly.

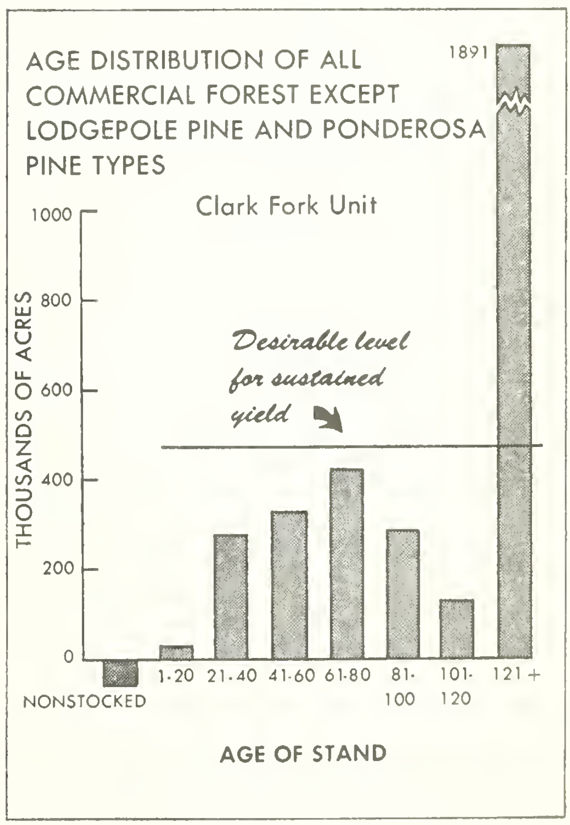
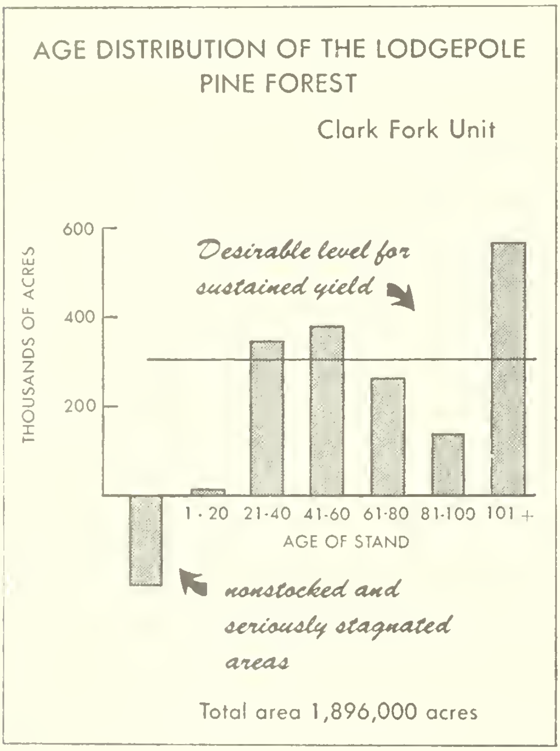


FIG 11

The lodgepole pine type presents a different problem. Superficially, at least, the age pattern is good (fig. 12), but when stand-size is considered, the situation is not so good. At least 9 percent of this type is stagnated. Many other stands 30 years and older have been overcrowded for so long that they are not likely to respond to management and probably never will produce sawtimber-size trees. In planning cultural work in the lodgepole pine type, it will be necessary to look at every young stand and appraise its vigor and potentialities. This will require a more complete understanding of lodgepole pine physiology and silviculture than we now have.



Erosion of quality

THERE HAS BEEN A DECLINE IN THE QUALITY OF TIMBER CUT IN THE CLARK FORK UNIT THAT HAS LARGELY PASSED UNNOTICED. Yet, a look at pictures of logging taken before 1900 suggests that either the horses and men were smaller then or that the logs are not as big as they once were. A few pictures hardly prove a trend; nevertheless, there has been a decrease in average log diameter that no one can actually measure. Whatever the decline has been, it is neither bad nor unreasonable. In the first place, the timber logged first was some of the biggest and best, and it was located in the easily accessible valley bottoms. It will not be possible to duplicate the 200-, 300-, or 500-year-old giants in rotations of 120 or 140 years. Another reason it takes more logs to make a load now than it once did is that the value of wood has increased and logs and trees are consequently being used that formerly were left behind as too small to be handled economically.

Log quality is a compound of size, growth characteristics, and freedom from defects. In this region, log size and frequency of knots are the principal factors foresters have to worry about. Large, high quality logs can be grown in rotations of 120 or 140 years, but they can be grown only by maintaining adequate growing space through thinning. The problem of knots likewise will need special attention if a significant amount of clear wood is to be produced. Wikstrom and Wellner's publication, mentioned earlier, discusses the limbiness problems in detail (*9*). Following, however, is the situation in brief.

Limb persistence is a characteristic of every softwood species in this region. The problem is less severe with larch because larch branches tend to be small, but it still is present. Rapraeger, in a very limited study, found that on one white pine tree, branch scars had not healed over for an average of 72 years after the limbs had died (*6*). On a second white pine tree, the average time for dead limbs to fall and the scars to heal was 93 years. How representative these two trees are is perhaps debatable. Nevertheless, we are perfectly safe in saying that the average period of dead limb persistence on natural growing stock in the Clark Fork Unit is at least one-half century. How much of a competitive handicap this is may be judged from a study by Benson H. Paul (*4*). He says that in the South, dead limbs persisted on shortleaf pine for an average of 12 years. On loblolly pine, the time span was 8 years, and on slash and longleaf pines, 6 years.

When trees are grown to ages of 200 years or more, there is generally still time to put on clear wood after the dead branches have dropped from the lower bole. However, if the pruning is left to nature, very little clear wood will be grown in the rotations of 120 to 140 years used in public management planning in this area. **PRUNING IS GENERALLY THOUGHT OF AS THE ULTIMATE IN FORESTRY AND SOMETHING OF A LUXURY. HOWEVER, IN THIS REGION, BECAUSE LIMB PERSISTENCE IS SUCH A SERIOUS MATTER, IT CAN BE MORE ACCURATELY DESCRIBED AS BREAD-AND-BUTTER FORESTRY, ALONG WITH THINNING.** There is a need to consider carefully what will happen in this region if both thinning and pruning are not made a part of management.

Since there is more than passing resemblance between the Clark Fork Unit of Montana and northeastern United States we can get an idea of what is at stake from the latter area. The problems of timber growing differ in the two regions in some respects, but it is appropriate to point out what happened to the eastern white pine in the absence of effective forestry. Lumbering in the United States began more than 300 years ago in eastern white pine stands renowned for their tall, clear trees. Yet, today the industry there is plagued with a high proportion of low-quality wood. It is reported that 55 percent of the white pine lumber now being produced in the Northeast is number 4 and 5 common, which means it is barely good enough to use (*8*).

The problem in the Clark Fork Unit likewise will be to keep log quality from drifting steadily downward and to stabilize it at a reasonable level. A big part of that task will be to reduce limbiness through pruning.

Stand regeneration

Some of the oldest forestry thought in this region was related to methods of establishing new stands following logging with emphasis on creating conditions that would facilitate the natural reseeding of the logged areas. With these beginnings, it is not surprising that consciously and unconsciously nature has been assigned the major responsibility for replacing the forest man has logged.

This policy which places dependence primarily upon natural reproduction has paid off well in some instances, for the new stands thus established have the vigor, density, and composition necessary for high yields. More often, however, stands thus established leave much to be desired.

VIEWED FROM THE ANGLE OF BUILDING UP FOREST PRODUCTIVITY TO SUSTAIN A LARGER TIMBER INDUSTRY, A POLICY OF TOO-COMPLETE RELIANCE UPON NATURAL REGENERATION HAS DISADVANTAGES AND DANGERS. In the first place, those young trees left standing after an area has been logged are very often poorer than they appear. Many of the small trees growing in sawtimber stands look young but are actually fairly old in relation to their size. What is more important, they lack the vigor of youth. Retarded trees vary in their capacity to respond to release, but in stand after stand the response is relatively small. New stands planted at the time of logging would, in many instances, pass them by and achieve volume yields not attainable with advance reproduction.

Natural reproduction, either in the form of young trees left after logging or established by natural reseeding following logging, may turn out to be costly for other reasons. One cost is the reduced productivity resulting from both understocking and overstocking of areas on which a big investment must be made in protection and administration over a rotation. If the decision is to plant after waiting in vain for natural reproduction, the cost of planting may be higher than it would have been if done immediately after logging, because brush has become established in the interim. On the other hand, the overstocking that sometimes results from natural seeding requires extra thinning measures not necessary in stands established artificially.

Dependence upon natural regeneration also reduces the opportunity to select species and to choose superior stock. This matter of species composition and quality of growing stock cannot be passed over lightly if we plan to make the most of the timber growing opportunity. For example, it might be a mistake to accept lodgepole pine on land best suited for spruce merely because a pine seed source is available or to accept slower growing natural stock instead of planting genetically improved trees.

Planting is not, of course, a cure-all. The planter has problems of seed source, survival, planting techniques, and cost. Nevertheless, in many situations natural regeneration will be too haphazard or will produce the wrong kind of stands. The only silvicultural solution to these situations appears to be to plant or seed. Each year about 20,000 acres of national forest and 30,000 acres in other ownerships are cutover. Only about 1,000 acres are planted each year — most of that on the national forests. In other words, nature is being depended upon to restock about 49,000 acres annually. The Forest Service is currently planning to expand its planting program on cutover areas. How far the program should be expanded is a moot point. The question can be answered only after a critical inspection of cutover areas and a detailed analysis of planting opportunities. The brief look at the problem in connection with this study indicates that it may be desirable to plant as much as 40 percent of the area logged each year; that is, about 20,000 acres in all ownerships. In any case, much more logged area needs to be planted if the Clark Fork Unit is to be managed for high production.

FORESTRY PROGRESS WON'T BE CHEAP

ANYONE HOPING THE SAWTIMBER CUT IN THE CLARK FORK UNIT WILL GO UP AND STAY UP IN THE ABSENCE OF A CORRESPONDING RISE IN THE FORESTRY EFFORT WILL BE DISAPPOINTED. Big yields require a substantial outlay of effort and there is already a considerable backlog of work to be done. The longer the delay in tackling this backlog, the harder it is going to be to catch up.

Twenty-twenty hindsight tells us that a big silvicultural opportunity was missed on the area burned during the region's turbulent fire years. During the first quarter of this century alone more than 1 million acres were burned in the Clark Fork Unit. Although these fire losses were regarded as disastrous at the time, there was a silver lining in the plumes of smoke. The fires made way for large areas of new forest in a region overloaded with mature stands. These young stands will play a key part in any future forestry program. Yet, they will not contribute as much to future yields as they might have merely because they were not thinned before they reached 20 to 30 years of age. The stands growing on the 1910 burn are a good example of the timeliness aspect of silviculture. It will cost from 2½ to 3 times more per acre to thin these stands now than it would have earlier.

A search of the record indicates that less than 20,000 acres have been thinned in the unit to date. Not even half that area has been pruned.

THE DELAY IN GETTING STARTED WITH THINNING IS GOING TO CUT INTO FUTURE YIELDS. Many stands have gone into a growth decline due to overcrowding from which they will never completely recover. Cores taken from tree after tree in stands 50 years and older tell the same story: booming growth rates have nosedived to various degrees as the canopy has closed in and competition has become stiffer (fig. 13).

When we look at what happened in the context of the times, it is difficult to see how the course of events could have been much different. Fifty years ago, forestry in the Clark Fork Unit was in a heavy shadow of uncertainty. The timber industry appeared to offer only a limited opportunity. Serious discussions were held as to whether we could afford even to protect some forest land. The outlook today is quite different. Timber production appears a more promising enterprise. While we still lack the data necessary to define the limits of the desirable and justifiable forestry program the area of uncertainty has been considerably reduced.

Just what it will cost to catch up with the silvicultural job in the Clark Fork area is an open question and will remain so until the goals are more clearly defined and better information is available as to the condition and potential of the forest. The best estimate we have of the total present job is based on an examination of Forest Survey plot data. It was possible to identify only certain obvious opportunities for planting, thinning, and pruning from the plot record. Yet, the job totaled to almost $20 a commercial acre, or $126 million in all (table 2).

This must be regarded as a conservative estimate of the total amount of work possible, as available Forest Survey plot data do not really indicate what needs to be done about such problems as dwarfmistletoe; nor do they show the magnitude of the regeneration task on cutover areas.

There is also the question of whether we want to do the total job. Any cost estimates must be tentative until the decision is made as to how much of the commercial forest area

Table 2. — *A minimum estimate of possible forestry measures in the Clark Fork drainage*

Forestry measures	National forests	Other owner-ships	Total
	— *Millions of dollars* —		
Pruning	18	18	36
Planting	19	20	39
Clearing	1	neg.	1
Thinning[1]	34	16	50
Total	72	54	126

[1]The term "thinning" is used here in a broader sense than defined in most textbooks on silviculture. It includes weedings, cleanings, and improvement cuttings as well as cuttings made in older stands to reduce stand competition. Thinning costs in this table are only for precommercial thinning where there are little or no commercial values to defray costs.

is to be devoted to intensified timber growing. Once we have the data needed to establish precise timber growing objectives it may be desirable to exclude the poorer sites from timber production and perhaps some other areas as well. In any case $4 or $5 million could be spent annually for 25 or 30 years catching up with the backlog on the national forests and meeting current silvicultural needs. A somewhat smaller expenditure would be required for catching up on all other lands.

ONCE THIS BACKLOG OF WORK IS COMPLETED, THE TOTAL TIMBER GROWING PROGRAM COULD BE KEPT ROLLING WITH A SMALLER OUTLAY. Here again it is impossible to be specific because timber growing objectives for the national forests have not been precisely defined and data on stand potentialities and treatment costs are very inadequate. However, the planting, precommercial thinning, and pruning program for Clark Fork Unit national forests probably should eventually settle back to something less than $3 million annually.

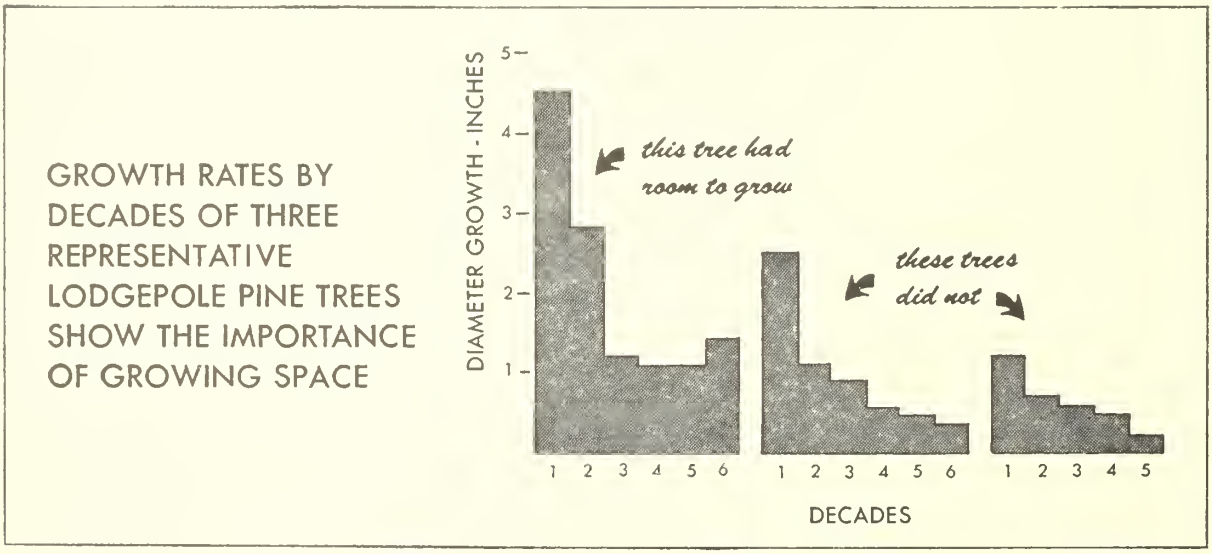


FIG 13

IS IT WORTH IT?

The answer to the above question will depend on who is answering, for the owners in the Unit have all degrees of capacity, purpose, and interests. From that standpoint, they may be divided into three groups: (See also table 3.)

1. Numerous small private owners.
2. A few larger managers such as the Anaconda Company, the Northern Pacific Railroad, the State of Montana, and the Bureau of Indian Affairs.
3. The national forests.

About 400,000 acres of commercial forest in the Clark Fork Unit are in farms and other small holdings. No figures are available to show how many of these small owners there are in this unit, but they probably number at least one thousand. With but few exceptions, the individual holdings of these owners are too small and lack the balance of growing stock required for long-rotation forestry.

The several really large private ownerships (including the semiprivate Indian lands) have the capacity to move into long-rotation forestry and presumably the incentive also. So does the State of Montana, which has been doing a steadily better job of managing its 256,000 acres of commercial forest in the Clark Fork Unit. State operations will be hampered by the fact that much of the State land is scattered and cutover.

Table 3. — *Approximate ownership of the commercial forest*

Ownership	*Million acres*
National forest	3.9
Other "large" ownerships	2.2
"Small" ownerships	0.4
Total	6.5

FORESTRY IN EACH OF THESE OWNERSHIP CLASSES REQUIRES A DIFFERENT TYPE OF EVALUATION. THE REST OF THIS REPORT IS DIRECTED PRIMARILY TO NATIONAL FOREST LANDS, EVEN THOUGH SOME OF THE CONSIDERATIONS APPLY TO THE OTHER TWO OWNERSHIP CLASSES AS WELL, AND SOME OF THE STATISTICS ARE FOR ALL FOREST LAND. Sixty percent of the commercial forest land is in the national forests. This fact, plus the avowed purpose of the Forest Service to maintain a high level of timber productivity and the capacity of the Federal Government to finance long-rotation operations, makes the national forests the best bet for raising timber production in the Clark Fork Unit to a high level.

Board-foot yields can be greatly increased

Natural stands in this region are not in the same class as the spectacular trees and acres in the South and on the West Coast. Nevertheless, well managed stands here can be very productive. For example, on medium sites harvest yields ranging from slightly less than 200 board feet per acre per year to more than 400 board feet are obtainable (*9*). Such production levels compare favorably with most of the forest in the United States.

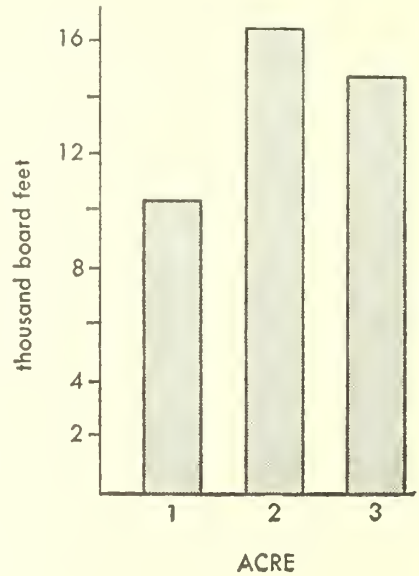
Lodgepole pine is often downgraded as a timber species; yet, as figure 14 shows, this species produces fairly high volume yields when the conditions of stocking are right. The acres described in figure 14 are on good land (that is, medium and better sites). Other lodgepole pine stands on equally productive land grew only matchsticks in the same length of time.

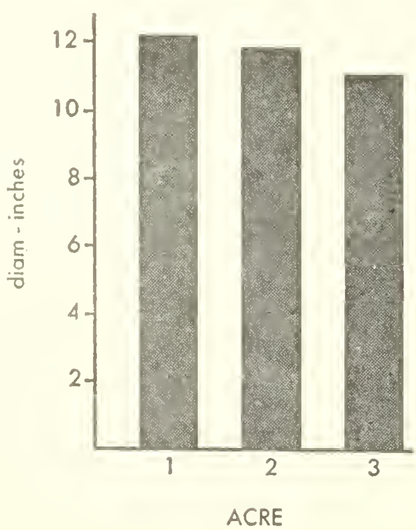
A thinning and pruning study shows that in the lodgepole pine type, for example, thinning in those stands in which it is not too late to thin would do three things:

1. Make it possible for all, instead of half, of the stands to produce sawtimber in 100 to 120 years.
2. Increase the average size of the harvestable trees.

In most Lodgepole Pine stands the trees and volumes are small. However, this situation is partly the result of circumstance. For example, there is an extensive stand in Flatrock Creek in which over-crowding has not been severe. Here the trees have grown well.

HERE ARE DATA FROM THREE TYPICAL ACRES IN THAT STAND WHICH IS 60 - 70 YEARS OLD ON GOOD SITE LAND





BOARD FOOT VOLUME PER ACRE

AVERAGE DIAMETER OF 100 LARGEST TREES PER ACRE

FIG. 14

3. Increase the number of harvestable trees.

The end effect of such gains on medium sites would be to produce a crop of 23,000 board feet per acre in trees 11 inches in diameter and larger. The present average yield of mature lodgepole pine sawtimber stands is 6,000 board feet per acre.

With thinning it will be possible to increase harvest yields even more in other types. For instance, in the spruce type, unmanaged stands of rotation age are yielding about 26,000 board feet per acre on medium sites. Thinning properly timed can boost the average yield to 49,000 board feet, which is much closer to the productive capacity of the soil (fig. 15).

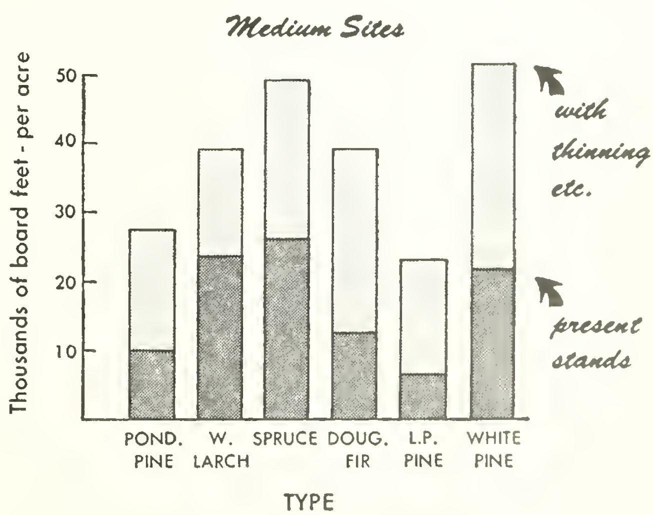
Full benefits from thinning will be realized only in stands fully stocked with vigorous trees. Thus, one step toward higher timber yields is adequate stand reestablishment on deforested and cutover areas. High priority, therefore, should be given to the task of improving the success ratio of stand reestablishment.

The first benefits from thinning are not likely to be spectacular. This is because many existing stands that need thinning have passed the point where they will respond completely to thinning. Nevertheless, some of these stands will have to be opened up to prevent a complete loss of productivity through stagnation and to achieve a partial buildup in yields.

Fast buildup of sustainable cut probably is not possible

There is wood physically available which could be used to expand industry in the Clark Fork. However, because of the imbalance in the growing stock already described, any big expansion now would constitute overcutting and a period of curtailment would inevitably follow. **HOWEVER, IF STAND REGENERATION, THINNING, PRUNING, AND OTHER SILVICULTURAL PROGRAMS WERE BEGUN NOW, A LARGER SAWTIMBER CUT COULD SOON BE JUSTIFIED ON THE NATIONAL FORESTS.** This does not mean that the total sawtimber cut for the Clark Fork Unit should be increased in the near future. Overcutting on other lands probably will offset any gains that can be realized on the national forests.

COMPARISON OF PER-ACRE VOLUMES OF WELL-STOCKED ROTATION-AGE NATURAL STANDS WITH VOLUMES POSSIBLE WITH ADEQUATE STAND REGENERATION AND THINNING



data for Western Montana

FIG. 15

Source: Wikstrom & Wellner

In fairness, we should point out that one of the main problems facing foresters in this region is that they lack a completely reliable basis for computing cutting budgets. The data available do not adequately describe the condition of the growing stock. As a consequence, forest managers have been unable to relate levels of cut to intensity of management. Thus, any estimate of future output is bound to be speculative.

Figure 16 probably represents as good an expression of the management opportunity as can be derived now for the 6.5 million acres of commercial forest of all ownerships in the Clark Fork Unit. The calculations and assumptions behind this chart are presented in Appendix A.

The story told by the chart is essentially this: **BECAUSE THE YIELD CAPABILITY OF THE FOREST DURING THE NEXT FOUR OR FIVE DECADES IS MORE NEARLY DEPENDENT UPON WHAT WAS NOT DONE IN THE PAST FIVE DECADES THAN IT IS UPON WHAT MIGHT BE DONE IN THE COMING YEARS, THERE WILL BE LITTLE CHANCE TO SUSTAIN A HIGHER SAWTIMBER CUT FOR A LONG TIME.**

- The first real upsurge of yields (on a sustained yield basis) cannot come until stands now under 40 years of age begin to move into maturity. Most stands older than that are too old to respond fully to release, but some will have to be thinned to keep them from stagnating. Commercial yields from thinning, likewise, are not likely to play an important part in the total production for several decades although there is probably some opportunity to increase present production by thinning.

POSSIBLE TREND OF SAWTIMBER YIELDS UNDER A FULL MANAGEMENT PROGRAM ON THE 6.5 MILLION ACRES IN THE CLARK FORK UNIT

— ALL OWNERSHIPS —

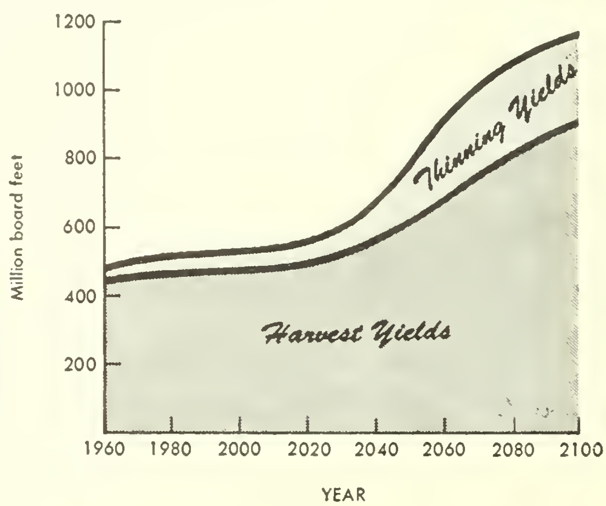


FIG 16

- The big payoff from present forestry effort will begin in three-quarters of a century. Yields will climb rapidly after that. It is physically feasible to plan on an ultimate annual output of from 1.1 to 1.2 billion board feet.

The prospects for industrial development are not, of course, entirely tied to the sawtimber supply. Even though the sawtimber situation appears to be deteriorating slowly, primarily because the forestry effort is not big enough, there is still a lot of wood available in smaller trees, largely unmarketable in the past.

To the extent that these less-than-sawtimber-size trees can be utilized, the cut could be increased immediately. The recent cut of all trees 5 inches and larger has been about 75 million *cubic feet* per year. If industry could adapt its appetite to using all the pole-size trees in mature stands, the currently sustainable production would appear to be about 25 percent larger than the present total cut.

Unless there is drastic technological change, the surplus of small trees is not and never will be a substitute for sawtimber for the same reason these trees are largely unmarketable today. Big trees are not only cheaper to log and manufacture than small ones; they have the size and quality characteristics for producing more valuable products.

This difference in value shows up in stumpage prices. Ponderosa pine sawtimber is selling for about $15 per thousand board feet. Lodgepole pine trees, which have essentially the same qualities but are mostly smaller than sawtimber size, are selling for only $5 per thousand board feet—where they can be sold.

Wood utilization men make the point that the best hope for using the small timber in this region lies in maintaining a substantial cut of larger trees. The bigger, higher value logs historically have carried a disproportionately large share of the cost of area development and thus have subsidized the less valuable material. Therefore, a national forest management program directed toward producing bigger and better trees should enhance the possibilities of industrial expansion that more completely utilizes smaller trees.

The big effect will be on values

THE ARGUMENT FOR INTENSIVE FORESTRY IN THIS AREA IS LARGELY TUNED TO THE FACT THAT THINNING AND PRUNING IN PROPERLY REGENERATED STANDS WILL PRODUCE REALLY HIGH CROP VALUES. Size increases from thinning alone will boost revenues considerably. For example, the value *per board foot* of 24-inch trees is three times the value of 12-inch trees (fig. 17). Revenue possibilities will increase still more if the stands are both pruned and thinned.

The man with the thinning ax and pruning saw can produce a particularly remarkable improvement in lodgepole pine revenue. The average gross value of merchantable lodgepole pine on the stump today is about $36 per

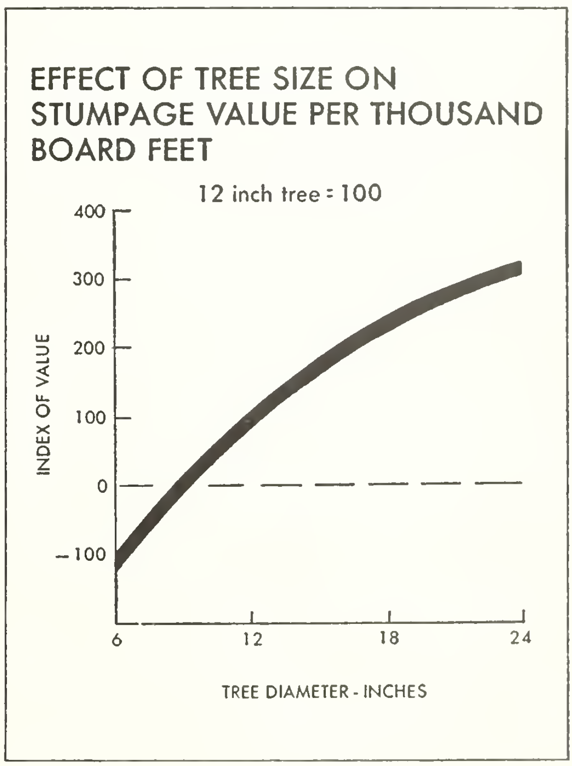


FIG 17

acre on medium sites, which is not much value for 100-plus years of growth. However, lodgepole stands that are thinned as they should be in the coming years will produce timber worth $269 or more per acre (at current prices). Thinning, plus pruning, can raise the crop value to $737, about 20 times the present level (*9*).

Crop values on medium-site western white pine lands carried through a rotation can be lifted from $330 to almost $2,200 an acre. The story is the same in each of the other types. Thinning and pruning can raise gross dollar returns 4 to 20 times higher than they are now (fig. 18).

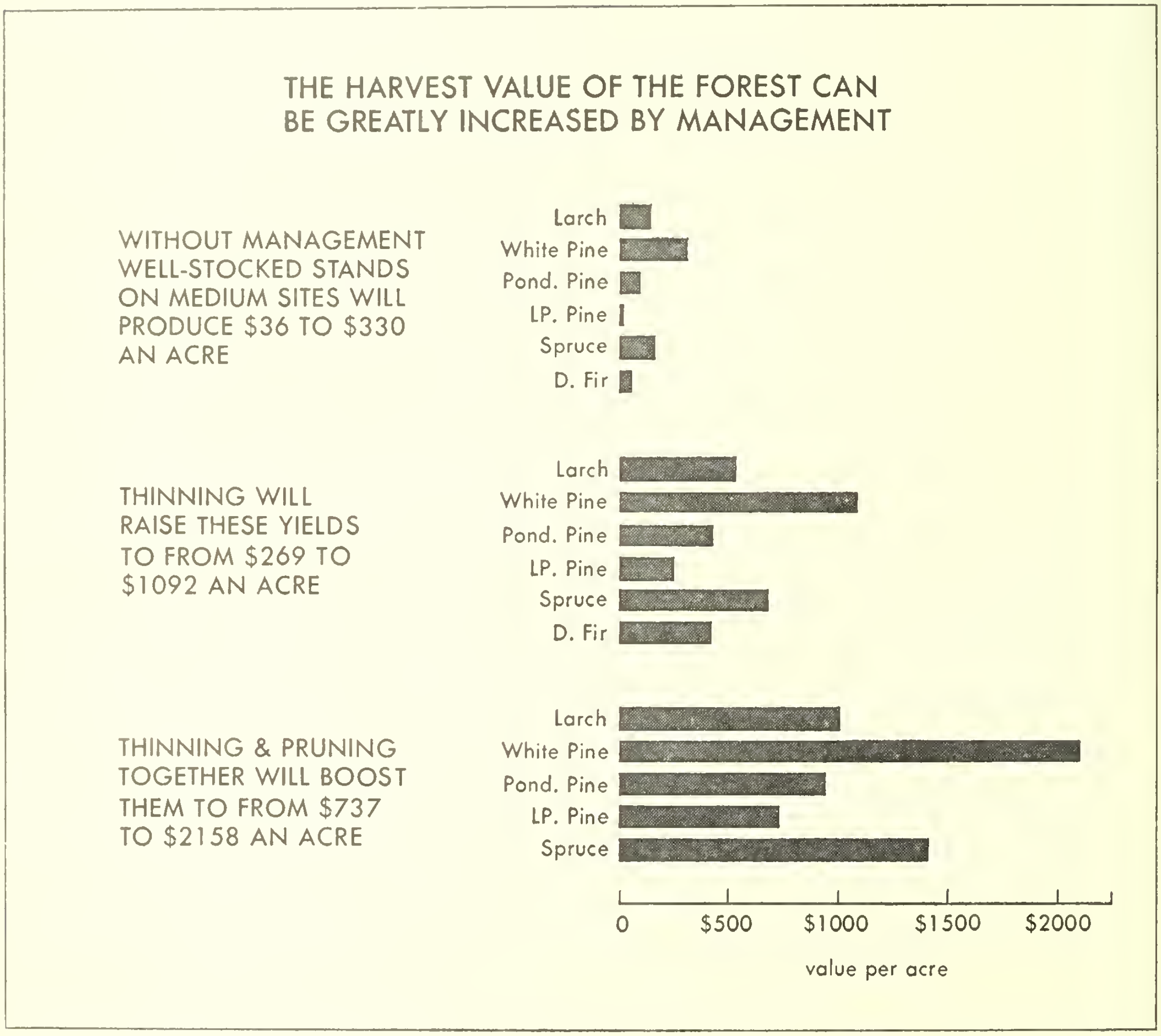


FIG 18

Ultimately values can be high

In timber management, as well as in other phases of national forest administration, there are two basic issues: WHAT needs to be done and HOW MUCH needs to be done to make these areas contribute as they should to the future needs of society? These issues also apply to private lands but they are the overriding consideration on public lands.

Although the **what** question is complex enough, as we have already shown, it is easier to resolve than the **how much** question. Primarily this arises from the fact that while Americans have embraced natural resource conservation with some enthusiasm, economic evaluation processes relating to resource management have not yet fully matured. There are, in fact, some rather substantial differences of opinion about the mechanics of analysis that make it necessary for anyone discussing the subject to state his point of view. Some would limit economic analysis to an acre-by-acre comparison of the capacity of land to produce an interest return on the estimated costs of production. Long-run values (usually based on present prices) are discounted to determine what expenditure of effort for stand regeneration, thinning, and other silvicultural measures could be justified. At the other extreme are those who feel that this type of analysis has three serious weaknesses as a yardstick for establishing public policy:

1. Because it encourages the assumption that the importance of timber to society as a whole is expressed by the capitalized market value of timber products.
2. Because it projects price relationships so far into the future that they lose meaning in a society like ours of rapid technological change and growth.
3. Because it seems more appropriate to consider the costs of maintaining a society as operating costs rather than as investments.

Examined in an investment framework, the earning power of the Clark Fork Unit, and for that matter any of the forests in the Mountain States, is hardly such as to arouse much enthusiasm. Table 4 shows the interest-earning capacity of different parts of the forest under more or less typical assumptions of silvicultural practice.

These calculations include no allowance for the value of the land or costs of controlling insects and diseases but neither do they allow for the historic upward trend of prices.

Table 4. — *Estimated rate of return on regeneration, thinning, and pruning investments by type and site*[1]

Type	Site		
	Good	Medium	Poor
	Compound interest return—percent		
Ponderosa pine	2.2	1.7	1.1
Spruce	2.4	2.2	1.4
Larch	2.4	2.0	1.3
Douglas-fir	2.0	1.7	.9
Lodgepole pine	2.7	2.1	1.2

[1]The costs and values entering these calculations are shown in Appendix B.

Some forest economists who make financial calculations like those in table 4 will say that because other nonmarket considerations are important, it is desirable to undertake a timber growing program even though the interest return is low. We, the authors of this publication, question the desirability of such computations in the first place, because the nonmarket considerations are so overwhelmingly important as to make the traditional investment calculations beside the point on public lands and possibly also on some of the larger private holdings.

We also feel that so long as it appears there will be a need for the timber, it is illogical to encourage the public to continue to pay 50 cents per acre per year to operate the forest of this area for an annual gross revenue of 51 cents plus certain other social economic values, when for 75 cents per acre per year the productivity of the land could eventually be increased to give a gross revenue of $1.39 along with other benefits. The following remarks are from that point of view.

If we focus our attention on the decisions to be made relating to the national forests, three factors seem both relevant and significant:

1. **INTENSIFIED FOREST MANAGEMENT IN THE CLARK FORK NATIONAL FORESTS APPEARS TO BE GOOD BUSINESS.** As we have said, the practice in economic evaluation of forestry generally is to consider each acre separately, calculating what it will cost to grow the stand, and comparing costs to harvest values sometime hence. There is a certain amount of inconsistency in the process, as fire protection is generally regarded as an operating cost and not an investment. Where long rotations are involved, the compounding of interest charges against the costs of the necessary silviculture tends to lead to the conclusion that the effort isn't very much worthwhile.

Although the investment concept of the forestry operation is applicable to certain situations, it is not mandatory that it be applied universally. The objective of society is to devise evaluation procedures to fit its needs rather than to warp its operations to fit the mechanics of an analytical system. The question so far as public forest land administration is concerned is, how much of the money received for stumpage and deposited in the Federal Treasury should be returned to cover stand regeneration and silvicultural work in young stands. In other words, the basic question is whether to consume the timber resource capital or to maintain it consistent with some specified timber growing objective. This question precedes any consideration of investment. That being the case, there appears much logic to considering the total timber-growing property or management unit as a single package. From this "one enterprise" viewpoint the costs on the acres that require silviculture (the young stands) become chargeable to the acres producing revenues (generally the sawtimber stands). When this is done, each year becomes a financial calculation unto itself.

In view of past experiences with the practice of depleting renewable resources, the consequences of not returning enough to the land hardly need to be proved. It is in this sense that intensified public forestry is good business. The situation is parallel to that of the farmer who holds out money for seed, plowing, and taxes from his harvest income, but none for the fertilizer required to maintain soil productivity. If he fails to recognize all of the costs year after year, he is merely easing himself into a marginal existence while enjoying a foolish satisfaction from "profits" that are partly capital depletion. By "plowing back" a substantial part of national forest timber revenues each year, it will be possible to greatly enhance the quantity, quality, and therefore value of future timber yields.[8]

2. **INTENSIFIED TIMBER MANAGEMENT WILL BRIGHTEN THE LONG-RUN PROSPECTS OF LOCAL COMMUNITIES.** The alternatives, so far as local communities are concerned, are worth restating. If efforts in stand regeneration, thinning, and pruning are not intensified, there will be only minimum opportunity to increase the total cut from the national forest. The quality of the timber harvested will decline: That is, the trees will be smaller and limbier. If history means anything, we may be sure the wood industries of the future will adapt to whatever raw material is available. However, it is hard to ignore the probability that the poorer their

[8]There is little direct relation between revenues and subsequent expenditures in actual practice. Except for certain permitted withholdings, the revenues are divided between the Federal Treasury and local governments. Congress determines and appropriates operating funds. Nevertheless, any evaluation of business opportunity requires some such comparison of costs and returns.

raw material the less the wood industries will contribute to local income.

If silvicultural practice is intensified to some degree, we may expect a corresponding increase in the value and potential contribution of the forest. The significance of this to community expectations for security and growth needs no explanation. As a matter of fact, if the governmental responsibility for economic continuity and economic opportunity is taken seriously, some degree of intensification of silvicultural practice is synonymous with sound administration of the national forests in the Clark Fork Unit.

3. **INTENSIFIED TIMBER MANAGEMENT HERE CAN SERVE NATIONAL INTERESTS AS WELL.** There are two aspects to this situation: The relation of the Clark Fork Unit timber to the Nation's total wood needs; and the relation of timber growing on these national forests to efficient multiple-use operation.

The U. S. Forest Service report, Timber Resources for America's Future (7), examined the long-run forestry outlook in this country and concluded that all of the forest area and forestry effort likely to be mobilized would undoubtedly be required to assure adequate timber supplies in the future. This establishes a good reference point for an aggressive public forestry program. However, even if one does not take these long-range prognostications seriously, a strong rationale can be developed for such a program. We must admit that the future is as much of an uncertainty as it ever was and that there is no good basis for predicting the political, technological, and resource context that our timber supply situation will be set in during years to come. However, this uncertainty is a two-way street in that the dangers of underestimating future needs are just as great as the dangers of overestimating. That being the case, it becomes a matter of national prudence to practice a "productive" level of management on public forest land. Prudent management requires no great sacrifices in a rich nation like this that has more manpower than it is able to use effectively. As Robert L. Heilbroner says in his book, The Making of Economic Society, "A society with unemployed factors can put its idle resources to work building capital without diminishing its expenditure on consumption" (2).

The Clark Fork Unit is an important headwater of the Columbia River system. It provides outstanding hunting, fishing, and other recreational attractions. Thus, the national forests here will have to be protected and administered regardless of the industrial wood they produce. Timber growing will, however, increase the efficiency of the whole national forest operation. Figure 19 illustrates the advantage to be gained. The data in this chart are only illustrative and have no more stature than any other calculations related to values so far in the future. Both the costs and returns may turn out to be quite different than have been assumed. The point they make is nonetheless valid. It is that once the productivity of the timber stands is built up by silvicultural effort (which will be many years hence) it would be appropriate to expect timber revenues at that time to make the national forests financially very productive, not only defraying the total cost of protection and management but returning a good surplus besides. A sizable expenditure for silviculture will be required for many years before that happy situation is achieved.

Facing into the future

In forestry, more than almost any other enterprise, looking ahead and developing clearcut objectives are essential forerunners of purposeful action. If we can agree that silvicultural effort beyond what has been done in the past is desirable in those areas to be dedicated to timber growing, the first step is to decide which areas these are. Productivity of some of the poorer land is undoubtedly too low to justify intensive cultural programs. Other very steep or fragile areas probably

AN ILLUSTRATION OF THE ALTERNATIVES:

EVENTUAL ANNUAL COSTS AND SAWTIMBER RETURNS FROM THE CLARK FORK UNIT NATIONAL FORESTS WITH A MINIMUM PROGRAM DESIGNED PRIMARILY TO PROTECT WATERSHEDS AND SUSTAIN A LOW LEVEL OF SAWTIMBER YIELD.

Basic costs of administration and protection	$1,950,000
Minimal expenditure for management sufficient to insure regeneration of all areas	1,000,000
Total expenditures	$2,950,000
Value of 300 million board feet annual cut	3,000,000
Net	+$50,000

EVENTUAL ANNUAL COSTS AND SAWTIMBER RETURNS FROM THE CLARK FORK UNIT NATIONAL FORESTS WITH A FULL PROGRAM OF STAND REGENERATION, THINNING AND PRUNING.

Basic costs of administration	$1,950,000
Costs of stand regeneration, thinning, pruning, etc.	2,920,000
Total expenditures	$4,870,000
Value of 600 million board feet annual cut	$9,000,000
Net	+$4,130,000

FIG. 19

should be withdrawn from commercial timber production simply to protect watersheds. During the coming few decades it probably will be necessary to concentrate efforts on the most productive lands. In any case, priorities of action need to be established. National forest administrators in this region are working with the Intermountain Forest and Range Experiment Station to develop new and better data for describing action needs.

Clarification of objectives is only part of the administrator's problem. At present he is handicapped by the lack of answers to important silvicultural questions. The two major timber questions he is asking the researcher today are: How can we do a better job of reestablishing spruce and Douglas-fir stands? and, What are the potentialities of tens of thousands of half-grown stands if we treat them in different ways?

* * * *

The national forests of the Clark Fork Unit are but a small part of the total public forest in the United States. Moreover, since they are operated with appropriated funds, the financial needs for public forestry must be weighed against the needs of other items in the public sector of our economy. Allocation of public funds involves considerations beyond the scope of this discussion. It is sufficient to say here, perhaps, that these public holdings that have been capably protected and managed in the past offer a substantial additional opportunity in the form of intensified silviculture.

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APPENDIX A

The information on potential yield summarized in figure 16 is based on cutting over an equal portion of the area during each year of the rotation wherever possible. Potential harvest yields for the first few decades were estimated by multiplying the average volume per acre in current sawtimber stands by the area to be harvested. Subsequent harvest yields were developed from a projection of existing stands and stands to be established under an assumed level of management which included a complete thinning program.

Table 5 shows the trend in harvest cut we estimate is possible with management in the Clark Fork Unit. Except in the lodgepole type, there is little likelihood that harvest cuts can be increased until the youngest of the present stands reach maturity. From then on, the cut could be increased so as to reach the potential for the assumed level of management by the end of the rotation.

The lodgepole pine yields presented in table 5 are predicated on dropping utilization standards from the present 11.0 inches d.b.h to 9.0 inches and later to 7.0 inches.

Table 5. — *Trend of harvest cut possible with management in the Clark Fork area*

Rotation year	Annual Yield			
	Ponderosa pine type	Lodgepole pine type	Other types	Total
	Million board feet			
1	91	100	260	451
21	91	120	260	471
61	91	137	260	488
81	91	182	260	533
86	110	182	260	552
98	168	182	260	610
101	168	182	368	718
108	212	182	368	762
121	212	182	387	781
141	212	305	387	904

Eventually, sizable intermediate yields from commercial thinnings can be expected in the Clark Fork Unit. However, to begin with, these yields will be small because there are so few stands in which commercial thinnings can be justified. Once the young stands now being treated precommercially attain sawtimber size, the amount of wood available in intermediate yields will increase. Table 6 shows the trend in harvest cut and the trend in yield from thinnings we estimate to be possible in the Clark Fork area.

Table 6. — *Trend of harvest cut plus thinning cut possible in the Clark Fork Unit with management*

Rotation year	Annual Yield				
	Harvest	Thinning			Total
		Ponderosa pine type	Lodgepole pine type	Other types	
	Million board feet				
1	451	—	—	34	485
21	471	—	—	34	505
51	471	8	—	34	513
61	488	8	8	34	538
71	488	17	8	61	574
81	533	17	29	61	640
86	552	17	29	61	659
91	552	37	29	61	679
98	610	37	29	61	737
101	718	37	50	135	940
108	762	37	50	135	984
111	762	46	50	135	993
116	762	46	50	159	1,017
121	781	46	53	159	1,039
141	904	46	53	159	1,162

It is possibly too much to assume that there will be a full scale thinning program during the first rotation. However, this optimistic assumption is tempered somewhat by conservative yield estimates in tables 5 and 6.

Basic information on yield estimates

Ponderosa pine type. — In order to estimate the ponderosa pine situation, a tabulation was developed from Forest Survey data comparing the area actually occupied by each age-class of timber with a theoretical stand table for the type. Table 7 converts the all-age ponderosa pine stands to an area unit basis for the purpose of estimating the area theoretically occupied by each age-class.

Table 7. — *Area units and acres theoretically occupied by each ponderosa pine age-class in the Clark Fork Unit by owner class and all owners*

Age class (years)	National forest		Other owners		All owners
	Area units	Acres	Area units	Acres	Acres
0 - 9	50.80	159,948	52.44	270,553	430,501
10 - 17	9.62	30,289	18.47	95,292	125,581
18 - 24	12.79	40,270	13.02	67,174	107,444
25 - 33	7.79	24,527	10.63	54,843	79,370
34 - 43	7.41	23,331	8.20	42,306	65,637
44 - 55	5.83	18,356	6.45	33,277	51,633
56 - 74	6.16	19,395	5.88	30,337	49,732
75 -100	5.28	16,625	4.89	25,229	41,854
101 -129	5.68	17,884	3.89	20,070	37,954
130+	28.64	90,175	16.13	83,219	173,394
Total	140.00	440,800	140.00	722,300	1,163,100

The critical point in the above tabulation is in the 56- to 74-year age-class. Thus, in a sustained-yield program, these and older stands should be utilized over an 85-year period. Following that, $\frac{1}{\text{Rotation}}$ of the area should be cut annually.

Table 8 shows the effective area to be cut over and the volume available by periods. Since the forest has been converted to equivalents of ideally stocked areas, the volume per acre used to estimate total volume yield is that which we estimate is possible under management (25,600 board feet).

Because the ponderosa pine type is generally understocked, the sawtimber volume obtainable from intermediate cuts will be insignificant until the fifth decade from now. Stands thinned at 60 to 70 years should produce a second thinning at 90 to 100 years. The higher site areas are expected to produce a third thinning at about 110 years of age.

Table 8. — *Trend in harvest cut possible in the ponderosa pine type in the Clark Fork Unit by area cut over and volume attainable*

Years	Effective area cut over each year	Annual timber cut
	Acres	*M bd. ft.*
1- 85	3,564	91,238
86- 97	4,303	110,157
98-107	6,564	168,038
108-116	8,300	212,480
117-123	8,300	212,480
124-131	8,300	212,480
132-140	8,300	212,480

Thinning yields shown in table 6 are based on thinning 8,300 acres each year in each thinning treatment and on the assumption that:

- The first commercial thinning will yield 1,000 board feet per acre beginning in the sixth decade from now.
- In 70 years the thinning yields will rise to 2,000 board feet per acre.
- In 90 years a second thinning will be possible yielding 2.5 thousand board feet per acre in addition to the 2,000 board feet above.
- In 110 years a third thinning will be possible on medium and better sites, raising the average yield from intermediate cuts by 1,000 board feet per acre. (8,300 × 2M + 8,300 × 2.5M + 8,300 × 1M = 45.7 million board feet, table 6.)

Lodgepole pine type.—About the only opportunity for increasing allowable cut in the lodgepole pine type in the next 50 years will come through increased cutting of smaller trees. As far as sawtimber is concerned, this merely means that a higher level of sawtimber cut will be achieved in this period only by lowering the standard of what is called sawtimber. This has already been occurring. The harvest cuts shown in table 5 are based on cutting over 15,200 acres per year. It is assumed that during the first two decades:

- Trees 9.0 inches d.b.h. and larger will be utilized.

- The average volume per acre cut will be 6,600 board feet.

During the third, fourth, and fifth decades:

- Utilization standards will drop to include half of the trees 7.0 inches to 9.0 inches in diameter.
- The average volume per acre cut will increase to 8,300 board feet.

Beginning with the sixth decade:

- All trees 7.0 inches and larger will be utilized.
- The average volume per acre cut will increase to 9,100 board feet.

Beginning with the eighth decade:

- Harvest yields should begin to reflect the impact of management and should average 12,000 board feet per acre.

By the end of the rotation:

- Harvest yields should be up to 20,000 board feet per acre.

There is little chance that intermediate cuts for sawtimber can be made in the lodgepole pine type during the next 50 years. Most of the less than rotation-age stands that are now sawtimber size lack the vigor necessary to make thinning worthwhile. Most likely, intermediate sawtimber yields in this type will not amount to much until stands now treatable precommercially have attained sawtimber size.

The intermediate yields shown in table 6 for lodgepole pine are based on the following assumptions:

- An intermediate cut averaging 1,000 board feet per acre over 15,200 acres will be possible beginning with the sixth decade from now.
- The intermediate cut per acre should increase to 1,500 board feet in the seventh decade.
- By the eighth decade, the intermediate cut per acre should be 2,500 board feet.
- In 90 to 95 years a second commercial thinning will be possible on the medium and better sites, raising the average yield per acre in intermediate cuts to 3,500 board feet for the 15,200 acres, although actually more acres than that will be thinned annually.

Other types

The data on trends in harvest yields in types other than ponderosa pine and lodgepole are based on cutting over the area in 140 years, or 24,450 acres annually. It is further assumed that:

- It will be impossible to materially increase per acre yields above the current level of 10,000 board feet during the next 80 years.
- After 80 years the effect of management should begin to be reflected in increased per acre yields, which should climb to 15,000 board feet.
- In 120 years the cut per acre should be up to 24,500 board feet per acre.

There are about 1.2 million acres of young stands in which thinning could be done. The intermediate yields shown in table 6 are based on the assumption that this area will be thinned commercially during the next 70 years and will yield 2,000 board feet per acre in intermediate yields. After 70 years, stands established following 1960 will begin to yield intermediate cuts. It is assumed that these stands will:

- Be thinned at age 70 at the rate of 24,500 acres per year, yielding 2,500 board feet per acre.
- At age 100 a second thinning will be made yielding 3,000 board feet per acre on another 24,500 acres.
- At age 115 to 120 a third thinning will be possible on the medium and better sites which will increase the average yield from intermediate cuts the equivalent of another 1,000 board feet per acre for 24,500 acres. (24,500 × 2.5M + 24,500 × 3M + 24,500 × 1M = 159.3 million board feet, table 6.)

APPENDIX B

SOME STATISTICS DESCRIBING THE CLARK FORK AREA AND FOREST RESOURCE

Table 9. — *Area in the Clark Fork Unit by major land classes*

Land class	Area-acres
Water area	122,317
Forest Land	7,646,662
Commercial	6,482,112
Noncommercial	1,164,550
Nonforest Land	2,636,863
All Land	10,283,525
Gross Area	10,405,842

Table 10. — *Commercial forest area by type and ownership class, Clark Fork Unit*

Type	Area by owners		
	Total	National forest	Other owners
	Acres		
Douglas-fir	2,168,028	1,173,183	994,845
Lodgepole pine	1,895,840	1,440,315	455,525
Ponderosa pine	1,163,086	440,813	722,273
Western larch	722,069	453,090	268,979
Engelmann spruce	300,168	231,299	68,869
Alpine fir	68,517	58,515	10,002
Whitebark-limber pine	54,123	31,125	22,998
White pine	49,507	49,438	69
Hardwood	28,166	1,650	26,516
Grand fir	11,308	10,892	416
Western redcedar	9,813	6,011	3,802
Mountain hemlock	6,303	6,303	....
Western hemlock	5,184	3,125	2,059
All types	6,482,112	3,905,759	2,576,353

Table 11. — *Commercial forest area by stand-size and two owner classes, Clark Fork Unit*

Stand-size class	Area by owners		
	Total	National forest	Other owners
	Acres		
Sawtimber	3,707,279	1,986,257	1,721,022
Pole	2,091,574	1,423,207	668,367
Seedling-sapling	584,536	425,841	158,695
Deforested	98,723	70,454	28,269
Total	6,482,112	3,905,759	2,576,353

Table 12. — *Estimated rate of return on regeneration, thinnng, and pruning investments by type and site on the Clark Fork Unit*

Species	Site	Treatment age		Treatment cost per acre			Crop value	Rotation	Rate of return
		Thin	Prune	Regen-erate	Thin	Prune			
		Year	Year	Dollars				Years	Percent
Ponderosa pine	G	10	20	60	20	30	1,984	140	2.2
	M	10	30	60	20	33	963	140	1.7
	P	20	40	60	20	42	456	140	1.1
Spruce	G	10	30	40	20	38	2,151	140	2.4
	M	20	30	40	20	35	1,426	140	2.2
	P	20	40	40	20	50	605	140	1.4
Larch	G	10	20	20	20	43	1,698	140	2.4
	M	10	30	20	20	53	1,011	140	2.0
	P	20	—	20	20	—	218	140	1.3
Douglas-fir	G	10	—	30	20	—	715	140	2.0
	M	20	—	30	20	—	446	140	1.7
	P	20	—	30	20	—	160	140	.9
Lodgepole pine	G	10	20	15	20	52	1,434	120	2.7
	M	10	30	15	20	55	737	120	2.1
	P	20	—	15	20	—	124	120	1.2

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RECREATION OPPORTUNITIES AND PROBLEMS IN THE NATIONAL FORESTS of the NORTHERN AND INTERMOUNTAIN REGIONS

as they relate to the development of a research program

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PREFACE

The following analysis is the first step in an expanded program of outdoor recreation research at the Intermountain Forest and Range Experiment Station. Its purpose is to describe the recreation situation and opportunity on the national forests within this experiment station's territory and to identify the principal problems related to recreation use—all for the purpose, of course, of pointing the way to more effective research. Many people in the Forest Service for a long time have been living with the problems of managing and developing the recreational assets of the national forests. The following discussion draws heavily from their experience and vision. Particular thanks are due D. B. Partridge, a veteran in the outdoor recreation field, who has counseled the author throughout the preparation of this report.

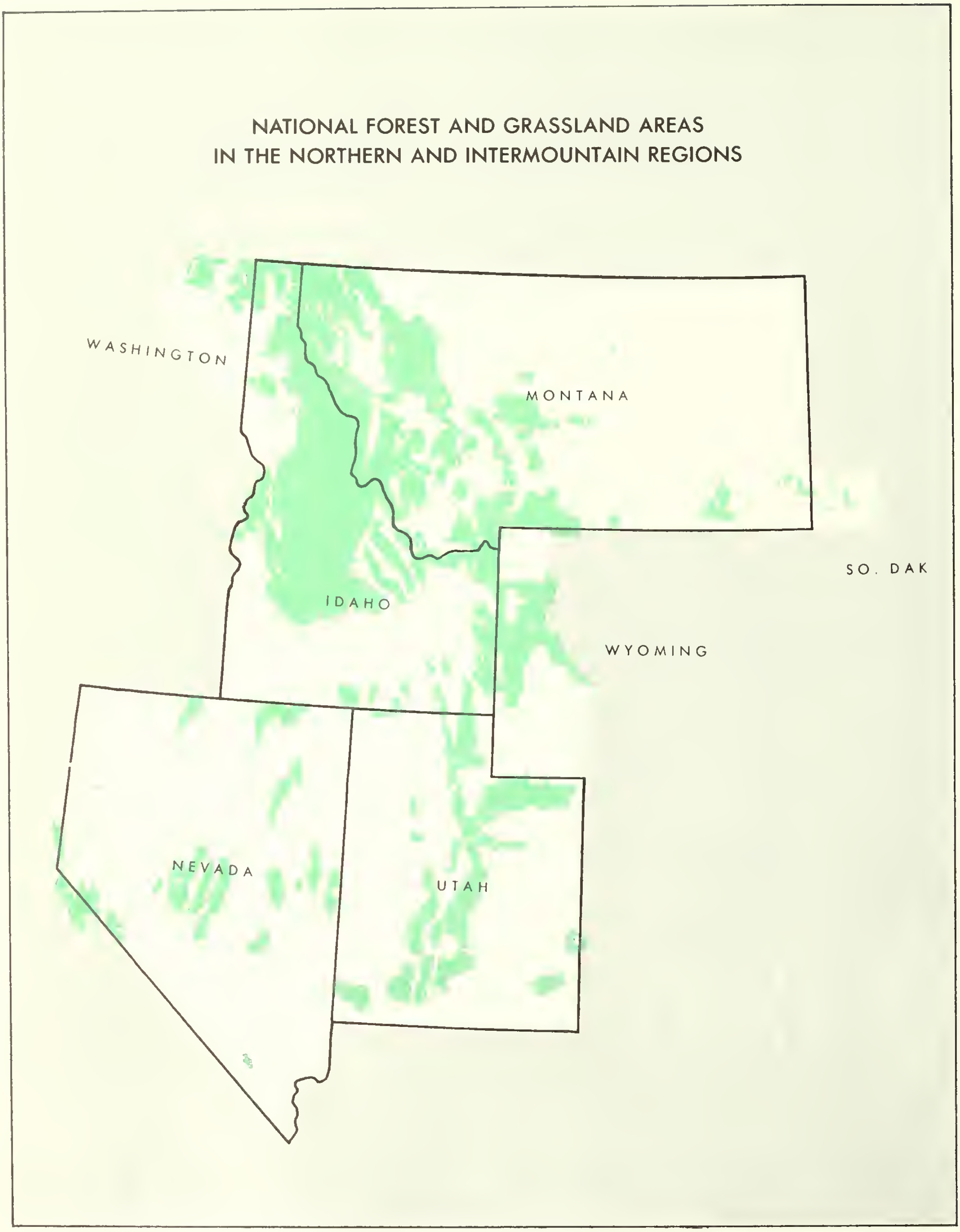

NATIONAL FOREST AND GRASSLAND AREAS
IN THE NORTHERN AND INTERMOUNTAIN REGIONS
WASHINGTON
MONTANA
IDAHO
SO. DAK
WYOMING
NEVADA
UTAH

Figure 1.

RECREATION ON THE NATIONAL FORESTS HAS GROWN UP AND HAS GROWN-UP PROBLEMS

People are becoming increasingly aware of recreation opportunities in the national forests of the Northern and Intermountain Regions[1] (fig. 1). This includes not only the general public, but Congress and national forest administrators as well. Not so long ago recreation was a minor partner in multiple-use management of the national forests. Today, however, it is beginning to receive its full share of emphasis in management decisions.

The new emphasis is not because national forest recreation is itself new. Actually, these public lands were something of a playground long before the first white men came, and we have written evidence that at least some of the early settlers took time out from the business of survival to relax on lands that are now national forests. More than a century ago, for example, Utah pioneers drove their wagons up into the mountains to escape the oppressive summer heat of the lower valleys in which they lived.

The increasing attention being directed to national forest recreation stems from the rising popularity of these forests as playgrounds. The more mobile, numerous, and affluent postwar society has turned to the national forests for leisure-time activity in constantly greater numbers. The interest of professional land managers in recreation is stimulated by the fact that the runaway expansion of recreation activity is creating serious problems in the development and management of the resource.

RECREATION VISITS TO THE NATIONAL FORESTS AND GRASSLANDS OF THE NORTHERN AND INTER-MOUNTAIN REGIONS

	Visits
1940	3,180,000
1959	20,329,000
1976	60,000,000
2000	160,000,000

Until very recently recreation development in the 34 national forests and 4 national grasslands of Regions 1 and 4 was low pressure, to say the least. There is no reason it should have been otherwise for in the past recreation use was not great. In 1940, for example, there were about 3 million visits to these areas for recreation purposes. Overall, at least, this was light use.

It all started with people just using the national forests. If they wanted to camp, they found an attractive spot and camped. If they were interested in fishing or hunting, they simply sought out the most likely locations and did so. This completely casual approach to recreation became less possible as the traffic increased. With mounting use, local concentrations developed and administrative actions were required. The big push to provide facilities for public recreation began during the 1930's with the Civilian Conservation Corps and has continued since then as finances have permitted. As more and more people took up skiing, ski slopes were developed to serve the crowds. As individual camping and picnicking areas became popular, tables, fireplaces, toilets, and other facili-

[1]The Intermountain Region includes Utah, Nevada, Idaho south of the Salmon River; and Wyoming west of the Continental Divide. The Northern Region includes Montana, Idaho north of the Salmon River, and northeastern Washington.

Within these Regions are 34 national forests and 4 national grasslands. Except in those few instances, where statistics are presented, the term "national forests" as used in this report includes both the forests and grasslands.

Figure 2. — Seeley Lake, Lolo National Forest, Montana. This scene repeated on lake after lake typifies the great new interest of the American people in the out-of-doors.

ties were installed to serve the public and to concentrate use so as to reduce problems of sanitation, safety, and fire. Mushrooming boat ownership has recently required construction of parking facilities and launching ramps (fig. 2).

One difficulty with this situation has been that because of limited financing the Forest Service has been, in the main, trying to catch up with use; whereas national forest administrators would have preferred to move out in front with planning and development. Nevertheless, the growing demands of recreationists appear to have been met fairly well and the history of recreation expansion on these national forests has, by and large, been a happy one. Thousands of people have been given the opportunity for relatively unregimented enjoyment of the out-of-doors. They have had the chance to wander where they would and enjoy what they wished. Only in recent years has the shoe really begun to pinch. Recognizing this, Congress has appropriated money for rehabilitation and expansion of national forest recreation facilities since fiscal year 1958. These two regions received $5 million for this purpose in the 2-year period, July 1, 1960 to June 30, 1962. The project has been called "Operation Outdoors."

Although much of the Operation Outdoors' money has been used in replacing worn facilities, this is only the more superficial aspect of the wear problem. More important is what has been and is happening to the environment in which these facilities are located. Anyone who has been around for long can see that the Seeley Lake Campground on the Lolo National Forest, the picnic areas along the Wasatch Front in Utah, and many others have lost much of their luster because of the heavy impact of human use. They are somewhat "shopworn" imitations of the beautiful spots they once were.

Serious though this situation is, it is overshadowed by a more pressing problem. The phenomenal growth of recreation makes it increasingly urgent to define the place of the national forests in the total recreation picture and to describe the kind of development necessary if these forests are to fill that place. Until we have done these things it will not be possible to develop the acute sense of value necessary to weigh recreation in relation to other uses of the national forests. How, for example, can we compare the relative values of a lovely meadow and the additional irrigation water made possible by converting the meadow alternately into a reservoir and a mudflat?

With some oversimplification the recreation situation can be summed up with the observation that the rapidly increasing demand for recreation—plus the rising demand for the other products of the forest as well—sets up a management task we are not yet entirely prepared to meet. As far as recreation itself is concerned, we face an array of questions that may, for convenience, be grouped into three overall problems:

- Finding the place of these national forests in the total scheme of American recreation.
- Finding the place of recreation on these national forests.
- Developing management measures adequate to prevent deterioration of recreation focal points.

Studies of the Outdoor Recreation Resources Review Commission and the Forest Service's own National Forest Recreation Survey are directed toward these problems. The discussion in the following pages, likewise, is focused on them.

DEVELOPING MANAGEMENT MEASURES ADEQUATE TO PREVENT DETERIORATION OF RECREATION FOCAL POINTS

What the vacationist seeks in national forests depends upon the time of year and his own interests. Yet, from the way people flock to the prettiest lakes, the most attractive scenery, and the shadiest glens, we may conclude that the principal attraction of national forests is an unspoiled natural setting with a strong emphasis on quality. It is somewhat ironic, therefore, that one of the main problems associated with outdoor recreation is the protection of such areas from their admirers.

This problem has many faces. It requires, for example, that twice a week someone fish out the beer cans, bottles, and papers from Big Springs on the Targhee National Forest. They have been tossed there by that small fraction of tourists that rangers wryly call "the slobs." It involves a never ending battle to keep power lines out of sight of scenic drives, to prevent the despoilation of streams by roadbuilding and other activities, to dispose of an increasing pile of garbage, and so on. So far as recreation use itself is concerned, the most serious and widespread deterioration of the native environment is occurring in places where people congregate.

There is a tendency to heap much blame on the dirty camper and the little vandal with the hatchet. Although these not-so-attractive Americans deserve all the criticism they get, they are in a sense red herrings diverting attention from the more serious site deterioration to which all users unintentionally contribute.

Excessive concentrations of people can impair both the physical and aesthetic qualities of any recreation site. Trampled vegetation and exposed tree roots are obvious examples of the physical site deterioration that results from pounding by too many human feet. In such areas the abused vegetation constitutes both site deterioration and reduced natural beauty.

A more subtle form of aesthetic downgrading happens when there are too many people in an area, even though there might be no physical damage. A lake may be loaded with natural appeal when 10 people are on its shores. It may still retain most of that appeal with 50 or even 250 people. But, at some point sheer numbers alone can transform the recreational opportunity. No longer is that lake a place where, as Whistler put it, "nature sings her exquisite song." Instead it has become just another body of water chiefly valuable for swimming and boating.

Swimming and boating are important vacation activities. However, a big part of the national forest recreation opportunity is an aesthetic intangible that should be safeguarded insofar as possible in the development program.

Campers and picnickers are a deteriorating force to be reckoned with

There are hundreds of camp and picnic areas on public lands in these two regions. Yet, only a handful of those that have been patronized to any extent are holding up well under use. The rest show signs of environmental deterioration. In some cases the damage, thus far, has been minor and evident only to the experienced eye. Elsewhere it has been severe.

The picnic areas in the Wasatch National Forest adjacent to Salt Lake City, Utah, are examples of abuse and deterioration at their worst. These areas have been literally overwhelmed with people and show all the signs of wear to be found in the more heavily patronized parks. Human feet have trampled and destroyed vegetation from the stream edge up the mountainside. Roots have been exposed. Topsoil is gone. In the Storm Mountain Picnic Area, for example, thousands of yards of soil have washed away because the protective vegetation is gone.

Badly deteriorated picnic and camp sites are not confined to Salt Lake City's backyard. Mirror Lake Campground, also on the Wasatch National Forest, Mackinaw Campground on the Fishlake National Forest, Redfish Point Campground on the Sawtooth National Forest, and Bison Creek Camp on the Deerlodge National Forest, are a few others in a state of advanced deterioration. As distressing a story as any is what has happened at Holland Lake Campground on the Flathead National Forest. This is one of the prettiest spots in the West, a place with magnetic qualities for recreationists. Heavy use has greatly deteriorated the camping area. The campground is currently being reorganized and expanded as part of Operation Outdoors. However, unless additional measures are taken, the expansion will only provide the opportunity for more wear and the old story of deterioration will be repeated (figs. 3 and 4).

It would be wrong to assume that all camp and picnic sites on national forests are so worn that they have lost much of their natural beauty. There are many attractive picnic and camping places in these regions. Nevertheless, all show signs of wear, and the worst situations today are a preview of a problem that will become more common unless aggressive steps are taken.

Aside from the decline in attractiveness, excessive wear at concentration points manifests itself in several ways; reduction of shade due to loss of trees, reduction of screening as shrub cover wears out, denudation of the ground, and an increase in dust and dirt. These conditions all lead to an eventual reduction of enjoyment. There is a tendency to attribute the trend toward camping trailers to the fact that the American people demand all the comforts of home when camping. This is probably an oversimplification. The trend has certainly been accelerated by the fact that there are fewer and fewer places the average person can find to set up a tent that are not dusty and dirty. Brand new picnic tables are small comfort if every passing car throws up a cloud of dust or if the youngsters come to the table grimy from the dirt underfoot. Yet this is a common fault of many camp and picnic spots. Even new developments such as Calamity Campground on the Palisades Reservoir are literally bathed in dust during dry weather.

* * *

Camp and picnic grounds in these two regions appear to be more fragile than those in some other parts of the United States. At any rate, site fragility can hardly be overemphasized. In most of this mountain country the growing season is short. Moreover, except for a few subirrigated streamside areas the moisture available in midsummer is generally scanty. The pinyon-juniper and drier ponderosa pine sites are better described as arid. Troubles generate from the fact that in their native condition, forest camps in these regions have a relatively low people-carrying capacity—a capacity frequently exceeded. In fact, some of the more popular spots are being subjected to visitor loads that would wreck a well-watered lawn.

There has been some tendency to accept this situation on the grounds that deteriorated forest camps are the inevitable price of outdoor recreation. However, such a resigned attitude doesn't appear either acceptable or necessary. In the first place, few persons are yet ready to admit population growth requires that the general public must be content with substandard camping and picnicking conditions. It is also a mistake to assume that continued heavy use of badly deteriorated areas signifies that the American public likes to eat and sleep in dirty and unsanitary places. The situation probably is similar to the case of the grizzly bears at West Yellowstone, Montana. Each night dur-

SOME OF THE WEAR AND TEAR OF RECREATION

Figure 3. — Storm Mountain picnic area near Salt Lake City.

Figure 4. — Spruces picnic area also near Salt Lake City.

Photos: Stewart Ross Tocher

ing the vacation season hundreds of people drive to the city garbage dump to see somewhat debauched bears paw through tin cans and paper in search of "tidbits." These people are willing to put up with unpleasant surroundings for the thrill of seeing dangerous wild animals in a more or less native habitat. This does not mean that they would not have had greater pleasure seeing these bears in a wilder setting without the smell of rotten vegetables. By the same token many people patronize worn camp and picnic areas to get away from the summer heat, to be near a boating lake or fishing stream or for some other reason although they would prefer more idyllic campsites.

Recreation technicians say that deteriorated forest camps are not inevitable in most cases if the American people are willing to pay the cost of proper development, maintenance, and control. The deciding factor, therefore, is how far we can afford to go. However, this economic evaluation cannot be made until we get a better idea of what needs to be done and what it will cost.

One fact needing no further proof is that artificial means will be necessary to maintain the natural beauty of all but the most lightly used camping spots. Some of the desirable measures go far beyond the usual concept of what is needed.

Water would do more than anything else for most campgrounds. For this reason the installation of sprinkling systems, revolting though the thought may be, would be desirable in many places. Occasional watering during the summer months would increase the lushness and impact resistance of the vegetation. It would make it possible to establish and hold a grass cover in many areas where trampling is not excessive. Sprinkling systems operating in the Guinavah Picnic Area and elsewhere on the Cache National Forest provide a fine example of what can be accomplished by watering.

Restoring and maintaining picnic and camping areas will require a broad action program beyond watering. Planting of shrubs will be necessary to provide screening between camping and picnic units, help channel traffic, protect the bases of trees, and provide ground cover. Some testing will be necessary to find additional species of shrubs that will thrive in a broad range of climatic conditions. Tree planting is badly needed in some areas to fill openings and provide replacements for older trees as they die out. Fertilizing should be considered as a means of accelerating the growth of planted shrubs and trees. Because some of the planting materials best suited for this particular job will not be generally available, it may be necessary to establish regional nurseries to produce the needed stock.

Camp and picnic areas may be divided into two parts; the part people occupy and the part that they look at. One big problem is how to channel traffic to prevent unnecessary trampling of grass, trees, and shrubs.

The problem of controlling dust, dirt, and wear differs from place to place depending upon soil and amount of use. In a few places, nothing needs to be done. At most locations roads and paths will have to be improved. Gravel will suffice on some, but in some cases hardtopping will be necessary. The area around tables and fireplaces presents a stickier problem and one that requires considerable thought. In certain circumstances it may be possible to maintain a pretty good grass cover close to tables by watering. Elsewhere a sawdust mulch may do the job. However, neither of these alternatives will work where traffic is heavy. Here it may be necessary to lay an asphalt "pallet" around the table and fireplace. At least some such pallets laid in the past have been unsightly and unsatisfactory, probably because they have been put on top of the ground rather than set in. In any case, a big problem is to find suitable surfacing for the pounded area around tables and fireplaces in heavily used camp and picnic grounds. Something also needs to be done about the "dust bowl" where one is supposed to pitch a tent and make a bed.

The whole problem of campground and picnic area development needs careful study not so much to find sturdier tables or fireplaces the muscle-bound picnicker cannot move, but to plan a strategy for keeping people on paths, pallets, and other areas designed to stand trampling, and off tree roots, and out of the bushes. This will involve not only establishing well defined paths but of inducing people to stay on them with strategically located shrubbery and other means. A big step in this direction has been accomplished in many camp and picnic grounds by constructing rock and log barriers to limit the movement of cars. In areas like Red Springs Campground on the Ashley National Forest and East Fork Campground on the Wasatch National Forest, vegetation formerly beaten down by cars is staging a comeback now that barriers have been erected.

The "landscaping" needs of properly designed camping and picnicking areas cannot be accomplished overnight. Development of such areas probably should be started a few years, and in some instances a number of years, ahead of their actual use. Sprinkling systems can be installed and watering begun. The necessary planting should be done and the planted stock given a chance to become well established before tables, fireplaces, signs, and latrines are installed and any use is permitted.

An outstanding example of the need for advance development is Pelican Point at Fish Lake on the Fishlake National Forest. It is only a matter of time before more camping space will be needed on this lake, and Pelican Point is an ideal place for such a camp except for the lack of trees. The longer the planting of needed trees and shrubs can precede the use of this area as a campsite, the more attractive and desirable it will be and the more able to hold up when the gates are opened to users.

The benefits of pre-use site preparation are obvious. Nevertheless, the pressure for new and enlarged picnic and camping facilities seems to require immediate action. Forest camps are often laid out and developed in a single season. In one case the camp sign was set up along the highway before the tables, fireplaces, and latrines had been installed. The dinner bell, figuratively, was rung before the table had been set.

* * *

Efforts to do a better job of developing and managing camp and picnic areas will be futile in these regions unless there is some control of use. There is a limit to the amount of traffic any piece of real estate can stand. The limits differ greatly from place to place depending upon soil, climate, and the care given, but there is nevertheless a limit.

Unfortunately, this limit is frequently exceeded on many camping and picnic areas, especially on peak days of the year such as the 4th of July, and it is chronically exceeded on the most popular ones. The campgrounds at Redfish Lake on the Sawtooth National Forest illustrate the problem at its worst. These campsites were built to accommodate about 300 persons at one time, yet an actual count on July 4, 1961, revealed that 2,500 people were jammed into this area, Coney Island style. This comparison may not show the full seriousness of the problem because there may be too many camping units per acre at Redfish Lake considering the impacts of normal use. Even if user impacts were reduced by eliminating some of the present camp spots, and by building more campgrounds elsewhere on the lake, the aesthetic impact might still remain. How many more than 300 people can be crowded around Redfish Lake before their collective presence tends to substantially reduce the level of individual enjoyment?

Hand in hand with intensified campground management techniques must be developed to keep visitor loads within the capacity of established units and established units within the capacity of areas to provide enjoyment.

It may also be necessary to reverse the current trend and reduce the number of picnic and camping units per acre in many camps. There is reason to wonder, for example, if site damage in Mirror Lake Camp on the Wasatch National Forest can be repaired without reducing the number of units in the area. It may be possible to relieve the peak flow problem with an approach tried in California where overflow camps have been established next to regular ones. They have minimum facilities and are opened only during periods of high visitor load.

No matter what is done along this line, ways must be found to keep more people from crowding into any area than can be properly accommodated without sacrificing recreational values.

Problems of sanitation are mounting steadily As many as 86 million visitor days may be spent picnicking and camping on national forests of the Northern and Intermountain Regions by the year 2000. This raises some horrible prospects so far as sanitation is concerned. Garbage collection and latrine maintenance has already become a big job and it will become bigger. Some ranger districts already operate municipal-type garbage trucks. By the year 2000 the annual policing and maintenance job on the anticipated 78,000 camping and picnic units will probably cost more than $5½ million. National forest administrators are not only worrying about the collection job, but also about what they will do with the increasing pile of debris. There has been some talk of need for incinerators.

A lesser aspect of the sanitation situation that probably will need more attention in years to come relates to the disposal of wash water presently tossed with a wide sweep into the bushes. In heavily used camps this may create minor health hazards, but in the long run the pile up of grease and soaps may be more objectionable from an aesthetic standpoint. It will also be hard on vegetation. This suggests that dishwater sumps may be desirable in some places.

Our wilderness is frayed in spots too The word "virgin" appears to be a relative term when used to describe forest land but, elastic though the word is, it can hardly be stretched to cover certain situations in the so-called wilderness. Probably 99.99 percent of the land in the Bob Marshall, Sawtooth, Uinta, and other wilderness and primitive areas is completely unspoiled. However, a tiny fraction is as beaten and abused as the most overpopulated picnic area—so much so as to take the edge off the wilderness experience. This mutilated fraction lies in the large camps used by hunters in the fall and by trail-riding groups in the summer. Some camps have had half a century of use and show it.

A composite picture of the most abused campgrounds is hard to forget. As we ride into them, our first sight is likely to be the weathered remains of last year's tent frames. A few plants struggle to survive in a bare area that has been torn and churned by horses hitched to trees. These trees, more than likely lodgepole pine, appear to be sitting on top of the ground because so much soil has blown or washed away from their roots. Every step our own horses take throws up a small cloud of dust. On the far side of camp the garbage dump—100 feet or less from the kitchen—is marked by a rusty old stove and a wide assortment of piled up cans and bottles.

The dump apparently hasn't been convenient for everybody because tiny trout swim through the neck of a broken gallon jug in the creek. A pot with a bullet hole in it lies half hidden along the water's edge. Here and there in the brush are caches of rusty tin cans that once held syrup, beans, fruit, and other food.

It is customary to blame the scattered tin cans on bears that specialize in digging into garbage pits. But it is obvious that they have had human help. For one thing many of the so-called "pits" aren't more than a foot deep.

If we wander out to where the horses graze after they have been released from the central hitching-eating-sleeping-storage area, we may find that other caravans have pass-

Photo: Don Tavenner

Figure 5. — This photo was taken in the bedding and eating area of the Brushy Park Camp in the Bob Marshall Wilderness Area. Uncontrolled hitching of horses not only causes the heavy wear indicated by the exposed roots; it also creates a shabby, dusty, unwilderness look.

ıre 6. — A cache near
erness area camp.

to: Don Tavenner

Figure 7. — Not in a wilderness area, but 5 miles from the nearest road. This is one of a number of garbage piles around a beautiful lake.

Photo: Roscoe B. Herrington

ed this way in recent weeks not leaving much to nourish our animals. Someone with a little better understanding of ecology may conclude that the vegetation is changing for the worse because of overgrazing. The original plants are being replaced by species better able to survive under heavy cropping.

This description is neither facetious nor overdrawn. It describes a real recreation headache plaguing the national forest administrator. This headache actually consists of three related problems that we may consider separately: campground wear, littering, and overgrazing.

* * *

Campground wear appears to be the easiest of the three problems to solve. At least it appears that much damage could be eliminated by better organized camps. Horses should be hitched in a single place away from the human bedding and eating area. One fidgety horse with metal shoes can do many times the damage to ground cover that a person can. Such traffic control would require the cooperation of the people who use the area, a pole fence here and there, and a hitching rack some distance away from the central camp.

* * *

The litter problem has many shades and aspects. Most people are probably reasonably neat and conscientious. However, enough are careless and thoughtless to require a militant antilitter program if the backwoods are to be cleaned up and kept clean. Moreover, there is a need to set up procedures and performance standards so campers will know precisely what is expected of them. In some situations will it be satisfactory to dig really deep garbage pits well away from the campsites and back from the main trails? Where garbage pits are not feasible or desirable (and that may be most places) should we plan to burn everything or should tin cans be flattened and carried out? E. J. Callantine, ranger on the Lewis and Clark National Forest, has suggested that a discreetly located incinerator might be provided for garbage disposal in some situations. In any case, the increasing number of wilderness visitors makes it quite unacceptable to toss empty bean cans into the bushes.

Apparently one big obstacle to the idea of providing formalized toilet facilities in main wilderness area campgrounds is a mental block to man-made structures in such places. Here again, however, there appears little choice when we balance the white flags of toilet paper scattered around the camp and the possibility of stream pollution against a few inconspicuous outhouses. These would be inconvenient to maintain, but this is part of the price of public use of back country.

* * *

Local overgrazing is by far the most troublesome aspect of wilderness use because there is no easy answer and because some "solutions" are likely to be controversial.

Horses are a necessary part of trail travel since few people are rugged or intrepid enough to tackle the larger wilderness areas with a backpack. Nevertheless, horses are hard on forage as well as on trails and campgrounds. A large hunting or trailriding group planning to stay out for a week requires about 2.5 horses for each "dude" on the trip. It is not surprising, therefore, that saddle and pack horses do a pretty good job of consuming all edible vegetation within easy range of overnight stops.

What to do about this situation has been the topic of many campfire arguments, but the time is rapidly approaching when some hard decisions will have to be made. There may be some chance to relieve the situation by developing more trails. Additional trails are undoubtedly needed to provide a wider enjoyment of the wilderness, but unfortunately meadows where horses can graze in high mountain areas are few and far between and most of them are already tapped by existing trails. There may be an oppor-

Photo: Stewart Ross Tocher

Figure 8. — In the minds of packers and many wilderness lovers the trail scooter is an instrument of the devil. It is "outlawed" in wilderness areas. Nevertheless the scooter is an efficient means of trail transportation, and doesn't eat grass. Regulation of scooter use in the interest of recreation values will continue to be a difficult problem.

tunity to increase forage production on a few flats, such as those in the South Fork drainage of the Flathead River in Montana (Bob Marshall Wilderness Area), by using mountain streams for irrigation and perhaps by fertilizing. But again, this is only a partial answer.

Sooner or later the choice will narrow to either reducing the number of pack and saddle animals allowed in the wilderness (except when they can go in and out in the same day) or to requiring that hay and concentrates be packed in. The day when all pack strings can live off the land is passing. This raises a nice problem in logistics, for it is all one horse can do to carry the hay he will eat in a week. However, the answer in some instances might be to airlift hay into central areas, and to store it under western-style hay sheds. Bringing hay into the wilderness raises other problems. Steps should be taken, for example, to avoid transporting cheap hay laden with weed seeds. Canada thistle is already widely scattered, but it would be unfortunate if such plant pests as leafy spurge, whitetop, Russian knapweed, and goatweed were allowed to become widespread in the back country.

Management of wilderness both for its own protection and the widespread enjoyment of people may require that horses be kept out of some areas altogether.

The assistance and cooperation of the American people are needed

Except for the few who find an emotional outlet in vandalism, people are more thoughtless than malicious. A society dependent upon sewers and garbagemen to carry away its offal and debris is not schooled in the ecological responsibilities of outdoor living. The problem is typified by the fellow who sits beside a sparkling stream extolling the beauties of nature while he tosses chewed-up orange pulp into the water where others will drink.

National forests have a particular need for public help and cooperation. Primarily this is because the national forest area is so large and scattered that controls are difficult. It goes beyond that, however. On these public forests we are trying to provide an opportunity for people to get out and enjoy nature with a minimum of supervision. For this reason, the extent of the national forest success in recreation management will depend a lot on the cooperation it gets. Nevertheless, stronger policing authority and additional laws to support that authority are required.

Commercial packers are one of the best sources of help. Some packers are already waging their own campaigns against tin cans, gum wrappers and other debris and are doing all they can to maintain the pristine quality of the wilderness. Similar support from the rest would go far toward solving wilderness management problems. The task of getting support from the general public is tougher, but the success of fire prevention campaigns indicates that much could be done. The importance of "scope of understanding" was illustrated by a situation at Fish Lake on the Ashley National Forest. A group of boys who stayed there carefully manicured their campsite and mixed dirt with the coals of their campfire in proper Boy Scout fashion before leaving. However, they apparently had not been completely enlightened because a ring of trees around the spot had been "beavered" down or badly scarred with hatchets.

Ivan H. Sims has suggested that an educational program could be built around the fact that the frontiersmen most of us would like to emulate never left a dirty camp. They obliterated as many signs of occupancy as possible for oftentimes their lives depended upon doing this. If that idea could be woven into national thought patterns, much good would result.

FINDING THE PLACE OF THESE NATIONAL FORESTS IN AMERICAN RECREATION AND THE PLACE OF RECREATION IN THE NATIONAL FORESTS

National forests have been available to the hunter, hiker, and others ever since they were established years ago. Nevertheless, the growth of recreation use, plus current interest in developing the recreational potential of these forests, creates a fairly new problem of orientation. We have to describe and evaluate the resource better than has been done so far. Beyond that we must identify and understand the features that give the recreation opportunity on these lands a character all its own. If these things can be done, national forest recreation will continue to have a unique and distinctive flavor.

To describe this opportunity it is necessary to consider the size and distribution of the national forests and grasslands. The 38 in these two Regions include a total of 56,757,907 acres of Federal land within their boundaries. This is one-fifth of the total land area in the two regions, and a much higher percentage of the mountain country where most recreation traffic occurs. The size of the national forest playground may be judged from the fact that the total acreage of wilderness, wild, and primitive areas is about 30 percent larger than the acreage in national parks, national monuments, and national recreation areas in these regions.

NORTHERN AND INTERMOUNTAIN REGIONS	Acres
NATIONAL FORESTS	56,757,907
Wilderness, wild, and primitive areas on the national forests	6,228,198
NATIONAL PARKS, MONUMENTS, ETC.	4,806,733
STATE PARKS	107,354

Acres alone do not tell the story. For the most part, these national forests are well distributed and therefore readily accessible to many people (fig. 1). We estimate that 95 percent of the population in these regions lives within 50 miles of national forest land, and 79 percent lives within 25 miles. Considering their total size and distribution, it is not surprising that national forests provide the lion's share of the nonsightseeing forms of outdoor recreation. In Idaho, Montana, Nevada, and Utah, 56 percent of the deer and elk harvested by hunters were taken within national forests. They probably don't provide most of the fishing because many of the bigger streams lie outside their boundaries. However, high mountain lakes and remote streams with their big fish are largely within the national forests. Nineteen of the 22 principal ski slopes in the Northern Intermountain Regions are either partly or entirely on national forest land, and at latest count there were 994 picnic and campgrounds on these forests.

These national forests, from the Colville to the Toiyabe, contain country that is unusual, beautiful, and spectacular. A list of their outstanding assets would include such places as the new Earthquake Lake on the Madison River, the magnificent Chinese Wall in the Bob Marshall Wilderness Area, and the jagged and beautiful Sawtooth range in Idaho. These scenic and geological highlights are, in a sense, the frosting on the cake. Nevertheless, the hard core of the recreational opportunity on national forests is the broad expanse of out-of-doors they provide for dispersed recreation of many kinds. They offer elbow-room in beautiful surroundings for relaxing the tensions of a high-octane society.

The challenge to the Forest Service is to continue to provide unspoiled elbow-room as the number of recreationists mounts. If we merely transfer downtown traffic jams to forest highways, that challenge will not have been met.

Photo: U.S.F.S.

BASIC ATTRACTIONS

Figures 9 and 10. — Insofar as numbers of people are concerned, two of the biggest recreation uses of the national forests are camping and picnicking. These people come to hike, fish, hunt, boat, swim, look at scenery, or just relax.

Photo: Stewart Ross Tocher

BASIC ATTRACTION

Figure 11. — The biggest offering of the national forests to the vacationer is out-of-doors.

Photo: Stewart Ross Tocher

BASIC ATTRACTION

Figure 12. — Skiing is easily the king of the winter sports. Most of the best slopes are on national forests.

Photo: Tom Reynolds

Figure 13. — For those who prefer greater privacy and are willing to make the effort, the back country, both in and out of the wilderness areas, provides a more primitive vacation opportunity. Some will walk, others will ride. All will have something to remember.

Photo: Tom Reynolds

Photo: Stewart Ross Tocher

THE FROSTING

Figure 14. — Little Redfish Lake in the Sawtooth National Forest. The scenic splendor of the Sawtooth Mountains makes a perfect backdrop for recreation use. The Sawtooth Valley is one of the superlatives in national forest recreational opportunity.

Photo: U.S.F.S.

THE FROSTING

Figure 15. — The Chinese Wall. This thousand-foot high cliff extends for miles along the Continental Divide in Montana. It is the product of millions of years of land shifts, water erosion, and glaciation. Today, visitors to the 950,000-acre Bob Marshall Wilderness Area can watch the mountain goats do the tightrope act here that they have been practicing for centuries.

Photos: Stewart Ross Tocher

THE FROSTING

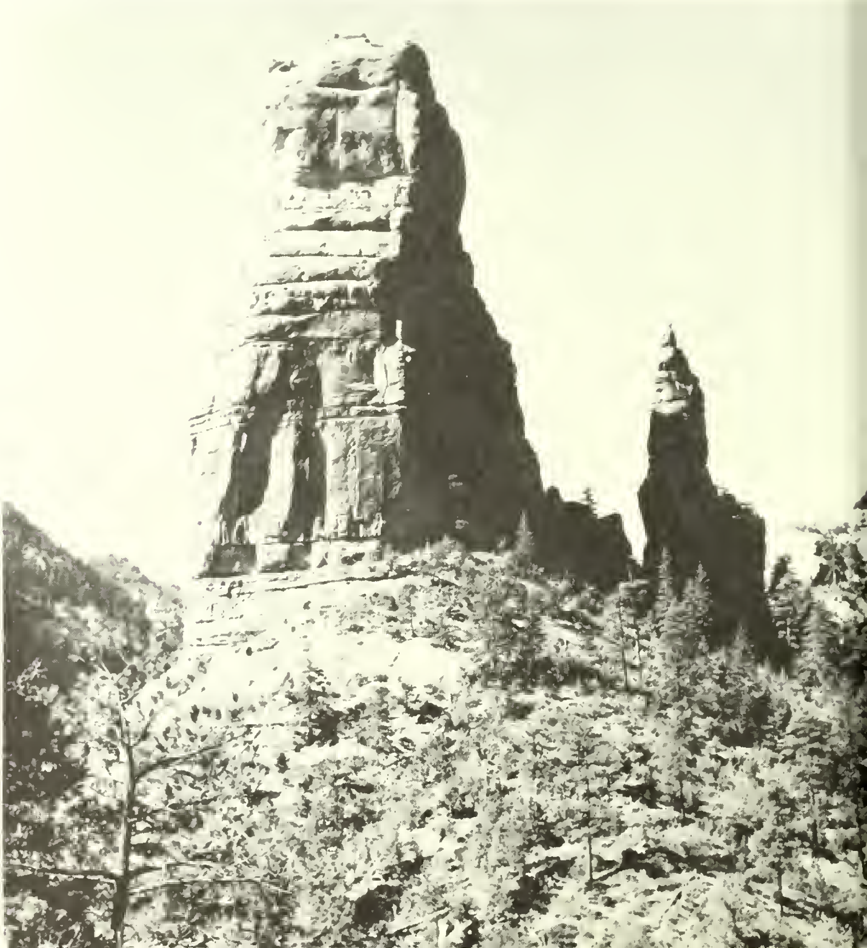
Photo: U.S.F.S.

Figures 16 and 17. — The national forests are heavily sprinkled with points of special beauty and interest such as the Wind Cave, above, on the Cache National Forest; and Earthquake Lake on the Gallatin National Forest, formed by the collapse of a mountain in 1959.

THE FROSTING

Figures 18 and 19. — The superlatives on the National Forests include many spots of geologic and archeologic interest besides Earthquake Lake shown on the preceding page. For example, there are the cliff dwellings of the prehistoric Anasazi Indians in Hammond Canyon located in the Manti-LaSal National Forest. Hammond Canyon itself is typical of the spectacular scenery of southeastern Utah. Its cliffs and steeples are carved from multihued Triassic and Jurassic sandstone.

Photos: Craig Rupp



National forest recreation should be nationally oriented

The famous vacation trip of Sir William Drummond Stewart from Independence, Missouri, to the Wind River Mountains in Wyoming in 1843 has been cited as the beginning of national use of the Mountain States forests for recreation. (Drummond took along 20 or so friends and an army of servants and horses.) However, while forest recreation may have started with this early trip, the national forests of the Mountain States are still a long way from being fully recognized and developed as a national playground. In this respect they have lagged far behind the national parks, which are well known all over the United States and which figure heavily in the vacation plans of families from coast to coast.

This does not mean that people from other places haven't visited national forests to enjoy them. On some occasions, more California cars than native ones can be counted in Utah and Idaho campgrounds. Some of the more atavistic backpackers in wilderness areas are from New York City. Nevertheless, national forests can hardly be mentioned in the same breath as national parks when it comes to out-of-region patronage. National forest recreational development has largely been locally oriented. It has been done chiefly on a piecemeal basis without particular consideration of how well the needs of families from New York or Iowa are being met. It is safe to say, therefore, that the country-wide recreation potential of the national forests has barely been scratched.

What and how much needs to be done to get broader patronage of the national forests is a moot point at this stage. The whole question requires a lot of imaginative thought and planning before it can be fully answered. However, the problem of camping facilities illustrates the situation. Almost every grade school child knows there are a lot of national forests in the West; many families have looked longingly at brochures describing "Your National Forests." Actually, though, long-distance use has been discouraged by the fact that most out-of-state people have found national forest camping a "hunt-and-peck" proposition. They haven't known where to go or what they would find when they got there. The plaintive and persistent cry of many camper tourists struggling to take advantage of their national forests has been, "Where do we go from here?" Each year many start out, literally groping their way from one place to the next, trading information about camping spots and "buttonholing" rangers to ask where the nearest campground is "out that way."

Steps have been taken to relieve this problem by issuing brochures listing and describing campgrounds. However, there is reason to believe more is needed than that. Cross-country tourists present a considerably different problem from the local camper. In strange country far from home, they need guidance and probably require conveniences, such as showers, not essential to local campers. Most national forest campgrounds probably are not particularly suited for cross-country campers. No network of camps has been set up with the needs of these people in mind. The problem of what kind of a setup would encourage greater nationwide use of these forests is a subject in itself. At this stage, we can only raise the question as to whether most existing national forest camping areas are particularly suited for such use.

The one thing that sets the western national forests apart from a playground standpoint is that they are well scattered. They are readily accessible to most of the West. Moreover, the 105 national forests and grasslands in the 11 western states represent a vast network of vacation opportunities for the family seeing America from a house trailer or a station wagon full of kids and camping equipment. The map on the following page shows the location of the western national forests and how well they fill in the country between the national parks.

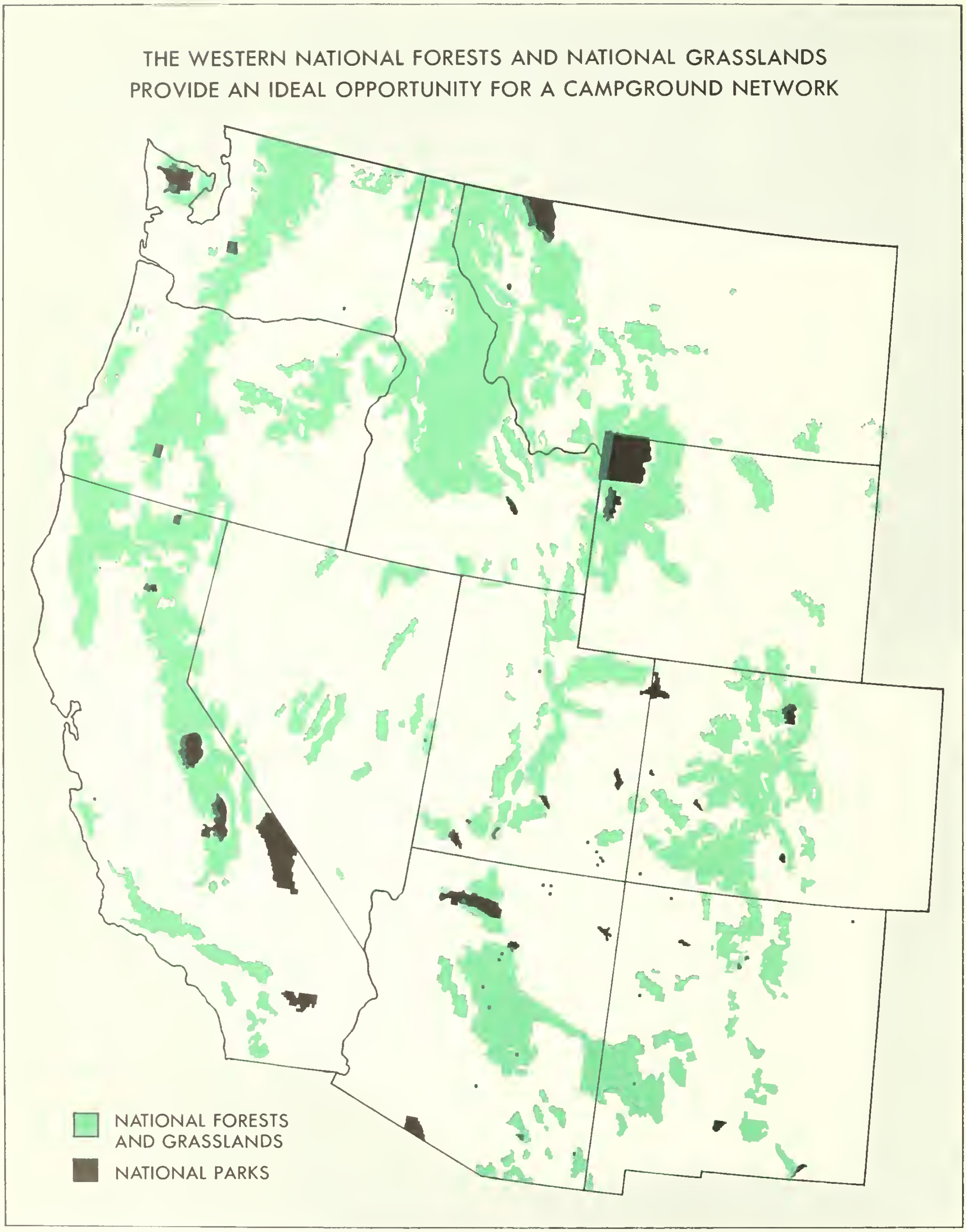

THE WESTERN NATIONAL FORESTS AND NATIONAL GRASSLANDS
PROVIDE AN IDEAL OPPORTUNITY FOR A CAMPGROUND NETWORK
NATIONAL FORESTS
AND GRASSLANDS
NATIONAL PARKS

Figure 20.

All this suggests that although the national forests have a prime responsibility for the "elbow-room" type of outdoor recreation, they could also play a larger role in providing the more domesticated kind of camping sought by that group loosely classified as "tourists." The national parks are already bulging with vacation travelers, and park officials are deeply concerned about how they can handle greater floods of visitors in the years ahead.

For these reasons, serious thought should be given to the possibility of developing a camping network in the western national forests specially geared to the needs of long distance vacationers. Needless to say, each campground in such a network should be located in relation to special recreational opportunities. Camps for travelers looking only for a place to stop overnight may not be a public responsibility.

A national forest camping network, arranged and tailored with the migrant camper in mind, would bring national forest vacations within reach of many more people.

National forest efforts should be coordinated with other outdoor recreation

The growing number of sun-loving, wide-roaming Americans poses a real challenge to all public agencies connected with outdoor recreation. It is a challenge that no agency can meet alone and one that can be met effectively only if there is expanded coordination and cooperation.

At least one shrewd observer, conscious of the logistics of outdoor recreation, has commented that one of the best things that has happened is the growing number of community and neighborhood swimming pools. His hope is that more adequate local recreation facilities will keep many people home who would otherwise travel, thus relieving what might become an intolerable pressure on the national forests and state and national parks. It is hard to know how much of a safety valve such local developments can be. The idea, nevertheless, does point up the fact that outdoor recreation is not something 10, 50, or 500 miles from home, but begins out on the patio.

This, in turn, suggests that local communities have a greater responsibility in outdoor recreation than most have recognized; that much joint area planning by national forest, state, and community administrators is needed; and that in default of local responsibility related to recreation, the national forest administrator must set some limits as to how far he will go in taking up the slack.

This whole problem is best illustrated by a situation in the Wasatch Mountains of Utah. Most people in the State live in a narrow strip along the base of this mountain range. During the summer they flock out of Salt Lake City, Ogden, and other towns into the mountain canyons. Since World War II, use has become so heavy that the picnic areas in these canyons have been overloaded. Several towns and counties have pitched in and helped by paving picnic ground roads, collecting garbage, and maintaining certain facilities. The newly created Wasatch Mountain State Park near Midway, Utah, should help the situation. It is apparent, though, that more needs to be done. A new look at the area's overall recreation problem is badly needed not only to define the job ahead but to determine an equitable division of labor and responsibility among local, state, and Federal agencies. To what extent, for example, does the pressure on Wasatch Front campgrounds reflect inadequacies of municipal park systems? Can the Wasatch Front National Forests continue to handle the recreation load they have in the past?

Group areas have been a prominent part of the picnic facilities on the Wasatch, Cache, and Uinta National Forests. They have been heavily used for family reunions, "beer busts," and company outings. Since there isn't enough room to go around, some thought has been given to converting group facilities to individual family units. There is reason to wonder if large gatherings that cause heavy wear and tear on the site have any place in national forests. Why shouldn't city parks provide facilities for large groups?

Whatever the Forest Service does in the recreation field should be coordinated with National Park Service efforts. For example, a national forest serves a substantially different purpose than a national park. By itself, each is lacking; together they provide an unparalleled recreation opportunity.

At this stage, the big question is how the programs of the two agencies can be more tightly interlaced. A commonly mentioned example relates to campground facilities. One worry of the Park Service is how to provide sleeping space for all who stop overnight. Forest Service planners recognize their responsibilty to help with this so-called "bedroom problem" by providing campgrounds near the parks.

There are, no doubt, many more opportunities for cooperation and coordination.

Recreation development on the national forests is a large and complex job

Camp and picnic areas have been the squeaking wheels of outdoor recreation, and have tended to dominate national forest recreation planning and development. However, if one of the purposes of the Forest Service is to develop a wildland playground so more people can enjoy it, the job is considerably greater than merely providing places where people can eat and sleep at low cost.

The task of handling thousands of square miles of land so as to enhance recreation value and still permit other uses is so complex that no one yet really understands all its ramifications. The breadth and depth of the problem are indicated by the following questions for which we do not yet have the answers:

- What are the recreational assets of these national forests, and how great a recreational opportunity do they provide?

It isn't enough to be able to tick off a list of vacation activities on the national forests. Before there can be much clear-cut planning, it will be necessary to know the extent of the various recreational opportunities. It may be possible to express some resources, such as big game, in quantitative terms. Perhaps other resources, such as scenery, can be described only in general terms.

- How do we handle a fisheries resource that is extensive but lacks the capacity to hold up under heavy pressure?

The fish themselves are the responsibility of State Fish and Game Departments, but the lakes and streams on the national forests, their accessibility, and the management of the land around them are the responsibility of the Forest Service. State Fish and Game Departments and the Forest Service, therefore, share the responsibility of providing for both the so-called "running board" fisherman unwilling to go far from his car and the more energetic angler willing to walk some distance for better fishing. An all-important decision to be made, therefore, is which back country lakes and streams are to have roads into them so that more people can enjoy them, and which are to be kept less accessible so fewer people can get more enjoyment. Rock Creek, near Missoula and Phillipsburg, Montana, typifies one problem facing State Fish and Game Departments and the national forests. This 50-mile long creek is one of the better fishing streams in the United States. It is naturally productive, and the road paralleling it is just rough enough to discourage many would-be fishermen. What can be done to maintain this as a quality fishing stream after a better road is built?

- How can we continue to provide a camping opportunity that is a delightful experience in its own right?

Many feel that one of the most important contributions national forests could make to human happiness is to provide a full range of camping opportunities from larger developed campgrounds to more remote unimproved spots for those seeking solitude. Emphasis should be placed on providing the kind of surroundings where camping itself is fun, rather than something that is put up with for the sake of being outdoors.

- Where should camp and picnic areas be located to do the most good?

Camp and picnic areas, for the most part, should be jumping-off points for other types of recreation. In the case of some lakes, the matter of location of camps presents few difficulties. However, where should the camps be established to best serve the hiker, the fisherman, and the family out to see the country?

- How do you tell the fascinating story of this mountain country — about the frontiersmen and loggers who walked across the pages of its history, about the geology that shaped is features, and other things of interest?

The National Park Service uses lectures, tours, signs, and displays to tell visitors about the interesting features of its areas. National forest type recreation requires less of this, but nevertheless, there is opportunity for more interpretive work. The question to be answered is: How far should we go in this direction, and what needs to be done?

- What can be done to establish and maintain the kind of private concessions required to enhance the recreation opportunity?

Resort facilities are required in many places to serve the public. Forest Service experience in this field has been both happy and sad. Some resorts on national forests are fulfilling their purpose; others are not. The worst are shabby and disreputable. Such resorts probably are discouraging rather than encouraging recreation use. This raises several questions: Why aren't these resorts more desirable? What can be done to improve the situation? How can resort establishment and development be better fitted into overall recreation programs to avoid such marginal situations?

- What place should summer homes have in future planning of the Forest Service?

In the early years of the national forests many waterfront sites were leased for summer homes, because this was the principal recreation demand on such areas. Subsequent demands for public access to shorelines have made it necessary to terminate summer home leases. This has been an understandably difficult and unpleasant task. The question of how much room there will be on the national forests for summer homes in the future is, therefore, very important.

* * *

The recreation management job of the Forest Service consists of molding an outstanding collection of real estate into a distinctive recreation opportunity. It will not be an easy task because the multiple-use concept that makes the whole national forest system available for recreation creates the difficult problem of integrating this use with others. Providing "aloneness" for an increasing number of people is almost a self-defeating operation and doesn't make the job any easier. Nor is the situation improved by the fact that an increasing proportion of the people who seek nature know little about the out-of-doors or how to go about enjoying it. Solving these problems calls for imaginative planning, new concepts, and new approaches.

Just what these new concepts and new approaches may involve is difficult to say. However, the tent cabins in Grand Teton National Park represent one example of the kind of thinking needed (fig. 21). Roscoe B. Herrington's micro-wilderness[2] is another. Herrington and others have proposed that much of the high mountain country be broken into pint-size primitive units easily traversed on foot.

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[2]The term "micro-wilderness" as used here has no particular relation to the formally reserved wilderness areas. It is primarily a management concept, applicable either to formally established wilderness areas or other high country in national forests.

Photo: Zach Stewart

Figure 21. — Part of the tent village in Grand Teton National Park. This ingenious development by the Grand Teton Lodge Company is one answer to the problem of providing low cost accommodations for seasonal traffic. Besides being clean, comfortable, and attractive, these cabins reduce wear on the surrounding site.

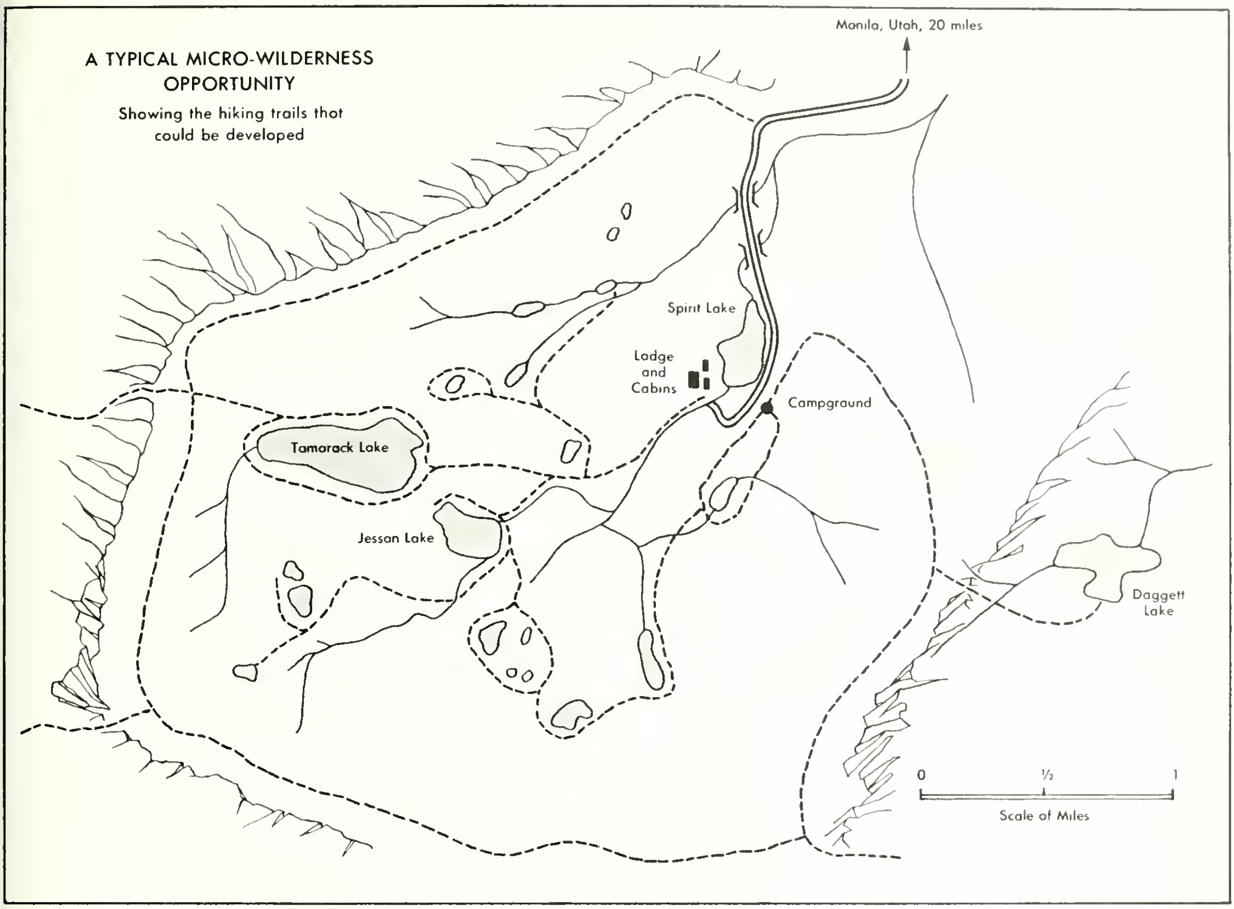

Figure 22. — An example of a "micro-wilderness" opportunity. At present, this area is tapped by road to Spirit Lake and by a trail that connects Spirit Lake with Tamarack, Jesson, and Daggett Lakes. Most people who visit this area stay at Spirit Lake to fish or camp. In a sense, many of these people are in the same situation as the traveler in a strange city who never goes beyond his hotel. He supposes there are interesting things to do and see but doesn't know where to look. Spirit Lake is overfished by people who need something to do. They may suspect that other beautiful lakes are nearby, but are unsure of their ability to find them. An adequate system of well-signed trails, and maps such as the one above would provide many with a more satisfying camping experience and would relieve congestion, campground wear, and fishing pressures at Spirit Lake.

The map in figure 22 shows one potential micro-wilderness in the Ashley National Forest. Of the high mountain lakes shown, only Spirit Lake is accessible by road. It has a resort and campground on its shore. Vacationers not wishing to go further may fish in this lake or otherwise amuse themselves. Those looking for better fishing or more primitive surroundings may walk 1 mile to Jesson Lake, or shorter or longer distances to other lakes. These lakes, nestled in glacial cirques, are very beautiful. Above Tamarack Lake is a high mountain meadow that looks into several year-long snowbanks. Thus, with an hour's walk at the most one can enjoy surroundings just as wild and lovely as those in the center of the 950,000-acre Bob Marshall Wildnerness. Many opportunities like this, scattered throughout the two regions, need only adequate jumping-off points, publicity, and well planned trails and signs to bring the wilderness experience to many who otherwise would have no chance to enjoy it. Such situations cannot take the place of the larger and legally established wilderness areas, but they do provide an ideal opportunity for the foot traveler with or without a pack. From such areas, both horses and vehicles probably should be excluded.

The micro-wilderness idea is but one example of the opportunity to develop a series of complete recreation units. This involves selecting the areas of greatest recreation value, establishing resorts and campgrounds from which recreation use can radiate and constructing trails, shelters, and any other facilities required for dispersing recreation use.

Finding the right multiple-use compromises will in some cases be difficult

The multiple-use concept is important to recreation because it provides a basis for assuring that other uses will not materially reduce the attractiveness of the country or its utility as a playground. Multiple-use is, however, a two-way street. At present, when interest in recreation is at high tide, there is equal danger that it will encroach unnecessarily upon timber growing and other uses as there is that recreation values will be impaired.

In some cases multiple-use is directly beneficial to recreation. For example, the elk herd in western Montana reportedly is larger than ever before because extensive logging has created a better game habitat. Fishing has been improved in some localities by the construction of reservoirs.

One of the more important conflicts today, so far as recreation is concerned, is between recreational and agricultural demands for water. At China Meadows on the Wasatch National Forest, for example, a proposal has been made to build a low dam for water storage. The water thus impounded would provide additional irrigation for farms, but the meadows would become a mud flat for part of the year, thus eliminating them as a recreational asset. The proposed reservoir on the North Fork of the North Fork Sun River in Montana would put a water barrier between the summer and winter ranges of the Sun River elk herd. On the other hand, overgrazing by saddle and pack stock in wilderness areas and by the over-large northern Yellowstone and Jackson Hole elk herds adds to the problem of watershed protection. In many ways multiple-use conflicts represent the most difficult part of national forest administration. If recreation development is to get fair consideration in decisions and is not to create unreasonable demands itself, we will have to develop a clear sense of purpose in recreation planning.

RECREATION RESEARCH SHOULD BE CAREFULLY FOCUSED

The rising popularity of national forests in these regions as playgrounds has sown a bumper crop of sociologic, economic, biologic, and engineering questions. Such a situation provides a wide-open opportunity for researchers, but it also presents a problem in priorities. Unless "first" questions are answered first, national forest administrators will not get the help they need as fast as they need it.

It is doubtful, for example, if top priority should be given at this time to long-range demand studies. Estimates of total recreation needs in decades to come are certainly less important than a better understanding of how to deal effectively with the erosive force of existing recreational use. We already know that recreation use will probably keep ahead of the Forest Service's best efforts for a long time to come.

The question of what comes next after the trailer house, outboard motorboat, and trail scooter, is likewise provoking. However, it is much less significant than the basic puzzler: How can national forest recreation opportunities be made available to more people while still preserving most of the original attractiveness?

This review of the many-faceted task of national forest recreation development suggests researchers can help most by first tackling three problems: How best to capitalize on the national forest recreational assets; management of recreation pressure points; the extent and character of current recreation use.

What is the nature of the recreation opportunity on the national forests and how can it best be developed?

A study is underway at the Intermountain Forest and Range Experiment Station to develop ways of measuring that illusive thing we call the recreation resource. Initial attention is being directed to the fisheries resource. The objective is to devise ways for expressing the size, location, and quality of the fishing opportunity in a way that will be useful in management planning. Similar study must be given to the problem of describing other recreation resources. Planners can be further assisted by research along four other lines:

- *Studies of development patterns needed to provide the most effective use of national forest recreation attractions.* Such studies would focus on questions like these: What kind of arrangements and facilities both inside and outside national forests would provide the most attraction and greatest benefit to regional recreation visitors? What combination of public and private development will yield the highest benefits? What combination of accessibility and inaccessibility will create the ideal balance for recreation? How far should the Forest Service go in providing interpretive services such as tours, lectures, and signs?

- *Studies of resorts and other concessions on national forests.* Some aspects of development are best handled by private enterprise. A better understanding of the concessionaire and his problems is needed. Why do some succeed while others become marginal economic ventures and a liability so far as the public is concerned? What development patterns would assure a higher degree of success in such operations?

- *Studies of the problems of developing recreation opportunities in a multiple-use setting.* Here the first task is to identify points of harmony and conflict between recreation and other uses. This sets the stage for the toughest recreation questions the researcher faces: What criteria can be used to evaluate recreation in comparison with other uses? How can an agency with multiple-use responsibilities best tackle the recreation job?

- *Studies of the need and opportunities for integrating national forest recreation programs with the efforts of others.* Forest Service planning should be integrated at the one end with the planning of the states, counties, and communities and at the other with the National Park Service. We need to learn how the Forest Service in these regions can team up with other agencies to provide a better recreational program for the American people.

What management measures will prevent unnecessary wear at the pressure points of recreation?

Deterioration caused by recreational use is an ecological problem. However, ecological studies of the existing situation would only prove the obvious. For that reason research can probably be most productive if it starts with studies of the procedures required to rehabilitate sites and maintain stable conditions. For some time to come studies relating to the management of recreation concentration points should deal with six interrelated subjects:

- Techniques to determine the "people-carrying" capacities of recreation sites.
- The strategy of minimizing wear and tear on camp and picnic areas.
- The selection and testing of shrubs and trees that are suitable for different sites and conditions.
- The adequacy of management alternatives from the standpoint of their effect on the capacity of land to withstand wear and tear.
- The cost of management measures required to deal with various situations.
- New approaches and concepts for handling people who come to the national forests for recreation.

What is the pattern of present recreation use on national forests?

There is a need to better understand what recreationists are doing on national forests. A better understanding of use patterns requires periodic surveys—a job that probably should be done by the administrator. He requires help, however, in the development of adequate survey techniques.

Beyond that, research scientists should conduct incidental studies of the recreation visitor—his needs, interests, and problems.

* * *

The Forest Service has an exhilarating opportunity to develop a national forest recreation program with a flavor all its own and a special place in the American scene. The researcher likewise has an excellent chance to contribute in this field. His studies on experimental campgrounds and planning units can provide a stronger foundation of knowledge, but beyond that he can play an important part in molding the philosophy and concepts of national forest recreation.

Photo: Stewart Ross Tocher

Figure 23. — Man does not live by bread alone. The everchanging face of nature never ceases to fascinate and beckon him to explore whatever lies just beyond the next bend.

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A FIELD TEST OF POINT-SAMPLE CRUISING

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BACKGROUND

The validity and usefulness of point-sampling as a timber cruising echnique are well established. Grosenbaugh and Stover's (1957) report of the est of wedge-prism point-sampling compared with plot sampling in southeast exas leaves no doubt that this technique, properly applied and with results roperly compiled, can be used effectively for reliable timber surveys. Their iscussions of procedures and methods of analysis indirectly indicate reasons hy some earlier trials of point-sampling may not have been valid tests of the echnique. Further tests of different methods for applying point-sampling to ther stand conditions can be patterned after their study to good advantage.

Trials by Shanks (1954), Larson and Hasel (1958), Lindsey et al. (1958), nd others have shown that point-sampling can yield more stand information for given cost than plot cruises. Furthermore, Afanasiev (1958) has indicated hat the point-sample may be less subject to errors when used by inexperienced rews than conventional plot procedures.

That errors can arise, however, in point-sampling while seemingly following recommended procedures has been demonstrated by Grosenbaugh (1949), eitschman (1956), and Stage (1951). For example, a prism or angle-gauge of a actor not suited to stand conditions can introduce errors in basal-area estiates. Qualifying trees are more likely to be missed or miscounted with smaller asal-area factors. Biased plot center locations are more likely to be serious hen the tree count is very low. These two considerations must be balanced in electing the basal-area factor. Guides to appropriate prism factors for varius stand diameters have been prepared for western conditions by Bell and lexander (1957). They state that with an appropriate prism factor, one should ount four to eight trees per point. Unfortunately, the data on which these ecommendations are based have not been published.

Furthermore, counting fewer trees per point necessitates sampling at more oints to attain the same cruise precision. Thus, certain basal-area factors ay be more efficient than others in obtaining stand information. Few data are vailable for evaluating relative efficiency basal-area factors in obtaining tand information.

The wedge-prism is the most popular device for point-sampling in the United tates--perhaps because of its simplicity and convenience. Various gadgets and echniques have been devised following Bruce's (1955) suggestions for rotating he prism to correct for sloping sight lines. On the other hand, Grosenbaugh (1958) recommends correcting for slopes by applying a single correction to the ntire point-sample based on an average slope perpendicular to the contour.

In rough country where plot surfaces are not simple inclined planes, the mean slope estimate by nature cannot be very objective. Slope adjustments on a tree-by-tree basis are critical only for marginal or near-marginal trees. Such trees can be checked under either system with equal ease by using a marginal tree computer (Stage, 1959).

In most tests that have shown good results in using wedge-prisms, marginal or doubtful trees have been carefully checked by measuring their diameter and distance from the sample point. However, the usual recommendation for extensive cruises is to tally such trees separately and add half of their total to the sample. Whether an optical illusion might cause the ratio of "ins" to "outs" to be other than 50-50 has never been checked so far as I know.

In addition to testing techniques of application, a study of point-sampling should also provide information helpful in designing timber cruises to meet specified limits of accuracy. By relating coefficients of variation for point-sampling to those for conventional plot procedures, the experience data from the older techniques can be made available for designing point-sample cruises.

OBJECTIVES

This study was a joint effort of the Intermountain Forest and Range Experiment Station and Region 1 of the U.S. Forest Service. Information obtained from it will be used to establish guidelines for point-sampling in the northern Rocky Mountains.

Specific objectives of the study were three-fold:

1. To determine the prism factors most appropriate for our stand conditions.

2. To isolate, as far as feasible, the sources of error that occur in using a prism of other than optimum factor for a particular stand condition.

3. To provide data on the relative numbers of point-samples needed to achieve the same precision of basal-area estimate as a given number of 1/5-acre plots.

PERSONNEL AND TRAINING

Forest Survey and Forest Management inventory crews made the variable plot estimates in conjunction with establishing regular sample plots to Intermountain Forest Survey standards. This study procedure somewhat restricted the method of measurement and the distribution of samples by forest type. However, the information could not be so economically obtained otherwise.

Field crews were trained at week-long schools held by Forest Survey and egion 1 Division of Timber Management in preparation for their plot establishent work.

FIELD DATA

The fixed area plot data consist of the diameters measured by diameter ape to 1/10-inch limits of all trees on two concentric plots established at ach location. Trees 11.0 inches and larger were tallied on a 1/5-acre circuar plot. Trees between 5.0 and 10.9 inches were tallied on a 1/50-acre plot.

The point-sample consisted of a count with each prism of all trees 5.0 nches and larger about the fixed-area plot center. It was intended to use hree prisms having basal area factors of 10, 15, and 25, but, not all crews ad complete sets. Trees clearly within the "plot" were recorded separately rom marginal trees. The latter were recorded as being visible from plot cener to the tree clear or obscured by brush or other trees. In addition, slope ercent, slope distance, and d.b.h. were recorded for the first two marginal rees encountered with each prism on each plot.

Slope adjustment of the prism point data was made on a tree-by-tree basis. ell and Alexander's (1957) method of determining prism rotation by an Abney evel was used. The Abney was sighted at d.b.h. and the bubble clamped. Then he Abney was turned at right angles, and the prism held on top of the Abney o that the line of sight was perpendicular to the face of the prism with the evel bubble centered.

ANALYSIS

Prism Calibration

A majority of the prisms used in this test had been factory calibrated to n even basal-area factor or to an even prism diopter. However, a few uncalirated prisms were also used. All prisms were calibrated by the author to stablish values for the uncalibrated prisms and to check the calibration on he others. The calibration procedure did not require movement of the prism to ttain coincidence of the deflected image with a point on the true image. By sing this procedure, personal bias is eliminated. Personal differences in rism calibrations have been noted by several authors. However, until these ifferences can be demonstrated as constant and persistent under varying condiions, an objective procedure such as that used in this study seems preferable.

A transparency of a fine white cross against a black field was projected n a smooth screen about 25 feet distant. A horizontal line through the image f the cross was drawn on the screen, and the location of the cross marked on he line.

Each prism to be calibrated was placed 6 to 8 inches in front of the projector lens. The prism was mounted so that the knife-edge was perpendicula to the light beam, and the viewing edge in the middle of the light beam. Thus two images of the cross appeared on the screen, the direct image from the portion of the light beam which passed over the prism and the deflected image fro the light passing through the prism. The prism was rotated until the deflecte image fell on the horizontal screen on the target. Then the prism was turned to obtain a minimum deflection of the image. The position of the deflected image was marked on the screen, and the procedure was repeated with the prism reversed. The distances (w) to the right and left deflected images from the true image were precisely measured and averaged. Then the distance (d) from the true image to the center of the prism was carefully measured. This proces was repeated twice for each prism so that four deflection measurements were obtained.

The ratio of distance to target (d) to deflection distance (w) or d/w has been called Q by Grosenbaugh (1958) and is related to basal-area factor by the equation:

$$BAF = \frac{43,560}{(Q + \sqrt{Q^2 + 1})^2 + 1}$$

Basal-area factors were computed from the two sets of measurements for each prism. The lower of the two determinations for each prism was used as th calibration for that prism since it represented the minimum deflection.

The new calibrated values for the prisms were about 1 percent higher than the values specified by the manufacturer. Consistency of the pairs of calibrations left little doubt that a real difference existed. However, it is not clear whether the difference is the result of differences in calibration procedure or in the specifications to which the prisms were manufactured.

The deflected image, of course, showed considerable chromatic aberration. The brightest (yellow) portion of the spectral image was used as representing the position of the deflected image. The difference in calibration depending on which portion of spectrum was used amounted to about a 1-percent difference in the basal-area factors obtained. This fact suggests one possible source of personal bias--persons who respond differently to the different energy bands in the spectrum could obtain somewhat different calibration values. Likewise the colors of the tree trunk and the background could affect the calibration.

Marginal Tree Measurements

Field Test

Marginal tree measurements were intended to supply information pertaining to the following questions:

1. Is the assumption that one-half of the count of marginal trees should fall inside the plot unbiased?

2. What order of precision can be attained using a hand-held prism without optical magnification? (For this purpose, caliper measurements of tree diameter would have been preferable in order to remove the component of variation due to elliptical tree cross sections. However, the organization of the study precluded their use.)

3. Do prisms of different basal-area factors vary in precision attainable?

4. Is the method of adjusting for slope unbiased?

Grosenbaugh (1958) has demonstrated that diameters measured by tape give an unbiased estimate of 1/K times the average distance at which a tree will qualify for counting with point-sampling. Thus, inclusion of elliptical trees should not bias the marginal tree data, although they will increase its variation.

Grosenbaugh has called the ratio, horizontal distance in feet divided by tree diameter in inches, the horizontal distance factor (HDF); this factor equals 24K. Figure 1 provides a visual representation of various horizontal distance factors as viewed through a prism for which the limiting HDF is 1.739 (basal-area factor of 25).

HDF ratios were computed for each marginal tree. Then these ratios were adjusted[1/] to a common base as though a prism having a basal-area factor of 25 had been used throughout the test. On the 801 plots measured, only 133 trees were considered to be doubtful for counting. Of these, 24 were discarded from the analysis because their measurements did not carry enough significant digits.

The marginal tree data for 109 trees, summarized in table 1, show the following:

1. There is no significance to the small difference between the mean adjusted HDF's for the two prism strengths compared. However, the variance of adjusted HDF for marginal trees to which visibility was clear is relatively greater for the 10x prisms than for the 25x prisms. The hypothesis that the variances of adjusted HDF associated with the two prism factors are from the same population can be rejected with a probability of between 90 and 95 percent. This fact suggests that use of the 10x prisms is proportionally less precise than use of the 25x prisms.

1/

$$\text{Adjusted HDF} = HDF_x \sqrt{\frac{BAF_x}{25}}$$

where $HDF_x = \frac{\text{Horizontal Distance in Feet}}{\text{Tree Diameter in Inches}}$ using prism x having basal-area factor = BAF_x

Figure 1.--Visual interpretation of marginal trees as viewed through a 25x prism for which the limiting horizontal distance factor is 1.739. Horizontal arrows indicate the actual HDF corresponding to the distance from prism to tree for each photo. Figures on the vertical arrows indicate the percentage of the actual tree count which would be within the indicated limits for marginal trees.

Table 1.--Analysis of marginal tree data comparing adjusted horizontal distance factors for prisms of two basal-area factors

Group	No. of trees	Mean adjusted HDF	Standard deviation of HDF	Std. error of mean HDF = σ_m	Percent of trees with HDF 1.739	Chi-square 1/	t = $\frac{1.739\text{-mean}}{\sigma_{mean}}$
Clear visibility							
10x prism 2/	36	1.692	0.199	0.033	72.2	6.25**	1.42
25x prism	41	1.669	.145	.023	70.7	6.24**	3.04**
All clear	77	1.680	.171	.020	71.4	13.30**	2.95*
Obscured visibility							
10x prism 1/	14	1.652	.255	.068	64.3		1.28
25x prism	18	1.625	.288	.068	72.2		1.68
All obscured	32	1.637	.270	.048	68.8		2.12*
All trees	109	1.667	.205	.020	70.6		3.60*

1/ Chi-square test for deviation from an assumed ratio of 1:1.
2/ Data for 10x prisms scaled so as to be on same base as 25x prism data.
* = significant at 95-percent level of probability.
** = significant at 99-percent level of probability.

2. The mean HDF of marginal trees (1.680) is significantly less than the limiting value of 1.739. This fact is also demonstrated by the observation that 71 percent of the marginal trees were within the "plot" boundaries. If we assume that the mean HDF of clear marginal trees represents the plot boundaries as actually established, the average plot area would be reduced to 93.3 percent of its proper size.

Correction for slope was checked by plotting HDF over inclination of the line of sight to the tree (fig. 2). The plotted points show the range of HDF values obtained. The horizontal solid line is drawn at the limiting HDF of the adjusted data. Some of the variation of these HDF's is due to the inclusion of elliptical trees. An indication of how ellipticity affects such data is shown by the dashed line in figure 2. This line represents the limiting HDF for a population of elliptical trees whose smaller diameter is nine-tenths of the larger diameter, and which are located on a 70-percent slope with their long axes perpendicular to the contour. The six crosses indicate the points that would represent six trees from such a population equally spaced in a quadrant starting along the contour and extending either up or downhill. The fact that these six points are equally distributed above and below the limiting HDF for circular trees is further evidence that ellipticity introduces very little bias in the horizontal distance factor.

In spite of the possibility of slope-oriented elliptical trees introducing a negative regression of HDF on slope of sight line, no such trend could be detected in the data. Furthermore, the variation about the average appears to be uniform throughout the range of slopes. Thus, sloping ground does not

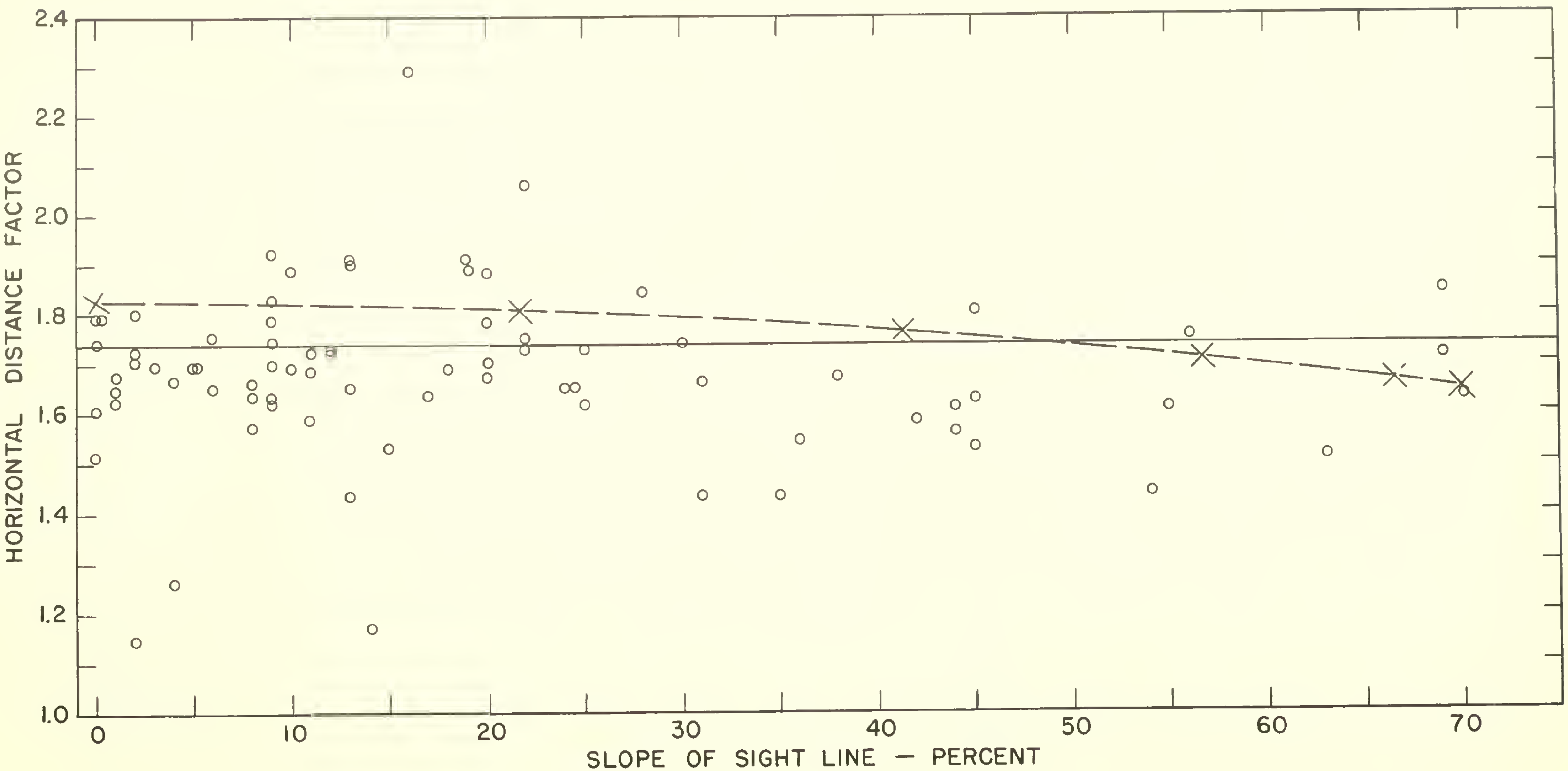

Figure 2.--Trend of horizontal distance factors to marginal trees is horizontal with respect to slope of sight line. Solid line indicates limiting value to qualify for counting. Dashed line indicates the same limit for elliptical trees (e = 0.9) growing on 70-percent slopes with their long axis perpendicular to the contour.

ecrease materially the precision with which a prism can be used with the reviously described slope adjustment technique.

Decisions on marginal trees must be made at greater distances with prisms f lower basal-area factors. To test whether sheer distance affected the relaive accuracy, the adjusted HDF's were plotted over slope distance to the tree. gain the trend is horizontal with approximately uniform variance. The 10x rism showed a wider spread than the 25x throughout the range of distances.

A necessary corollary of the observation that HDF is dispersed uniformly bout a horizontal line with respect to distance is that there will be a negaive trend as tree diameter increases (see fig. 3). Its regression coefficient s significantly different from zero at the 95-percent level of probability. his negative trend could arise from either of two measurement sources in these ata: one, an error in the use of the prism; and the other an error in the conrol measurement.

1. With regard to the former, the crews were instructed to keep the top edge of the prism even with the breast-height point on the trees. Thus, when the prism is rotated to correct for a 40-percent slope, the deflected image of the side of the tree differs in level from the d.b.h. point by 0.20 times the tree diameter. The number of comparisons with points above b.h. should equal those with points below b.h. However, greater rates of taper below breast height than above would cause more marginal trees to fall within the limit than outside. This effect would be more serious with larger trees than with small ones.

2. As to the latter source, errors in taped diameters (such as a sagging tape, or irregularly shaped cross sections) tend to overestimate diameter and thus give a lower HDF. Such errors would be more serious on large trees than small ones.

The latter source would introduce no bias in the basal area estimate based olely on the tree count obtained by the prism. The effect of the first source ould be minimized by comparing the sides at a level such that the average of he high and low images is slightly above the true breast height.

Photo Judging Test

The field data have demonstrated that the average HDF of the marginal rees does not coincide with the theoretical limits. Study of a series of hotographs similar to those in figure 1 indicates why this discrepancy may ave occurred.

Eleven photographs had been taken of a tree viewed at the edge of a calirated prism. Each photograph was taken at a slightly different distance from he tree for HDF's ranging from 1.659 to 1.834. The limiting HDF of the prism was 1.739. At each setting of the prism, a transit was centered over the prism, and the horizontal angle turned from one side of the tree to the other at the marked breast height. The HDF for each photograph was derived mathematically from this measured angle. The eleven photographs were arranged at random on a panel.

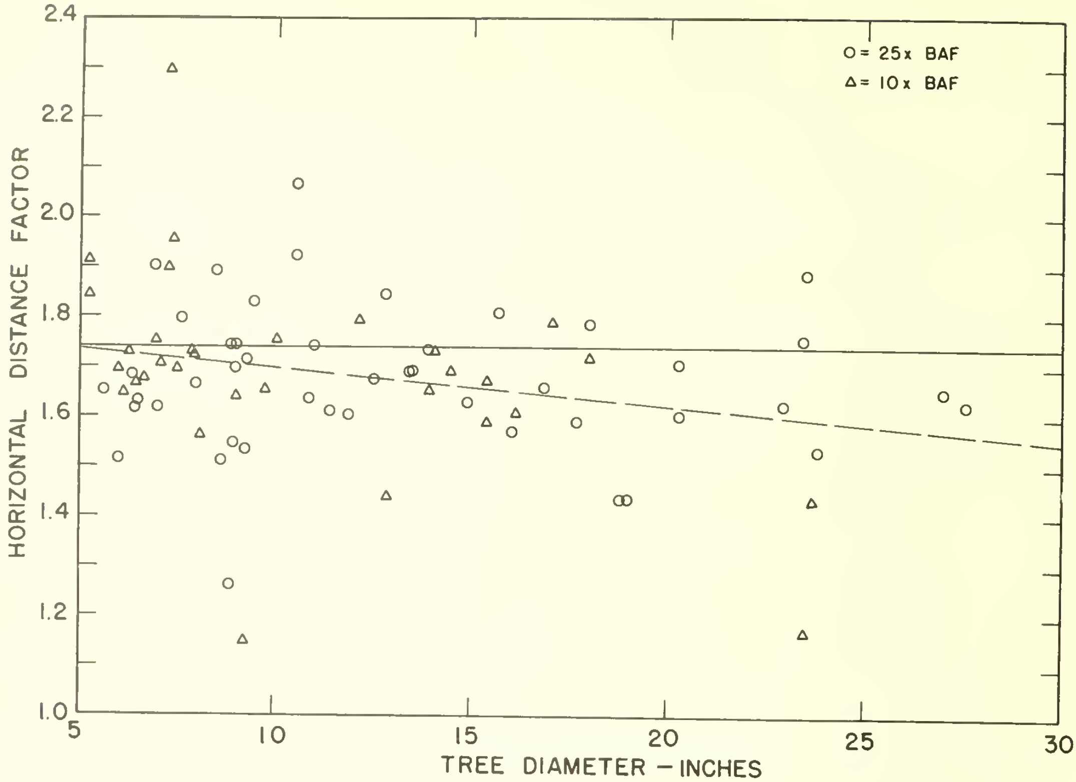

Figure 3.--Dashed line indicates the trend of marginal tree horizontal distance factors with tree diameter. Regression coefficient is significantly different from zero at the 95-percent level of probability.

Students of the University of Idaho mensuration class plus a number of other interested persons were asked to match photographs. Each person matched a sample photo with one from the panel which was "out" to an extent equivalent to that by which their sample tree was "in" or vice versa. The results of 86 such matchings with seven different sample photos show that there is a pronounced tendency to equate trees that are well within their "plot" with trees that are just barely out. Seventy-one percent of the pairings were in this direction, 19 percent matched the trees evenly, and 10 percent matched trees further out with trees just inside the limit. The mean HDF of the pairings was less than the limiting value. The t-value for the difference was 7.7, which corresponds to a probability well beyond the usual thresholds of significance.

From a theoretical standpoint, these results are just opposite to what would be expected. A 10-inch tree that is exactly marginal at 17.39 feet would have images that overlap by a visual angle of 26.4 seconds at 17.30 feet. To obtain a lack of overlap of an equal angle, the tree would have to be 17.49 feet away. Thus a tree 0.09 foot inside the boundary would appear to correspond to one 0.096 foot out. However, visual matching of photographs and the results of field measurements to actual marginal trees show that the balance is in the opposite direction. Apparently marginal trees that should not be counted are nore easily determined as being out than the converse. Thus, the assumption that one-half of the tally of marginal trees ought to be counted cannot be relied upon as unbiased.

Plot Basal Area Estimates

Comparison of Means

The comparisons of point samples to plot samples were intended to test one technique of using prisms for general timber cruising purposes. That is, the prism was to be the only means of estimating basal-area. Doubtful trees were not checked for counting other than optically through the prism. However, doubtful trees were recorded separately and counted as one-half the usual value. Thus the precision is not comparable to tests such as those of Grosenbaugh and Stover (1957) or Keen (1950) in which marginal trees were carefully checked by taped distances.

Plot data were classified (1) into stand strata composed of three stocking classes, two size classes, and four species groups, and (2) into ten diameter groups. The stand strata were determined by the type in which the plots fell and not necessarily by the plot data. This procedure avoids the skewed distribution of small plots with respect to larger ones at the extremes of density when grouped according to their respective stockings, as noted by Grosenbaugh and Stover (1957).

The strata were defined as follows:

Stocking classes:

Well = 70 percent + crown closure
Medium = 40-69 percent crown closure
Poor = 10-39 percent crown closure

Stand-size classes:

Sawtimber = more than 1,500 bd. ft. in trees 11"+ d.b.h.
Poletimber = stands failing to meet sawtimber specifications but at least 10-percent stocked with 5"+ d.b.h. trees and with at least 5 percent in poletimber (5"-10.9" d.b.h.) trees.

Species groups:

Ponderosa pine
Douglas-fir and western larch
Lodgepole pine
Western white pine (including western redcedar, hemlock, and grand fir)

The data were compiled by species groups, but differences between species were insignificant except as could be explained by size or stocking.

Differences between prism and fixed-plot estimates of basal area are expressed as a percentage of the latter in table 2. These data show a tendenc to underestimate basal area in stands of sawtimber size, especially when the stocking is high. This trend is evident in the data for both basal-area factors but is more pronounced with the 10x prism. On the other hand, there is a consistent tendency to overestimate basal-area of poletimber stands with the 25x prism.

Table 2.--Percent differences between prism and fixed plot basal-area estimates with their associated standard errors[1/]

Group	Stocking class: Well	Stocking class: Medium	Stocking class: Poor	All stocking
		Percent		Percent
25x prism[2/]				
Sawtimber	-11.0 ± 3.6**	-2.3 ± 3.7	-7.6 ± 8.0	-5.5
Poletimber	+14.5 ± 6.6*	+2.3 ± 4.7	+18.2 ± 20.5	+7.9
All sizes	-6.8 ± 3.3*	-1.1 ± 3.0	+8.7 ± 7.2	-3.1 ± 2.2
10x prism[3/]				
Sawtimber	-25.4 ± 5.9**	-16.1 ± 4.4*	+17.6 ± 9.3	-21.0
Poletimber	-0.1 ± 7.4	+3.1 ± 11.9	[4/] +41.7 ± 20.4	+2.7
All sizes	-22.6 ± 5.6**	-14.5 ± 4.3**	-14.7 ± 8.8	-18.7 ± 3.4**

1/ Standard errors were not obtained for size classes independent of stocking.

2/ Data from 524 plot comparisons.

3/ Data from 299 plot comparisons.

4/ Consists of only seven pairs of observations.

** = Difference significant at 99-percent level.

* = Difference significant at 95-percent level.

Data comparing both prism factors to the fixed-area plot are available or 299 plots. Their over-all means are as follows:

Means of Estimation	Mean Basal-Area--Sq.ft./acre
1/5-1/50-acre plot	114.3
25x prism	113.7
10x prism	93.0

The difference between the means for the two prism strengths amounted to 18 percent of the fixed plot estimate of basal-area. These data, compared to a common base, show that for the types encountered the 25x prism was better suited than the 10x to the conditions of size and stocking.

Figure 4 shows the percentage difference between the prism and plot stimates by mean diameter of the trees on the fixed-area plot. The trends of he two prism estimates are parallel. The 25x prism means exceeded the plot eans to a greater degree in stands of small diameter trees than did the 10x ata. Conversely, the 10x prism resulted in more serious underestimates in tands of large diameter trees than did the 25x prism.

Underestimates of basal-area are readily ascribed to trees overlooked in ense stands or at great distances from the sample center, and to the biased reatment of marginal trees. However, the overestimates that occurred in stands f small diameter are not so readily understandable. Several possibilities can e mentioned:

1. The hand-held prisms may not have been kept directly over plot center. If the prism were between the tree being viewed and plot center, an overestimate of basal-area would result which would be more noticeable in stands of small diameter.

2. Bias in plot center location results if plot center locations at or very close to the position of a tree bole are rejected. This bias would cause some overestimate in basal-area at the sizes and densities encountered if the trees tended to be uniformly spaced.

3. There was positive correlation between diameter and mean stand basal-area. For comparisons in which the plots were grouped according to the mean diameter of the fixed-area plot only, it may be assumed that they were also grouped according to the fixed-plot basal-area. The overestimates in the smallest diameter classes and the underestimates in the largest classes can be explained in the light of Grosenbaugh and Stover's (1957) discussion of the distribution of small (prism) plot means with respect to larger plot means. The difference in the means can be attributed then to logical characteristics of sampling procedure and do not represent bias if the general means coincide. The 10x prism plot size was greater than the corresponding fixed plot for tree diameters of about 6 to 11 inches. In this range, the relation of prism to plot would be reversed. Thus the fixed-plot estimates exceeded the prism estimates in these diameter classes, although they fall in the lower part of the distribution.

Relative Efficiency for Cruising

Forty-two percent as many trees per plot were tallied with the 25x prism as with the 1/5-to 1/50-acre plot design. For the 10x prism, 18 percent more trees were tallied than with the fixed-area plot.[2] Over-all, the same level

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2/ The number of trees for the prism estimate was obtained from the mean basal-area of fixed-area plot, the basal-area factor of the prism, and the number of plots. Thus, the possibility that some trees may have been missed with the 10x prism does not confound the present discussion.

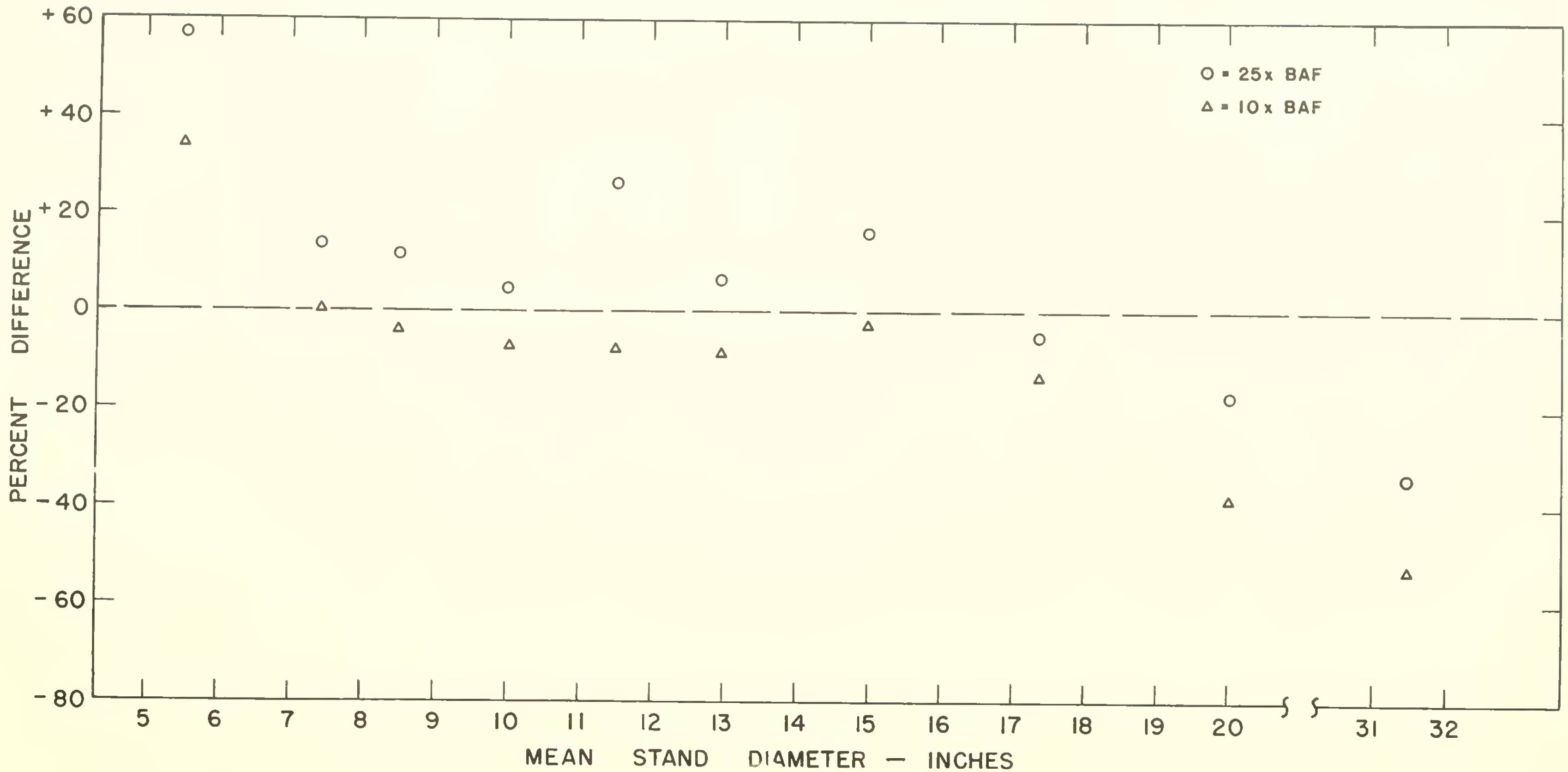

Figure 4.--Ratio of prism basal-area estimate to fixed-area plot basal-area estimate decreases with increasing mean d.b.h. of trees on the fixed-area plot for both 10x and 25x prism data.

of precision could have been achieved with fewer prism samples than with the fixed-area plots. Table 3 shows this relation by stand strata. The last column for 25x data shows that 87 percent as many prism plots would be required as with the fixed-area plots. With only 42 percent as many trees per plot, the prism estimate could achieve the same level of precision with 36 percent as many trees to consider as with the conventional plot cruise. Even in the least favorable stratum, well-stocked poletimber, the percentage is only 69. For the 10x prism data, the relative efficiency is 58 percent by number of trees.

Table 3.--Relative numbers of prism plots required to achieve precision equivalent to that on one hundred 1/5- to 1/50-acre plots for basal-area estimates by stand strata[1/]

Group	Stocking class			All stocking
	Well	Medium	Poor	
25x prism				
Sawtimber	82	111	121	
Poletimber	161	103	80	
All sizes	83	109	107	87
10x prism[2/]				
Sawtimber	50	57	64	
Poletimber	91	89	[3/] 246	
All sizes	41	58	63	49

1/ Equals: $\left(\frac{\text{Std. dev. prism b.a.}}{\text{Std. dev. plot b.a.}}\right)^2$

2/ The 10x prism data were obtained on only 299 of the 524 plots for which 25x prism data were obtained. The over-all coefficient of variation of the fixed-area plots was 71 percent for all plots vs. 80 percent for the 299 plots. Hence, the two prism strengths should not be compared in this table.

3/ Based on only six degrees of freedom.

The relative efficiency of the two prism strengths depends on their respective standard deviations. For the 299 plots on which both prisms were used, the square of the ratio of their standard deviations $(\sigma\ 25/\sigma\ 10)^2$ is 2.03. Thus 203 25x prism plots should have a standard error of the mean equal to that of 100 10x prism plots from the same timber. However, the 25x plots would contain only ten twenty-fifths or 40 percent as many trees per plot as the 10x plots. Thus, (40 percent) (203 percent) = 81 percent as many trees would be needed when counted with the 25x prism as with the 10x prism.

Since the 10x prism requires fewer plots and the 25x prism requires fewer trees, the decision on their actual relative efficiencies must depend on time studies of the variable cost per tree tallied vs. the fixed cost of plot establishment for each prism. Such data were not obtained in this test.

CONCLUSIONS

For general use in northern Rocky Mountain forests, the prism having a basal-area factor of 25 (4.79 diopters) appears to be most generally suitable. However, for well-stocked large sawtimber, a higher basal-area factor may be even more desirable. For stands of small diameter and good visibility, such a lodgepole pine stands in Montana, the 10x prism is suitable and perhaps more efficient than the 25x prism from the standpoint of efficiency.

Marginal trees should be checked for tallying by careful measurements to avoid bias in the basal-area estimate. It is doubtful that use of a hand-held prism reduces the task of checking marginal trees as compared to a fixed-area plot procedure. However, shortcutting this job is less likely to affect the accuracy of prism data than it would fixed-area plot data. Quite satisfactory basal area estimates were obtained here without any distance measurements when the appropriate prism strength for the stand conditions was used.

It seems quite clear that either prism factor considered in this test is more efficient than the 1/5- to 1/50-acre plot from the standpoint of efficienc. Fewer plots and fewer trees per plot are necessary for prism estimates of basa area than for fixed-area plots to attain equal statistical precision.

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RANGE RESOURCES AND MANAGEMENT PROBLEMS IN NORTHERN IDAHO AND NORTHEASTERN WASHINGTON

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INTRODUCTION

The area encompassed by this report includes the six counties of northeastern Washington and ten counties of northern Idaho (fig. 1), for a total of 20.58 million acres. A little less than two-thirds of this is in northern Idaho (table 1). The importance of the grazing resource in this area can be obscured easily by the overshadowing dominance of timber values. Approximately 70 percent is covered by forest, and wood processing is a major industry. Nevertheless, forage utilization by both domestic livestock and big game is an integral part of the economy.

The area supports more than 350,000 cattle and 65,000 sheep (table 2). Estimated valuation of all livestock in 1954 was 38¼ million dollars (table 3). Big-game animals contribute much more to the economy here than in many other areas in the West. Approximately 23,000 deer and 7,000 elk are harvested annually (table 4). The dollar value of this big-game resource has never been accurately determined, but a conservative estimate by the author places annual hunter expenditures in recent years at more than 6 million dollars. This figure does not consider the many intangible big-game values such as recreational pleasures obtained by the nonhunters who use this resource. Both livestock numbers and big-game harvest have varied considerably. However, the trend appears to be upward, and the demand upon the forage resource is likely to increase. This appears especially true for big game because of increased recreational pressures.

The contribution of livestock and big game to the economy of northern Idaho and northeastern Washington has entailed certain costs. Both livestock and big-game range have suffered varying degrees of depletion, primarily because many livestock operators and big-game managers do not thoroughly understand relations between animals and vegetation. They did not recognize the limited grazing capacity of the range, and grazing management systems for sustained forage production were practically nonexistent. Part of the resulting depletion can be attributed also to failure to apply knowledge that was available. As a consequence, large areas of formerly productive bunchgrass range have undergone type conversion to low-producing annuals; many once luxuriant subalpine herblands are now actively eroding; and numerous examples can be seen of abuse of winter range for deer and elk.

Despite the present impoverishment of large portions of the area's range lands, there is still potential for substantial livestock and big game production. A large livestock industry can be maintained by a combination of range improvement and development of grazing on forested lands. Values of the big-game resource are just beginning to be realized. The great potential for big-game production on a sustained yield basis can be achieved by development of methods for habitat manipulation and for control of animal distributions. Research provides the key to forage improvement on depleted areas as well as for integrated and full use of the grazing resource.

Production of livestock and big game in northern Idaho and northeastern Washington depends upon highly diverse grazing lands. These vary from open low-elevation grasslands to both permanent and transitory forest ranges, to mountain meadows and subalpine herblands. Each of these broad types presents peculiar problems in grazing management. Most involve serious multiple-use considerations. All demand attention if their full grazing potential is to be achieved.

GRAZING TYPES

Open low-elevation grasslands are the traditional livestock ranges of this area. They have been subjected to grazing pressures ever since early settlement, which began about 1860. The effect of this prolonged use is shown in the present depleted condition of much of the range. Two-thirds of the most productive native grassland has been converted to cultivated farming, largely to production of wheat in the noted Palouse region. The remaining grasslands make up 10 percent of the total land area and 27 percent of the total area grazed (table 5). They are used primarily for fall-winter-spring grazing. Livestock grazing is the principal use, and no serious multiple-use conflicts are involved.

Permanent forest range, as used here, applies primarily to the relatively open ponderosa pine[1/] type. This type can support a good understory of herbaceous and shrubby species even under a mature timber stand; consequently, a permanent forage supply is possible on any given area. This is in distinct contrast to conditions in the more moist forest types.

The ponderosa pine type occupies approximately one-fourth of the total forested lands in northern Idaho and northeastern Washington (fig. 1). The bulk of forest grazing has occurred on this type. These ranges are grazed by livestock during spring, summer, and fall. Heavy indiscriminate use has left much of the permanent forest range in relatively poor condition. Large numbers of deer live here and occasionally face critical shortages of winter browse. Timber and watershed values also must be considered in resource management for these lands. Grazing, therefore, must be integrated with management for these other valuable land uses.

1/ Scientific names for all species mentioned in this report are listed in the Appendix.

Transitory forest ranges occur in the more dense western white pine, Douglas-fir, and associated forest types. These types provide grazing only where the dense tree cover has been opened by logging or fire. They generally produce abundant forage for a number of years prior to closing of the regenerated tree stand. Since very little palatable herbage is produced under a closed canopy, the forage resource in any one place is temporary or transitory.

These dense timber types make up the bulk of the forest in northern Idaho. The white pine type alone occupies more than one-fifth of the total forested land in northern Idaho and northeastern Washington. Such forest types are suitable for livestock grazing only during the summer and early fall months. Generally, livestock use has been comparatively light and sporadic. It appears that a much greater grazing potential exists here than is currently being utilized. Logging continually brings new areas into forage production as tree reproduction crowds out desirable forage on other areas; thus, this transitory range type can be considered a permanent grazing resource. However, timber and watershed values are even greater here than in the drier ponderosa pine type.

Certain portions of transitory forest ranges have special importance for maintaining the large herds of elk and deer in northern Idaho. These areas often receive year-round use by big game, and they are vital as a source of browse. Restricted wintering areas are the limiting factor in determining animal numbers. Some of these wintering areas are badly abused. Continued existence of this important big-game resource depends upon maintenance of desirable habitat in an area where natural plant succession is toward a dense tree stand--an unproductive big-game habitat. Continued production of big game, like production of livestock, will require integration with other important forest uses.

Mountain meadows are scattered throughout the forested areas. These meadows are relatively flat, natural grassy openings near the head and along the course of streams. They are usually surrounded by dense stands of trees. Even though such meadows probably occupy less than 1 percent of the area of northern Idaho and northeastern Washington, they contribute significantly to the total forage resource. Deep fertile soils and ample moisture produce a luxuriant growth of palatable grasses and sedges. Livestock graze here during the summer. These areas can withstand heavy use and are not often badly abused. Some meadows, however, are producing considerably less than their potential, and a few are actively eroding.

Subalpine herblands, like mountain meadows, form only a small part of the range area, yet furnish an important part of the summer forage. These herblands are natural openings on high-elevation slopes and ridges. Areas in good condition produce abundant grasses and forbs, but they are very sensitive to grazing abuse. A combination of high precipitation, unstable soils, fairly steep slopes, and a short growing season with extreme weather variations make proper resource use very difficult. Much of this subalpine grazing type is in various stages of deterioration; soil erosion is prevalent.

* * * * * * *

The problems involved in utilizing these five grazing types fall generally into two categories--restoration of deteriorated range and integration of grazing with other land uses. Both kinds of problems relate equally to livestock and big-game range. Detailed descriptions of these grazing types and of the problems involved in grazing management for each are presented in the following pages. Relative severity, or urgency of the problems and research priorities are also discussed. The future of livestock and big-game grazing in northern Idaho and northeastern Washington depends upon satisfactory solution of these problems.

OPEN LOW-ELEVATION GRASSLANDS

The status of low-elevation grassland ranges, in comparison to that of other range types, is an anomaly in several ways. Deterioration on the original vegetation often results in a change to annuals that have a reduced but significant grazing value. The climate, soils, and vegetation under poor range condition do not tend toward severe soil loss by water erosion. In addition, multiple-use considerations are few.

Much of the nearly 2 million acres of this range is in poor to depleted condition. The original vegetation consisted primarily of productive bunchgrasses with an interlacing of perennial forbs. Daubenmire (1942) classified this vegetation into three separate zones. From the most dry to more moist, these zones are: (1) big sagebrush-bluebunch wheatgrass-Sandberg bluegrass, (2) bluebunch wheatgrass-Sandberg bluegrass, and (3) Idaho fescue-bluebunch wheatgrass. Characteristic dominant species in each zone under climatic climax conditions are indicated by the zone name. Additional characteristic species include prairie junegrass, subalpine needlegrass, arrowleaf balsamroot, and silky lupine. When this vegetation is abused by overgrazing, palatable perennials are destroyed; thus, less desirable perennials and annuals are permitted to invade and increase. Severe disturbance often results in establishing an almost complete stand of annuals consisting mostly of cheatgrass brome. Annual fescues and other annual bromes also are often abundant. Such annual grasses still permit considerable grazing. Their major disadvantages, aside from reduced quantity and poorer quality of feed, are large annual fluctuations in production and early drying.

Fortunately, even poor-condition bunchgrass ranges do not suffer depletion of the soil corresponding to that of the vegetation. The limited soil erosion is attributed to the low amount of precipitation (only 15 to 25 inches annually) and fairly good soil cover by invading species. Much of the area is underlain by basalts and is classified as "rough and stony lands" with "incomplete development of soil profiles" (U.S. Dept. Agr., 1936). The deep northern Chernozem soils in the loessial regions of eastern Washington and adjacent portions of western Idaho are now largely in wheat and pea production. The remaining portion occurs in "channeled scablands" to the south and west of Spokane, and in the foothill and canyon areas of Idaho and Washington. In some places, such as the lower slopes of the Snake and Salmon Rivers in Idaho (fig. 2), the topography is almost precipitous. Although the soils on these steep topographies are remarkably stable with respect to water erosion, they are subject to considerable displacement by trampling.

Figure 2.--Open low-elevation grazing lands along the Salmon River; used primarily in fall-winter-spring period.

Grazing is practically the sole use of these low-elevation range lands, and it will probably remain the only use. Arable lands have already been removed, the area is too arid for timber production, and the low precipitation and relatively stable soils make watershed values insignificant. Big-game use on the area is negligible. Therefore, management can be directed almost exclusively toward livestock production.

Improvement of low-elevation ranges offers opportunity for substantial improvement in the livestock industry. These ranges are badly needed for fall, winter, and especially spring grazing. Adequacy of spring grazing is the limiting factor of many livestock operations. As a result, such ranges are overused and the animals are often forced on the summer ranges too early.

Two different approaches can be used for improvement of low-elevation ranges. Grazing management systems can be used to improve ranges not badly depleted and those not suited to present cultural methods of artificial revegetation because of rocky soils or steep slopes. Some low-elevation ranges could be greatly improved by seeding with adapted introduced grasses. Substantial forage gains and an extension of the grazing period would result. The increased forage produced by seeding suitable depleted areas would open the way to lighter use on other areas and facilitate improvement by proper grazing management.

Forage production could be improved considerably by applying available information. Productive forage species and methods suitable for seeding gently sloping, rock-free ranges are available (Short, 1943; Ensminger et al., 1944; Friedrich, 1947; Hafenrichter et al., 1949; Schwendiman, 1954; Evanko, 1955). Much has been done to determine the general ecology of bunchgrass vegetation found here (Weaver, 1917; Daubenmire, 1942), the reaction of vegetation and soils to grazing (Daubenmire, 1940; Daubenmire and Colwell, 1942; Young, 1943), and plant forms with respect to determinations of utilization (Lommasson and Jensen, 1943; Heady, 1950). The Soil Conservation Service has published a series of range condition classifications for various conservation districts lying within the bunchgrass zone of eastern Washington (Humphrey, 1945; Marsh and Humphrey, 1946; Spencer, 1947a, Gilbert, 1948). Factors to consider in grazing management practices for this type of range are discussed by Anderson (1952). The information contained in these publications and others provides a foundation for developing sound management practices for such range. Unfortunately, full use has not been made of this information.

Research Problems

The current fund of knowledge concerning this grazing type is relatively great, but considerable information is still needed to permit its full development as a range resource. Grazing management techniques for improving the less depleted areas and those unsuited for seeding need to be worked out fully. Detailed grazing management practices are required for forage maintenance on both seeded and naturally improved ranges. This will involve grazing systems, periods, and intensities for different classes of livestock. Information is needed on the relative desirability of maintaining various forage levels. For example, we should seriously consider managing as permanent annual types those ranges that have been converted to annuals but which are not suited to seeding.

Many of the depleted low-elevation ranges cannot be revegetated with high-yielding exotic grasses because of inadequate equipment and methods. Both equipment and techniques need to be developed for seeding rocky soils, rough topography, and steep slopes. The place of fertilization in revegetating these relatively dry range areas needs to be determined. Can fertilizers help in establishment of seedlings, or in boosting production of existing vegetation?

Invasion of undesirable plants is a serious problem on low-elevation ranges. Northeastern Washington and northern Idaho appear to be plagued by an overabundance of exotic range weeds (Noxious Weed Control Task Force, 1952). The most severe and widespread infestation is by common St. Johnswort. More than one-half million acres of rangeland in the northern Idaho and northeastern Washington area are infested by this very aggressive perennial (Harris, 1951). The ecology and control of common St. Johnswort in this area have been reported in some detail (Pringle, 1952; Tisdale et al., 1953; Evanko, 1952, 1953, Nelson, 1956). A wealth of information on chemical and biological control is available from other areas. Biological control by beetles (Chrysolina gemelata and C. hyperici) specific to the plant appears very promising in northern Idaho and northeastern Washington. A problem for future work is determination of management practices to prevent reinvasion of ranges cleared of common St. Johnswort.

Both Dalmatian toadflax and diffuse knapweed are exceedingly aggressive invaders of depleted ranges in this area. Present infestations of these two weeds are small and spotted, but both weeds threaten large range areas. Studies of Dalmatian toadflax and diffuse knapweed have been largely restricted to preliminary determination of effectiveness of various herbicides. Medusahead rye, a Mediterranean annual grass, is a worthless species that reportedly can dominate badly depleted drier sites in portions of Idaho. Ecological studies of Medusahead have been made in Idaho (Sharp and Tisdale, 1952), but little information on control is available. These three weed species severely threaten low-elevation rangelands in this area. As yet, little is known of their ecology or of methods to control them. Their potential spread needs to be determined and suitable direct and indirect control methods developed.

PERMANENT FOREST RANGE

The approximately 3.6 million acres of ponderosa pine lands in northern Idaho and northeastern Washington (Forest Survey Staff, 1937; Buell, 1937; Pissot, 1953) constitute most of the permanent forest range (fig. 3). This relatively open forest type is of prime importance for spring-summer-fall grazing. It occupies the fairly low (1,500 to 3,000 feet) southern and western fringe of forests indicated in figure 1. Demand for spring range has continually subjected these areas to heavy spring grazing pressures. Summer use is alleviated somewhat by availability of later developing summer ranges. Management of this grazing type is greatly complicated by the necessity for integrating grazing, timber production, watersheds, and wildlife production.

The open nature of ponderosa pine forests provides a permanent forage resource in understory vegetation. This is the driest belt of forest in northern Idaho and northeastern Washington (20 to 30 inches annual precipitation), and is dominated only by ponderosa pine. Understory vegetation, however, can be diverse. Daubenmire (1952) classified the climax ponderosa pine zone into four separate associations on the basis of the following characteristic undergrowth species: bluebunch wheatgrass, antelope bitterbrush, common snowberry, and mallow ninebark. Besides these four, prevalent understory species include: Idaho fescue, arrowleaf balsamroot, Spalding rose, and western yarrow.

Figure 3.--Permanent forest range in an open stand of ponderosa pine.

The soils, also diverse, are derived from several parent materials: basalts, granites, aeolian deposits, and glacial deposits in the more northern areas. Much of the land is classified as "rough and stony" (U.S. Dept. Agr., 1936).

More open portions of the adjacent Douglas-fir zone also can be considered a permanent forage resource, especially where a good understory of pine grass is present. However, the overall contribution of this type is very small because its area is small.

Grazing these areas has had an impact upon forage production and upon other land uses as well, but effects of overgrazing a large part of the permanent forest ranges have never been completely evaluated. Abuse of grazing areas has changed species composition to undesirable annuals and perennials. However, the impact of grazing upon timber production has been less apparent. Permanent forest ranges are very important for production of both wood and forage. Overgrazing can markedly affect tree regeneration, and no doubt influences annual increment. On the other hand, grazing capacity has been severely reduced on some areas by overabundance of young conifer regeneration (Harris, 1950). Big game also contribute to the grazing-timber conflicts, for both white tail and mule deer are found in this type the year around. During the winter, elk graze portions of the ponderosa pine zone along the major drainages of northern Idaho. Certain areas are considered critical game winter ranges; on these and other local areas, deer have considerably damaged ponderosa pine reproduction. Watershed values are important and have suffered under too heavy grazing. Although the erosion potential is not severe, soil loss with watershed depletion does occur. Such multiple-use considerations greatly complicate resource management.

A substantial increase in forage production is possible in this permanent forest range type. Better grazing management practices alone could probably improve this range type considerably. General recommendations for grazing these ranges have been made (Spencer, 1947; McLaughlin and Sundquist, 1948; McLaughlin and Geiger, 1948), but detailed grazing systems for improvement and maintenance are required. Grazing values probably can be increased by such silvicultural practices as thinning; however, logging disturbance can be at least temporarily detrimental to forage production (Garrison and Rummell, 1951). The effects of such practices need to be fully evaluated if they are to be used positively.

Research Problems

The major problem on these forested rangelands appears to be in the integration of grazing and timber production to obtain maximum resource use. Full integration requires a thorough understanding of the effects of grazing upon timber production as well as the effects of silvicultural practices upon forage production. Although several workers have studied the influence of grazing upon forage production on similar ponderosa pine ranges (Pickford and Reid, 1948; Rummell, 1951; Harris, 1954), very little information is available about the effect upon timber production: this is practically a virgin field for study.

The key to full development and proper management of this resource is research. One primary need is a workable formula to answer the economic questions of land use.

What is the relative value of different forested sites for the production of trees, for the production of forage, and for simultaneous production of trees and forage? This is a basic question. The answer will be found in a composite of the answers to many unknowns. A knowledge of land potential for timber and forage production is a first necessity.

What is the effect of grazing by livestock and game on timber stand establishment? What is the effect upon timber increment? This probably involves both soil compaction and the influence upon competing vegetation. And, of course, what are the effects of forest management practices on forage production? No doubt greatest resource values can be obtained from most of the ponderosa pine type by harvest of both forage and timber. It will be necessary to develop compatible grazing systems and silvicultural practices to do this effectively. Answers to the above questions will be needed for the development of such dual management.

TRANSITORY FOREST RANGE

The dense forests of western white pine, grand fir, and associated mesophytic tree species in northern Idaho and northeastern Washington are not ordinarily regarded as forage producers, yet such forests have provided grazing in the past and contain an even greater potential. These dense forests can be grazed only when opened by logging or fire (figs. 4 and 5). An abundance of forage, predominantly browse, is usually produced following opening. Since this production does not persist in the closed timber stands that eventually follow, the grazing values are considered transitory. The total forage resource, however, is considered permanent because logging continually brings new areas into seral vegetation stages suitable for grazing.

Relatively dense forest types constitute much more than half of the total forested areas. The western white pine and associated species type alone covers nearly 4 million acres, while the combined western larch and Douglas-fir types occupy 3.4 million acres, and the lodgepole pine type another 1.3 million acres (Forest Survey Staff, 1937; Buell, 1937; Pissot, 1953). The numerous climax forest associations found here were described in detail by Daubenmire (1952). In most of these, a significant amount of forage is produced only in early seral stages. Closed forest stands are practically useless for livestock and big game. Abundant moisture (25 to 45 inches annual

Figure 4.--Such clear cut and burned white pine areas can produce an abundance of livestock feed before regrowth of the timber stand; however, down logs somewhat hamper grazing.

Figure 5.--A partially cut white pine stand can produce abundant herbaceous growth. Such transitory range might be used for 10 to 15 years.

precipitation) permits luxuriant herbaceous and shrubby growth following tree removal. Generally, herbaceous species predominate only the first few years following clearing. Brush species, such as Scouler willow, redstem ceanothus, Rocky Mountain maple, myrtle pachistima, huckleberry, and many others then dominate the site until tree regeneration crowds them out. Many shrub species are palatable and readily used by sheep and cattle, as well as by elk and deer.

The feasibility of grazing domestic livestock on such areas in the summer has been demonstrated (Young et al., 1942; Ingram, 1931; Lommasson, 1947). These mesophytic forests are usually at higher elevations than the ponderosa pine zone, and vegetal growth begins later. Livestock grazing of the seral vegetation stages has never been very extensive; a much greater potential for grazing appears to exist here than is now being utilized.

Seral vegetation in portions of the mesophytic forest areas play a major role in maintaining the large big-game herds in northern Idaho. South slopes near the river bottoms are vital as winter ranges (figs. 6 and 7). The large deer and elk herds, especially the elk, have built up since the numerous and extensive forest fires in the early part of the century. These early fires, primarily the 1910, 1919, 1926, 1929, 1931, and 1934 burns, created bounteous big-game habitat in the resulting extensive brush fields. Shaw (1954) reported that elk were rarely seen in the Selway drainage of north-central

Figure 6.--Deer and elk winter range along Lochsa River in northern Idaho.

Figure 7.--Such big game winter ranges occur on single or repeated burns. Browse species such as willow and maple often reach heights of 20 feet or more.

Idaho as late as 1913; but by 1935 elk population in this drainage had increased to an estimated 11,000 head. Other herds increased similarly in major drainages of north-central Idaho As these tremendous brush fields gradually revert to coniferous production or attain heights beyond the reach of animals, progressively less usable range is available. This, combined with reduced fire occurrence and overuse of key wintering areas, has resulted in a general leveling and reduction of animal numbers in many drainages. Examples of such reductions are the decrease of elk in the Selway drainage from 11,000 in 1935 to 7,000 in 1949, and in the Lochsa drainage from an estimated 12,000 in 1936 to 2,100 in 1949 (Shaw, 1954). Maintenance of the big-game resource depends upon provision of a stable habitat commensurate with the number of animals desired.

These mesophytic forest areas can probably contribute more to grazing than is now being realized. Increase of summer livestock use should be possible after development of special grazing practices. Of course the primary value of most of this forest land is for timber production. However, diligent management should enable these areas to support considerable summer grazing without detriment to timber production. Possibly grazing at specific times and intensities might even benefit timber production by assisting in establishment of reproduction (Young, et al., 1942) and by reducing fire hazard (Ingram, 1931). Increased use here not only would provide for more livestock, but also might reduce grazing pressures on other areas now receiving too heavy summer use. The big-game resource would be benefited greatly if wildlife use could be placed in its proper relation with respect to other, often conflicting, uses. Once this recognition is obtained, big-game habitat areas could be so designated, and management of deer and elk could be placed on a sound sustained-yield basis.

Research Problems

Utilization of forage and browse in these mesophytic forest areas presents special problems. In some respects, the conflict between livestock grazing and timber production is not as great here as in the open ponderosa pine type. The high timber producing values plus the transitory nature of grazing should obviate severe conflict--grazing of livestock being purely secondary on such sites. However, if grazing practices can be developed that will not be objectionable to the silviculturist, these forested lands will yield additional return. To capitalize on this forage value, research needs to determine the grazing management required for proper timber development. Maintenance of forage values, per se, need not receive the same consideration here as on the permanent range types. However, methods for livestock distribution need to be developed in order to fully utilize the forage produced.

Forest use by big game often severely conflicts with timber production. Maintenance of this wildlife resource without critical winter range areas devoted almost exclusively to game use does not appear possible. Low-lying, south-slope winter ranges are the limiting factor in determining big-game numbers in this area. Maximum browse is obtained only from seral shrub stages;

therefore, tree growth must be precluded for the most part. However, shelters and means of access provided by adjacent timber stands are a valuable habitat adjunct for elk and mule deer, and they are a necessity for white-tail deer. Criteria are required to facilitate designation of areas where game production should be given preference over other land uses; then decisive action should be taken to so classify these areas and to improve habitat suitability to its best possibility.

Much basic information is required for the development of good management practices for winter range areas. This includes knowledge of the productivity of successional stages for big game and the natural persistence of desirable stages. Development of artificial means for maintaining such stages can then follow. Pengally (1953) found that browse production reached a peak 10 to 15 years following logging, and decreased gradually thereafter until conifers again dominated. However, he studied only a small segment of the problem area. Knowledge of palatability and nutritive value of shrub species precedes determination of productivity; fortunately, considerable information is available on this subject (Young and Robinette, 1939; Pengally, 1953; Woolfolk, 1953). However, little is yet known about the amount of use desirable species can withstand.

The elk winter range problem on the extensive burns in central Idaho is perplexing. Elk demonstrate distinct preference for certain areas and, during years of heavy snowfall, they show extreme reluctance or inability to move to adjacent areas that have more browse available. During occasional severe winters (perhaps one or two out of every ten) animals concentrate on relatively small "critical" ranges. Here utilization becomes extremely heavy and many elk die from starvation. The problem is one of either finding ways to distribute the animals over a larger area during such winters or to provide sufficient browse on the critical ranges to sustain the desired number of animals.

Many key winter range areas urgently need restoration. Remedies for at least three typical conditions of browse deterioration are needed. Many of these areas exemplify one or more of the following problems:

1. On some areas, browse species have grown beyond the reach of game animals. Such species should be restored to usable production.

2. On some deteriorated winter game range areas (chiefly in the ponderosa pine zone), browse has been so seriously suppressed--some patches have been killed--that slopes have been left virtually bare.

3. On still other winter range areas, reproduction of conifers and increase of undesirable species have crowded out valuable browse.

Direct methods of management are needed to restore and maintain key winter ranges at a productive level.

Mountain meadows supply an important part of the summer forage. These grassy, stream-bottom openings occupy not more than 2 percent of the total summer range area, yet provide a significant amount of summer forage. Forage production here is many times greater than on adjacent forested ranges. Reid and Pickford (1946) reported that similar meadows in eastern Oregon and Washington have a potential production equal to 20 percent of the total summer range forage even though they cover only 1 to 2 percent of the summer range area.

Figure 8.--A typical mountain meadow in good condition.

Grassy meadows are scattered throughout the forests of northern Idaho and northeastern Washington (fig. 8). These areas are comparatively flat, natural openings near the head and along the course of streams and are often surrounded by dense stands of trees. Their relatively deep, fertile soils and good moisture relations permit luxuriant herbaceous growth. Perennial grasses and grasslike plants predominate when the meadows are not depleted by overuse. The most prevalent species include Kentucky bluegrass, redtop, tufted hairgrass, and timothy. Sedges and rushes dominate the more moist spots. When subjected to continual heavy use, the soils become compacted and the meadows take on the characteristics of a lawn. Kentucky bluegrass, redtop, and clover then form a dense, low-vigor sod. This sod is broken up by further depletion, which permits the invasion of such undesirable forbs as western yarrow, common dandelion, cinquefoil, and sheep sorrel. Meadows can withstand a surprising amount of abuse before erosion becomes obvious.

Artificial or induced meadows sometimes form along formerly wooded stream bottoms that have been clear cut, burned, and then heavily grazed. Often the resulting grass-clover sod so dominates these areas that tree reproduction is impeded. Continued grazing enables them to remain essentially a grazing type.

Meadows in northern Idaho and northeastern Washington are not generally badly depleted. Although many are deteriorated vegetatively, most have not begun to erode actively. Deterioration is demonstrated by a change in species composition and reduced production of forage. The threat of severe damage from continued abuse is present, and such damage can be disastrous (fig. 9). Once gullying starts, the water table drops, the habitat becomes drier, and the growth potential is seriously reduced. Damage can be irreparable.

Research Problems

One fundamental requirement for most judicious management of these meadows is knowledge of the vegetal level toward which management should be directed. What species composition, natural or seeded, will continually produce the most pounds of beef and still adequately protect the soil?

Figure 9.--Erosion can be catastrophic on depleted mountain meadows.

Differences in site potential need to be considered. When the most productive levels are known, grazing management systems need to be developed to obtain and maintain the desired kind and quantity of vegetation.

High potential productivity and physiographic suitability make these meadow types well suited for intensive management. However, the details for such management need to be developed.

What restorative practices can increase production on meadows that have deteriorated vegetatively? Studies in Oregon (Pickford and Jackman, 1944) show that seeding to desirable species is possible. Can fertilizers boost production economically in such meadow types? Cooper and Sawyer (1955) found that application of nitrogen and phosphorous to eastern Oregon meadows substantially increased vegetal production. Pocket gopher depredation has been severe in some Oregon meadows (Moore and Reid, 1951), but such rodent activity has not been assessed on northern Idaho and northeastern Washington meadows. Would control yield a significant forage increase here? What are the possibilities of drainage for increasing forage production on very wet meadows? The effectiveness of all these practices needs to be determined.

Figure 10.--Typical subalpine herblands in the Seven Devils Mountains of Idaho. This area is essentially an open sedge-grass-forb type with scattered patches of conifers.

SUBALPINE HERBLANDS

Subalpine herblands, as the name suggests, are natural openings on high elevation slopes and ridges, approximately 5,000 to 7,500 feet elevation, dominated by herbaceous growth (fig. 10). This grazing type occupies a very small portion of the total grazing area in this region but can produce considerable forage during the summer. Unfortunately these ranges are very sensitive to grazing abuse. Their potential productivity, sensitivity to abuse, and importance as key watersheds, give them a significance as problem areas far beyond what their size alone would indicate.

Two different kinds of subalpine ranges apparently occur in this area. Fairly extensive grass-forb slopes are in the southern part, especially in the Seven Devils Mountain region of Idaho, while in northern Idaho and Washington are found more limited openings in which grasses dominate. The relatively balanced mixture of grasses, grasslike plants, and forbs in the more southerly areas includes Idaho fescue, sedges, aster, eriogonum, hawkweed, and western yarrow. In the northern areas, pinegrass, Idaho fescue, green fescue, bluebunch wheatgrass, and sedges predominate; lesser amounts of such forbs as western yarrow, penstemon, and sieversia also occur. Such good condition herblands support an abundance of vegetative growth and provide excellent cover to protect the soil from erosion.

Climate, soils, and physiography all contribute to sensitivity of the vegetation to disturbance and to the erosion potential. Most soils here are of granitic origin and are readily erodible. Heavy runoff from melt of the deep winter snowpack, late spring rains, and occasional high intensity summer storms demand good protection to prevent loss of soil from slopes. The plant growth that provides soil protection must persist under severe growing conditions. The growing season is very short, and temperature variations are extreme. Establishment of reproduction is hampered by rapid drying of soils following snowmelt and spring rains. This combination of weather and soil factors necessitates caution in any land use that tends to disturb either vegetation or soil.

Many subalpine herblands are seriously depleted because they have been grazed too heavily by cattle and sheep during the short summer grazing period. Forage depletion and sheet erosion are evident in many areas; active gullying is severe on others (fig. 11). Such areas now produce only a fraction of their original forage. The most serious result of overgrazing, however, is loss of the basic resource, the soil mantle--which has taken hundreds, if not thousands, of years to form.

Research Problems

Some high elevation openings are so sensitive to disturbance that grazing probably should be excluded entirely. These extremely sensitive areas need to be protected from disturbance to protect their paramount watershed values. Criteria are required to enable delineation of areas that can be grazed safely from those where grazing would result in watershed deterioration.

Figure 11.--Overgrazing of subalpine herblands results in forage depletion and severe loss of soil.

Many of these herblands require restoration. Where soil loss has not been great, a thin but well distributed cover of desirable perennials remains. Some of these areas may be restored simply by using appropriate grazing management practices. Grazing practices (including systems, intensities, and livestock distribution controls) need to be developed for restoration and for maintenance after the areas are restored. Such practices are required for areas still in fair to good condition to prevent possible future degradation. Condition and trend guides established by Pickford and Reid (1942) for subalpine grasslands in northeastern Oregon and southeastern Washington may be useful in management here.

Other areas are in such depleted condition that cessation of grazing probably will not suffice by itself to stop erosion. Such intensive artificial methods as trenching, gully damming, and seeding of soil-holding perennials may be required.

Peterson's (1953) findings regarding suitable forage plants for seeding high altitude range in Montana may be applicable here. The effectiveness of such methods for halting soil loss needs to be determined. In addition, most of the severely depleted areas have undergone a corresponding deterioration in site quality. Consequently, the suitability of various sites to different methods of restoration also needs to be determined. The active state of degradation of much of the subalpine herbland and the irreparable damage through soil loss should spur development of restorative and maintenance practices.

RELATIVE RESEARCH NEEDS

Acreage figures alone do not accurately reflect the grazing values of the various types. On the basis of area, forested lands dominate the grazing types in northern Idaho and northeastern Washington: more than 70 percent of the total area grazed is in forests. Less than 25 percent of the grazing lands are open low-elevation grasslands, and only a few percent are mountain meadow and subalpine herblands combined. However, productivity per acre is much greater on the more lush mountain meadows and subalpine ranges than on the forested and low-elevation grassland ranges.

The bulk of the grazing area is in forests, but the most critical livestock range problems relate to subalpine herblands, many of which are actively eroding. Critical watershed values, high forage potential, and sensitivity to grazing abuse add urgency to solving grazing problems on these ranges and indicate high priority for research. Mountain meadows and low-elevation grasslands lack equivalent urgency for improved management because their soils are more stable even under heavy grazing and because multiple-use conflicts seem less severe. Although major portions of these latter two types are deteriorated and relatively unproductive, erosion is not serious.

Forested ranges appear to be less abused than the other grazing types. However, livestock use here must be integrated not only with watersheds but with timber and wildlife production as well. Development of the transitory range resource might considerably alleviate overgrazing of other summer range areas. Forested areas have a special significance in meeting the habitat requirements of the large herds of elk and deer for which northern Idaho is noted. These animals depend completely upon winter ranges provided by seral shrub stages within the forested zones.

More is known about low-elevation grasslands than about any other grazing type in this area. Less is known that would facilitate livestock management on forested areas and mountain meadows. Very little information is available to help solve the severe problems on subalpine herblands. Thus, for the most urgent problems, we have the least information available.

The contrast in available information is equally great when comparing livestock and big-game use. Lack of specific information about management of big-game habitat is a gross anomaly when we relate the significance of this resource to the economy of the area. The seral shrub game habitat is unique as a problem type. On the other hand, results of studies conducted on livestock range throughout the Northwest and northern Rocky Mountain regions presumably have some application to much of the permanent livestock range in this area. The need for research, then, appears to be more urgent on transitory big-game livestock ranges than on permanent livestock ranges.

One of the greatest needs for research on northern Idaho and northeastern Washington range lands is an adequate ecological understanding of the various range types. Achieving full use of the forage resource and development of intelligent management practices requires an understanding of the vegetation structure, successional patterns, and species and community responses to grazing pressures. At best, this basic information for most areas is very sketchy. Therefore, synecological studies, including studies of grazing influences, seem to warrant high priority under all types.

A summary listing of major grazing types subdivided into broad problem categories with suggested priorities for research is given below. The two problems considered most urgent for reasons already discussed are restoration of big-game habitat on transitory forest ranges, and restoration of subalpine herbland. The following list of suggested relative priorities does not mean to imply that certain problems are not important: all are important in varying degree.

Major Range Management Problems in
Northern Idaho and Northeastern Washington

Grazing area	Problem category	Research priority
Subalpine herblands:	Restoration practices	1
	Integrated grazing management	2
Transitory forest range:	Restoration of winter range	1
	Integrated grazing management	2
Permanent forest range:	Restoration practices	3
	Integrated grazing management	2
Open low-elevation grasslands:	Restoration practices	3
	Grazing management	4
Mountain meadows:	Restoration practices	3
	Grazing management	4

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A P P E N D I X

Table 1.--Forest and nonforest land in northeastern Washington and northern Idaho

Land Classification	Northeastern Washington[1]	Northern Idaho[2]	Total
	- - - - - Thousand	acres	- - - - -
Total forest	3,930	10,226	14,156
Commercial forest	(3,708)	(7,760)	(11,468)
Noncommercial forest	(222)	(2,466)	(2,688)
Nonforest	4,088	2,341	6,429
Total	8,018	12,567	20,585

1/ Kemp and Pissot, 1949.
2/ Pissot, 1953.

Table 2.--Livestock in northeastern Washington and northern Idaho, 1925, 1935, 1945, 1950, 1954[1]

Livestock	1925	1935	1945	1950	1954
Cattle					
Northeastern Washington	109,318	77,760	192,092	172,313	214,239
Northern Idaho	77,568	61,176	142,439	117,982	158,717
Total	186,886	138,936	334,531	290,295	372,956
Sheep					
Northeastern Washington	41,655	99,251	72,961	46,145	42,108
Northern Idaho	68,312	86,523	29,290	23,194	27,751
Total	109,967	185,774	102,251	69,339	69,859
Total animal units	208,879	176,091	354,981	304,163	386,928
(= 5 sheep) (= 1 cow)					

1/ U.S. Census of Agriculture, 1925, '35, '45, '50, '54.

Table 3.--Value of livestock in northeastern Washington and northern Idaho in 1954[1]

Livestock	Northeastern Washington	Northern Idaho	Total
	- - - Thousand	dollars	- - -
Cattle	20,785	15,397	36,182
Sheep	696	480	1,176
Horses and mules	465	432	897
Total	21,946	16,309	38,255

1/ U.S. Census of Agriculture, 1954.

Table 4.--Harvest of deer and elk in northeastern Washington and northern Idaho[1]

Big game	1952	1953	1954	1955	1956
Deer					
Northeastern Washington	13,769	16,725	14,903	17,441	--
Northern Idaho	5,752	10,581	13,155	10,600	11,800
Total	19,521	27,306	28,058	28,041	--
Elk[2]					
Northern Idaho	5,207	7,339	8,669	6,001	8,240

1/ Data obtained from correspondence with the State of Washington, Dept. of Game, and the State of Idaho, Fish and Game Dept.

2/ Essentially no elk kill in northeastern Washington.

Table 5.--Land area classification by ownership and type in northern Idaho and northeastern Washington[1/]

Ownership	Total land area	Forest not grazed	Nongrazed farm land	Forest grazed	Non-forest grazed	Total area grazed
	- - - - - -	- - - - - -	Thousand	acres	- - - - - -	- - - - - -
Federally owned or managed						
National forest	8,073	6,412	--	1,063	598	1,661
Indian	741	--	--	646	95	741
Other	439	289	--	110	40	150
Total	9,253	6,701		1,819	733	2,552
State and county	1,066	646	--	350	70	420
Private	10,132	1,685	4,218	3,059	1,170	4,229
Total all ownership	20,451	9,032	4,218	5,228	1,973	7,201

1/ Independent compilation by the Spokane office of Intermountain Station. Totals are slightly different from those given in table 1.

COMMON AND SCIENTIFIC PLANT NAMES

Antelope bitterbrush	*Purshia tridentata*
Arrowleaf balsamroot	*Balsamorhiza sagittata*
Aster	*Aster* spp.
Big sagebrush	*Artemisia tridentata*
Bluebunch wheatgrass	*Agropyron spicatum*
Brome	*Bromus* spp.
Cheatgrass brome	*Bromus tectorum*
Cinquefoil	*Potentilla* spp.
Clover	*Trifolium* spp.
Common dandelion	*Taraxacum officinale*
Common snowberry	*Symphoricarpos albus*
Common St. Johnswort	*Hypericum perforatum*
Dalmatian toadflax	*Linaria dalmatica*
Diffuse knapweed	*Centaurea diffusa*
Douglas-fir	*Pseudotsuga menziesii*
Eriogonum	*Eriogonum* spp.
Fescue	*Festuca* spp.
Grand fir	*Abies grandis*
Green fescue	*Festuca viridula*
Hawkweed	*Hieracium* spp.
Idaho fescue	*Festuca idahoensis*
Kentucky bluegrass	*Poa pratensis*
Lodgepole pine	*Pinus contorta*
Mallow ninebark	*Physocarpus malvaceus*
Medusahead rye	*Elymus caput-medusae*
Myrtle pachistima	*Pachistima myrsinites*
Penstemon	*Penstemon* spp.
Pinegrass	*Calamagrostis rubescens*
Ponderosa pine	*Pinus ponderosa*
Prairie junegrass	*Koeleria cristata*
Redstem ceanothus	*Ceanothus sanguineus*
Redtop	*Agrostis alba*
Rocky Mountain maple	*Acer glabrum*
Rush	*Juncus* spp.
Sandburg bluegrass	*Poa secunda*
Scouler willow	*Salix scouleriana*
Sedge	*Carex* spp.
Sheep sorrel	*Rumex acetocella*
Sieversia	*Sieversia* spp.
Silky lupine	*Lupinus sericeus*
Spalding rose	*Rosa spaldingi*
Subalpine needlegrass	*Stipa columbiana*
Timothy	*Phleum pratense*
Tufted hairgrass	*Deschampsia caespitosa*
Western larch	*Larix occidentalis*
Western white pine	*Pinus monticola*
Western yarrow	*Achillea lanulosa*

PRELIMINARY AERIAL VOLUME TABLES FOR PINYON-JUNIPER STANDS

By
Karl E. Moessner

INTRODUCTION

The increased interest in pinyon-juniper stands as a source of charcoal and other wood utilization products has created a need for reliable volume estimates of this woodland type.

Pinyon-juniper stands have always been important to the Southwest, where it was often the only available source of fuel and fenceposts. Rarely more than 15 to 30 feet in height, this mixture of pinyon pine and one or more species of juniper extends in open stands over an estimated 51 million acres in Arizona, Colorado, Nevada, New Mexico, and Utah. This is roughly 2.5 times the area of commercial forest land. Most of the area occupied by this type is largely incapable of producing sawlog species because it receives so little precipitation, but it is important as a watershed forest and winter range capable of producing some essential wood products.

THE PROBLEM

These short scrubby conifers of small size, rapid taper, and brushy appearance discourage the sawlog forester, and present a real problem in volume estimating to private owner and public forester alike. Pinyon pine and the several junipers are not only poor in quality, but often their rapid taper and multiple stems make the estimating of utilizable wood products extremely difficult. Per acre values are usually so low that conventional ground cruising methods may cost more than the products are worth. What has been lacking is a reliable cruising technique, easily applied and cheap enough to provide estimates in line with the value of the product.

Little is known about either tree or per acre volumes in this woodland type, even though some fuelwood studies (6, 7) of both one-seed and Rocky Mountain junipers were made in the late 1930's. Data from these studies provided tables showing fuelwood volumes in cubic feet by diameter at stump height and maximum crown width, as well as by d.b.h. and total

Figure 1.--This tree at the edge of a pinyon-juniper stand illustrates typical characteristics of the species: relatively small size, rapid taper, and brushy crown.

height. These, of course, were ground volume tables and they could do little to reduce the cost of conventional cruising techniques. Aerial estimating techniques, however, can make the estimation of pinyon-juniper stands practical. These techniques, which combine sampling and precise stand measurements made on aerial photos with the use of adequate volume tables, offer a possible 50- to 75-percent reduction in the cost of timber estimating. They are particularly applicable to estimates of low value stands.

THE TABLES

The development of aerial photo volume tables is the first step towards effective use of aerial estimating techniques. The following two aerial volume tables have recently been compiled at the Intermountain Forest and Range Experiment Station, Ogden, Utah:

1. The cubic-foot volume table.--This table lists per acre volume in cubic feet by average stand height and crown cover percent in four crown diameter classes. The format is that used in previous aerial volume tables published by the Central States and the Intermountain Forest and Range Experiment Stations.

2. The fencepost table.--This table lists number of juniper fenceposts per acre by average stand height and crown cover percent in four crown diameter classes. The same format is used.

ACCURACY

Standard measures of accuracy are shown at the bottom of each table. The standard error of estimate (in percent) for the cubic-foot table is somewhat higher than that for previously published aerial volume tables. In pinyon-juniper stands we are estimating extremely short trees with a narrow range of total height and crown cover, and with very low per acre volumes. Therefore, this ±60 percent represents a low 100 cubic-feet-per-acre error, which is quite satisfactory for most purposes.

The fencepost table is our first attempt to construct an aerial table for estimating products. The high standard error of estimate for this table indicates extreme variability in number of posts per acre largely introduced by some 10 to 15 percent pure pinyon plots. Since present photo interpretation techniques do not enable the interpreter to separate pinyon and juniper on the available small scale aerial photos, this variability must be accepted in constructing a practical table. Additional research, particularly if conducted on large scale aerial photos, will undoubtedly help us to improve this table.

These two tables are preliminary in that they are based on only 48 locations measured in Utah. We hope to test them throughout the Southwest. As more data from Forest Survey field plots become available, the tables can be revised.

HOW TO USE THESE TABLES

To use these aerial volume tables you must be able to measure consistently on aerial photos the three independent variables used in constructing the tables:

1. Average total height of the dominant stand.--This average is based on the five tallest trees within the acre plot, and is recorded to the nearest 5 feet. In practice, this average is obtained from five independent measurements of the tallest trees within the acre plot. Measurements are made by parallax wedge or other parallax measuring device of equal accuracy.

2. Average crown diameter of the dominant stand.--This average is based on the five largest crowns as measured by the crown diameter

scale and is recorded in 5-foot crown diameter classes. In practice, this average is usually obtained from five independent crown measurements of the tallest trees.

3. The percent of crown cover of the dominant stand.--This percentage is obtained by comparison with the crown cover scale, which reads the midpoint of the nearest 10-percent class. In practice, crown coverage of the dominant stand is used only when stands are clearly two-storied. In even-aged stands the crown coverage percent includes crowns of the entire stand.

The table is entered with these three readings. For example: if five measurements of the tallest trees on the acre plot result in an average total height of 20 feet, and if five crown diameter readings of these or comparable trees result in an average crown diameter between 13 and 17 feet, and if 25 percent of the acre is covered by crowns of this stand, then we can expect the cubic volume to average 330 cubic feet per acre, and on the average we can expect to have thirty-nine 7-foot posts per acre.

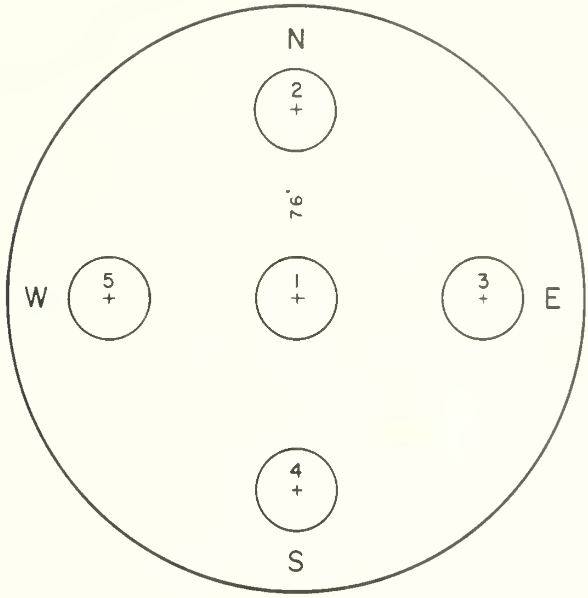
HOW THE TABLES WERE CONSTRUCTED

The basic data for this study were obtained from 48 field locations measured by Forest Survey field crews during the summer of 1961. The locations comprised a random sample selected from the 2,000 to 3,000 photo points, within the State of Utah, previously classified as pinyon-juniper type. The center of each selected location was pinpricked on aerial photos. Using these photos, field crews located each sample point on the ground and measured a total of five 1/50-acre circular plots in a diamond-shaped pattern (fig. 2) within the circular 1-acre location. Independent measurements of these same 1-acre locations were then made on the aerial photos. Finally, the relations between measurements of total height, crown diameter, and crown coverage, and the cubic-foot volume and number of fenceposts per acre were studied and the table compiled.

Field measurements.--Five 1/50-acre circular plots (a total of 1/10-acre) were measured at each selected location. All live trees and clumps with stems 5 inches d.b.h. and larger, and with a minimum length of 4 feet to a 4-inch top diameter were measured for cubic volume. Measurements consisted of butt diameter (12 inches above ground), length to the nearest 1 foot, top diameter to a minimum of 4 inches d.o.b. and bark thickness. Gross cubic volume was computed by Smalien's formula.

The number of fenceposts was tallied on all live juniper trees and suitable stems in clumps. Minimum requirements were a 7-foot length

Figure 2.--Distribution of a 5-plot grid on a circular 1-acre area. Each of the five plots is 1/50 acre; hence each grid provides a total measurement of 1/10 acre at each location.



with a maximum butt diameter of 7 inches and a minimum top diameter of 3 inches. Ten-foot lengths were tallied as 1-1/2 posts. In addition, total heights and crown diameters were tallied on a minimum of one dominant tree in each species (pinyon or juniper) found on each 1/50-acre subplot. The resulting measurements, a minimum of five per location, were used to obtain average total height and crown diameter.

Photo measurements.--Aerial photos on which plots were pinpricked and measured were nominal 1:20,000-scale USDA panchromatic prints. Precise measurements were made, independent of the field data, for all commonly used aerial volume variables. These are:

Average total height of the dominants: Obtained from the five tallest trees at each location, as measured by parallax wedge.

Average crown diameter of the dominants: Obtained from the five largest crowns at each location as measured by the dot-type crown diameter scale.

Crown cover percent: Obtained by comparison with the printed crown cover scales, and checked by the average of three dot counts per location, made with a 28-dot-per-acre microdot shield.

PRELIMINARY AERIAL VOLUME TABLE--PINYON-JUNIPER TYPE

Gross cubic volume per acre by average stand height, average crown diameter, and crown coverage[1/]

Average stand height (feet)	Crown cover (percent) 5	15	25	35	45	55	65	75	85	95
	- - -	- - -	- - -	- - -	Ten cubic feet	- - -	- - -	- - -	- - -	- - -
					4- TO 7- (5) FOOT CROWN DIAMETER					
10	2	2	2	1	1	0				
15	2	5	7	10	11	13	15	17	19	21
20						14	18	22	26	30
					8- TO 12- (10) FOOT CROWN DIAMETER					
10	2	2	2	2	2	2	2	2	1	1
15	12	15	17	20	22	25	27	29	31	33
20	12	16	21	26	31	35	40	44	49	53
25							41	48	54	61
					13- TO 17- (15) FOOT CROWN DIAMETER					
15	13	16	19	21	24	26	29	32	34	36
20	22	28	33	38	43	48	52	57	62	67
25		28	35	42	49	56	64	71	78	85
30								73	82	91
					18- TO 22- (20) FOOT CROWN DIAMETER					
15	5	8	11	14	17	19	22	25	27	30
20	24	30	35	40	45	51	56	61	66	71
25	32	39	47	55	62	70	77	85	92	99
30			47	57	67	77	87	97	107	116
35								97	109	121

1/ Figures in blocked out areas are based on field data.

Note: Average stand heights and crown diameters were obtained from field measurements, and crown cover was obtained from photo measurements of field plots. Cubic volume was computed from field measurements.

Based on 48 Forest Survey field plots randomly located in Utah.

Aggregate deviation: Table -0.17 percent low.
Standard error of estimate: ±60 percent of mean plot volume.

PRELIMINARY AERIAL VOLUME TABLE--PINYON-JUNIPER TYPE

Number of 7-foot juniper fenceposts per acre by average stand height, average crown diameter, and crown coverage[1/]

Average stand height (feet)	Crown cover (percent) 5	15	25	35	45	55	65	75	85	95
	- - - -	- - - -	- - - -	- - - -	Number of posts	- - - -	- - - -	- - - -	- - - -	- - - -
4- TO 7- (5) FOOT CROWN DIAMETER										
10	4	7	9	9	6	2				
15			17	29	39	46	52	56	57	57
20				35	57	77	95	111	125	136
25					61	94	124	153	179	203
30						97	139	180	219	255
8- TO 12- (10) FOOT CROWN DIAMETER										
10	7	7	6	2	2					
15		13	24	33	39	43	46	46	44	41
20			28	49	68	85	99	112	122	130
25			18	52	83	112	139	164	186	207
30				40	84	125	164	201	237	270
13- TO 17- (15) FOOT CROWN DIAMETER										
10	4	1								
15	8	17	24	30	33	34	33	30	24	17
20		19	39	56	72	85	96	106	113	118
25		8	40	69	97	123	146	168	187	205
30					108	146	182	216	248	277
18- TO 22- (20) FOOT CROWN DIAMETER										
10										
15	8	14	18	20	20	17	13	6		
20	9	27	43	57	69	79	87	93	97	98
25		25	54	80	105	127	147	165	181	196
30				90	126	161	193	224	252	279

1/ Figures in blocked out areas are based on field data.

Note: Average stand heights and crown diameters were obtained from field measurements, and crown cover was obtained from photo measurements of field plots. Number of fenceposts was computed from field tallies.

Based on 48 Forest Survey field plots randomly located in Utah.

Aggregate deviation: Table 3.1 percent high.
Standard error of estimate: ±117 percent of mean plot volume.

EVALUATION OF FIELD AND PHOTO DATA

Studies have been made to determine the most useful variables in the construction of aerial volume tables; but the conclusions vary with studies and do not consider pinyon-juniper. Most studies find average total height and crown cover significantly related to volume (1, 2, 3, 4, 11), but at least one recommends average total height alone and another crown cover alone (12) while a third bases an entire set of aerial tables on crown diameter alone (5).

Reliable measurements of total height and crown diameter can be made on the aerial photos (9) or on the ground, but past studies disagree as to which technique is better. Crown cover is difficult to determine on the ground, but is easily estimated on aerial photos either by crown cover scale or by dot count (2); the latter system is much slower. Because the conclusions of previous studies did not agree, we decided to use all three variables. We were interested in the accuracy of photo measurements in pinyon-juniper; so we compared the photo measurements of total height and crown diameter with those obtained in the field. These data from the 48 locations studied are summarized:

Average height and average crown diameter obtained from photo and field measurements

Measurement	Average all plots		Mean aggregate error	Std. error of estimate	Coefficient of correlation
	Photo	Field			
	---Feet---		Feet	Feet	
Av. ht. of dominant stand (five trees)	15.6	15.0	+0.6	±2.5	0.819*
Av. cr. dia. of dominant stand (five trees)	12.7	12.8	−.1	±3.2	.632*

* Significant at 95-percent level.

We also compared estimates of crown cover percent made by printed scale and by microdot:

By microdot count	29.1
By crown cover scale	26.5
Mean aggregate error	−2.6
Standard error of estimate	±4.4
Coefficient of correlation	0.917*

* Significant at 95-percent level.

These comparisons indicate that the five-tree averages for total height and crown diameter can be obtained from either photo or field measurements with about the same accuracy, and that crown cover can be estimated by comparison with crown cover scale about as well as by dot count.

Although field and photo measurements did not appear to be significantly different, we assumed the field measurements of average height and crown diameter would have less chance of bias. Since the crown cover scale used on aerial photos is the most efficient means of measuring crown cover, we used these readings instead of dot counts. We then computed correlations and tested the three variables for their usefulness in the tables. The following tabulation lists some of the single as well as the multiple curvilinear correlations between these variables and cubic volume and number of fenceposts.

Correlations of stand variables with cubic volume and number of fenceposts

Stand variable	Cubic volume	Number of fenceposts
H (Average height five dominant trees)	0.7256**	0.3418*
CD (Average crown diameter five dominant trees)	.4519**	.0674
CC% (Crown cover percent total stand)	.3722**	.3960**
H, H^2 (Curvilinear)	.7797**	.5339**
H, CC%	.7791**	.5710**
H, H^2, CD, CD^2, CC%, $CC\%^2$ (Curvilinear)	.8031**	.5800**

* Significant at 95-percent level.
** Significant at 99-percent level.

In the case of cubic volume, the best single correlation (0.7256) was obtained with average total height. Both crown diameter and crown cover were also correlated, but this may have been partly due to interaction between these independent variables. The curvilinear relationship using all three variables and their squares produced the highest multiple correlation (0.8031). Even though this addition was not necessarily significant, it agreed with previous studies (8, 10) that had indicated some advantages might be realized by using the three variables.

In the case of number of posts, correlations were much lower, with crown cover the best (0.3960), and height next (0.3418). Multiple correlation using all factors again proved just slightly higher (0.5810).

In machine compilation of the table, the six-term multiple regression was used because at this time our knowledge of pinyon-juniper does not justify dropping any practical aerial photo variable.

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RESEARCH PAPER NO. 70 DECEMBER 1962

LOGGING SLASH FLAMMABILITY AFTER FIVE YEARS

by

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UNITED STATES DEPARTMENT OF AGRICULTURE

OGDEN, UTAH

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ABSTRACT

During the 5 years after it was cut and placed on sample plots, slash of nine northern Rocky Mountain tree species changed greatly in appearance and flammability. Western white pine, lodgepole pine, western redcedar, and western hemlock still retained relatively large amounts of fine slash components well above the ground; experimental burning showed that flammability was still high. Grand fir and western larch had deteriorated most, and they exhibited very low flammability. Douglas-fir, ponderosa pine, and Engelmann spruce were intermediate.

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CONTENTS

LOGGING SLASH FLAMMABILITY [1]
AFTER FIVE YEARS

INTRODUCTION

This paper reports the final phase of research that has determined the flammability of slash for nine species of northern Rocky Mountain conifers[2] at three ages.[3] Visual characteristics, rate of fire spread, and fire intensity for 5-year-old slash were studied by essentially the same methods as had been used previously on freshly cut and 1-year-old material. Final experimental burning was done in July and August 1960 on a specially prepared site in the Priest River Experimental Forest in northern Idaho.

In the earlier stages of this study (*2, 3, 4, 5*),[4] rate of fire spread bore the same relation to relative humidity and quantity of fuel per acre for all species of freshly cut slash, increasing as relative humidity decreased and as fuel quantity increased. The relationship to fuel quantity did not change when slash aged 1 year, but the apparent effect of relative humidity became stronger. Rate of spread varied considerably with species, in response to variations in relative amount of fine fuel components and shape of branches. Aging 1 year reduced rate of spread 25 percent or more for all species except western white pine; greatest reductions were noted for species that lost their needles over winter. In general, fire intensity, as indicated by radiation measurements, was proportional to rate of spread. Presence of a moderate amount of fresh slash of any species raised the rate-of-spread component of fuel type to "Extreme." After a year the rating dropped to "High" for some species.

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[1] For easy reference and comparison, this publication uses the same order and essentially the same format as "Logging Slash Flammability," Intermountain Forest and Range Experiment Station Research Paper 58.

[2] Western white pine (*Pinus monticola* Dougl.), lodgepole pine (*P. contorta* Dougl.), ponderosa pine (*P. ponderosa* Laws.), western redcedar (*Thuja plicata* Donn), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), Engelmann spruce (*Picea engelmannii* Parry), Grand fir (*Abies grandis* [Dougl.] Lindl.) and western larch (*Larix occidentalis* Nutt.).

[3] "Age" in this usage means time elapsed since cutting.

[4] Italicized numerals in parentheses refer to items in *Bibliography*.

SUMMARY

At the end of 5 years important changes in visual characteristics of fuel were: virtually total loss of needles by all species, concentration of needles on or near the ground, and compaction of the fuel bed (all species but hemlock). Incipient rot was apparent in the branchwood of all species, but advanced decay and appreciable breaking up of large limbs occurred only in grand fir. Average rate of fire spread for all species was 23 percent of that in fresh slash, ranging from only 18 percent in grand fir slash to 36 percent in lodgepole pine. Western white pine, ponderosa pine, and western hemlock showed essentially the same residual percentage as lodgepole, and larch the same as grand fir. Western white and lodgepole pine had the highest (and almost identical) rates of spread; following in decreasing order were hemlock, ponderosa pine, redcedar, Douglas-fir, Engelmann spruce, larch, and grand fir.

Quantity of fuel per acre had a somewhat less apparent effect on rate of fire spread in 5-year-old slash than in 1-year-old, and the apparent effect of relative humidity was nearer that determined for fresh slash than that for 1-year-old slash. These changes are not very significant, however, because only two weights could be burned, and the effects of fuel quantity were confounded with those of relative humidity on a few plots.

Fire intensity in 5-year-old slash was reduced further from that found for 1-year-old slash; the reduction was about the same in medium (20 tons per acre) as in heavy (32.5 tons per acre) slash. This finding supports an earlier one that fire intensity is essentially proportional to rate of spread in any given kind of fuel.

CHARACTERISTICS OF FIVE-YEAR-OLD SLASH FUEL COMPONENTS

Information on the characteristics of 5-year-old slash was obtained entirely from the 63 plots used for testing rate of fire spread and fire intensity. Representative plots were photographed, depth of slash was measured at four points on each plot, and a careful written description was prepared for each species.

In general, significant changes in slash fuels during the first 5 years after cutting were loss of foliage, sifting down of lost needles toward the ground line, and compaction of the entire fuel bed. Major exceptions were grand fir, which disintegrated rather spectacularly, and western hemlock, which appeared to undergo little change after the first year. From visual characteristics, comparative flammability was estimated as follows, by species in descending order: lodgepole pine, western white pine, western redcedar, western hemlock, Douglas-fir, Engelmann spruce, ponderosa pine, western larch, and grand fir. These ratings were based on examination of all medium and heavy plots; they did not take into account differences in quantity associated with species on cutover areas. Differences among the first four or five species appeared slight, and the ranking therefore was quite tentative. The following sections and figures 1 to 4 document slash characteristics in greater detail.

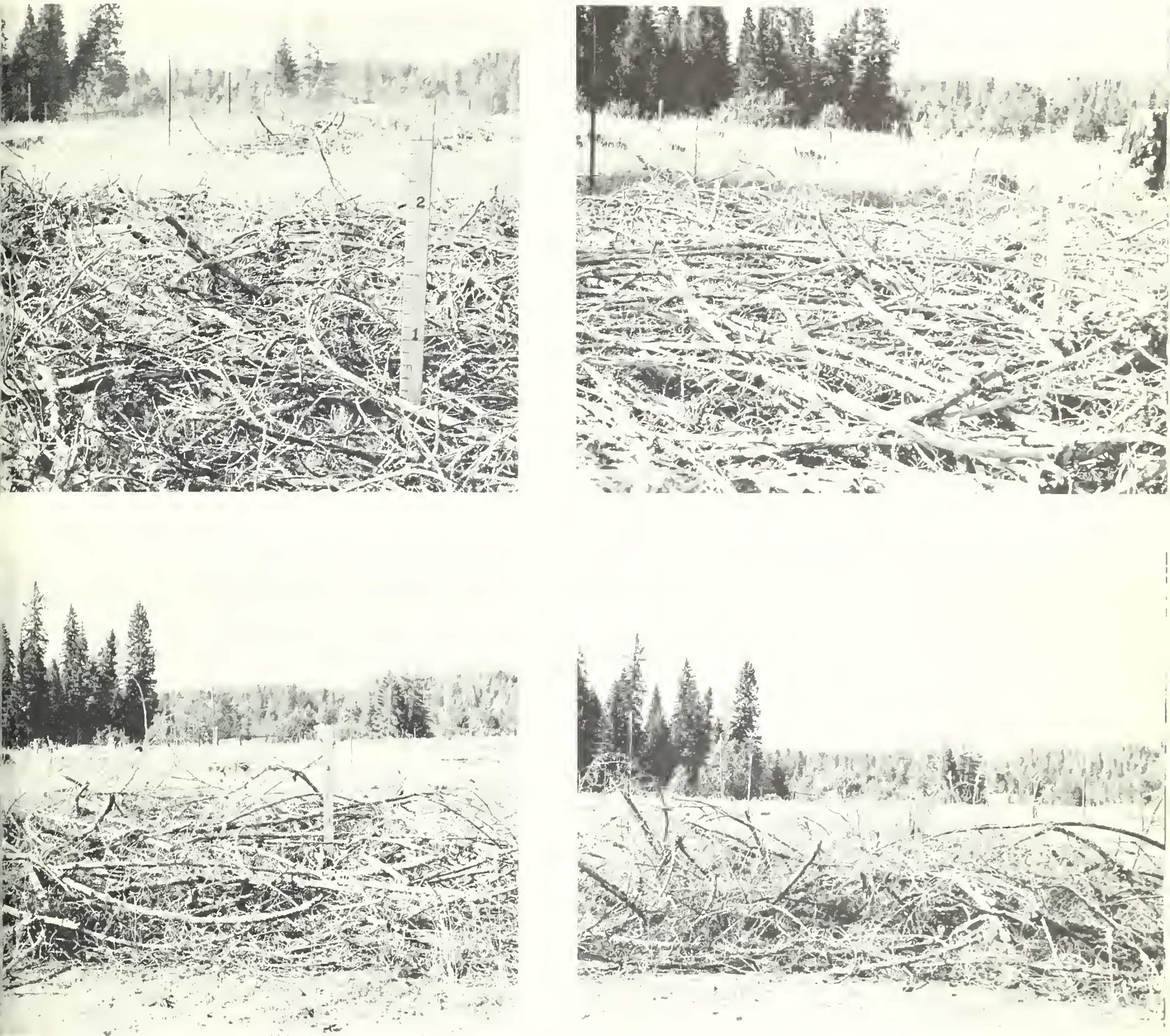

Figure 1. Five-year-old heavy slash (32.5 tons per acre) of: upper left, western white pine; upper right, western redcedar; lower left, Douglas-fir; lower right, western hemlock. Note retention of some needles by white pine, loose bark in redcedar and to a lesser extent in Douglas-fir, absence of appreciable compaction in hemlock. [Cf. (3) figures 4, 5, 6, 7.]

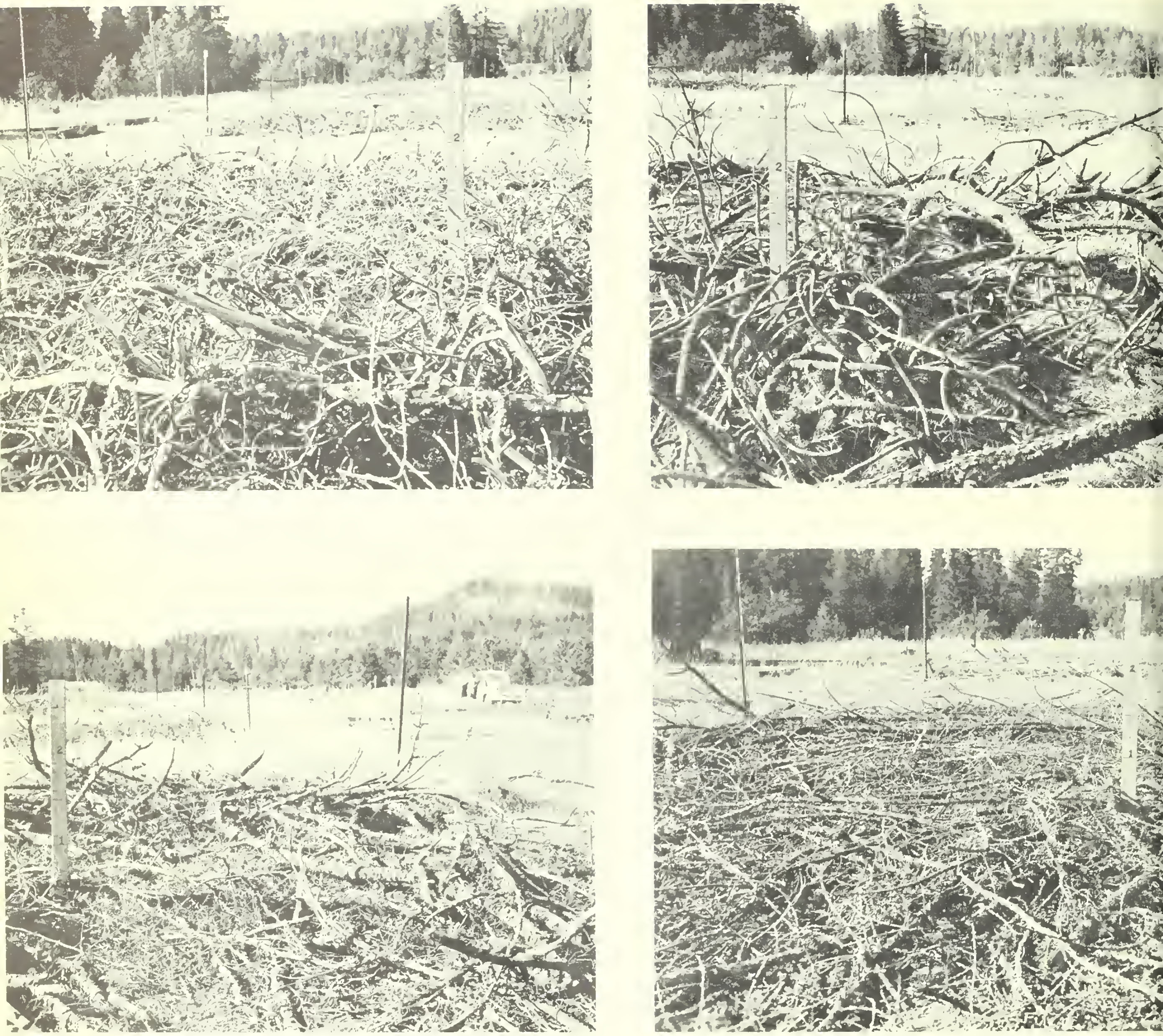

Figure 2. Five-year-old heavy slash of: **upper left**, lodgepole pine; **upper right**, ponderosa pine; **lower left**, Engelmann spruce; **lower right**, western larch. Almost total loss of bark from lodgepole pine twigs contrasts with minimal loss from those of ponderosa pine and larch. Note mat of needles and jumble of twigs on the ground in spruce slash.

CHANGES DUE TO AGING

Foliage.—Nearly 25 percent of the white pine needles in the protected lower portions of the fuel beds remained attached to branches. All needles and foliage from the other eight species had fallen to the ground, creating layers or mats of varying thickness. Long needles often formed relatively loose mounds or hummocks on the ground. Foliage from the short-needled species lay in dense mats that frequently were bound together by fungus mycelium along the surface of the ground. These mats appeared likely to sustain only a smouldering fire while the looser layers of longer needles would permit surface fires to spread readily. Rotting of needles was negligible, and incorporation into the soil was not observed (it would hardly be expected on the study site).

Twigs and branches.—At the end of 5 years western white pine, lodgepole pine, Douglas-fir, western larch, and western hemlock retained approximately 75 percent of their twigs in the original state. Most of this fine material had fallen from slash of the other four species. Twigs from slash of Engelmann spruce, western redcedar, and grand fir contributed materially to depth and continuity of the surface fuels available for burning.

Bark.—Disintegration of bark on some of the species was quite pronounced, but on ponderosa pine and western larch most of the bark was still intact. Lodgepole pine had lost the most bark; an estimated 75 percent had fallen to the ground. The bleached appearance of twigs and branches on the lodgepole pine plots was distinctive. Bark remaining on twigs and branches promoted spread of fire in the plots of western redcedar. Split lengthwise and hanging loosely in conspicuous strips, this bark added a considerable volume of flashy fuel. Douglas-fir slash also had considerable loose bark.

Wood.—Advanced stages of cubicle rot were evident in the branchwood of grand fir. The appearance of the grand fir plots at the end of the 5-year period indicated that this species decomposed more rapidly than any of the others. Branchwood was well broken up and mostly close to the ground. The twigs and branchwood of ponderosa pine showed little external evidence of decay, but when the bark was removed, considerable dry rot could be seen. Western larch, Douglas-fir, and western redcedar had the least amount of incipient decay.

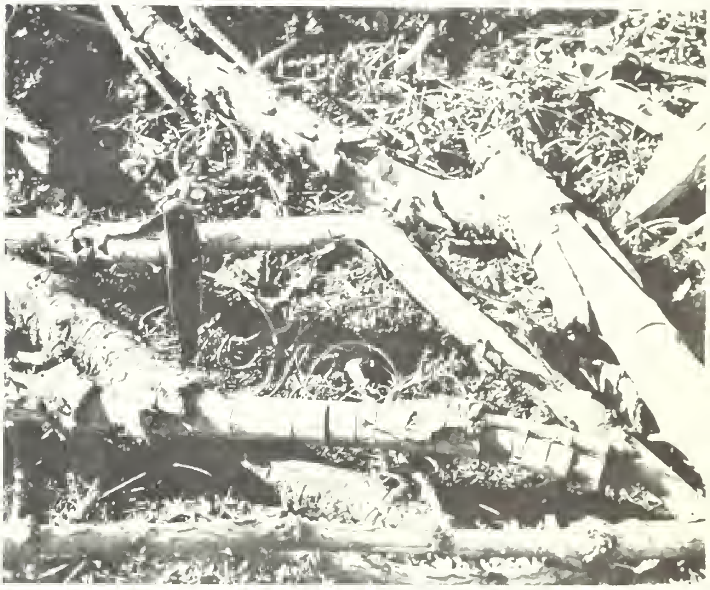

Figure 3. Five-year-old heavy slash of grand fir. Upper, general view showing disintegration of branches and concentration of fuel near the soil surface; lower, closeup showing typical rotted condition of large branchwood.

FUEL BED CHARACTERISTICS

Continuity.—By the end of 5 years the originally sparse fuel of the light (7.5-ton) plots had become so scattered that fire obviously could not spread continuously. Disintegration of aerial components virtually destroyed their ability to burn, and fuel added at the ground level as a result of this disintegration was negligible in comparison with the area to be covered. The thin, intermittent layer of needles was hardly distinguishable from the surface of the mineral soil. Some needles had been scattered by wind and animals, and some were becoming mixed with surface soil.

On the heavier plots gravitation of fine components toward the bottom of the fuel bed further reduced continuity of aerial fuels. The same process appeared to have increased continuity at the ground line. On both the medium and the heavy plots enough connected ground fuel appeared available to carry at least a smouldering fire over the entire plots under very dry conditions. The change in location of fines appeared likely to reduce the rate at which fire could spread but not the full extent of coverage.

Depth and density.—Depth of slash of all species except hemlock had decreased, as anticipated (tables 1 and 2). Hemlock branches continued to curl high above the ground, and apparent depth therefore was greater than at the first measurement. The greatest decreases in depth were in Engelmann spruce and grand fir; they resulted from the loss of most twigs and smaller branches. Density tended to increase in the lower portions of the fuel beds as depth decreased. The trend for all species but hemlock obviously was from an essentially aerial, though low, fuel toward a ground fuel having appreciable depth only in the heavier concentrations of the more durable species. Grand fir slash could be considered purely a ground fuel 5 years after cutting; larch and Engelmann spruce were virtually so.

Table 1.--Depth (in feet) of evenly distributed, lopped slash in relation to species, age, and weight

Species	Year of cutting			1 year old			5 years old		
	Tons per acre			Tons per acre			Tons per acre		
	7.5	20.0	32.5	7.5	20.0	32.5	7.5	20.0	32.5
Western white pine	0.51	0.80	1.00	0.32	0.54	0.78	0.12	0.35	0.55
Lodgepole pine	.51	1.04	1.29	.38	.66	.90	.18	.60	.70
Ponderosa pine	.34	.97	1.36	.44	.69	.96	.25	.32	--
Western redcedar	.35	.53	.84	.24	.66	.76	.30	.40	.60
Douglas-fir	.23	.63	.83	.23	.67	.72	.38	.60	.48
Western hemlock	.30	.62	.92	.31	.71	.88	.25	.82	1.12
Engelmann spruce	.49	.92	.96	.40	.58	.88	.08	.25	.32
Grand fir	.46	.76	.94	.26	.52	.74	.12	.20	.29
Western larch	.30	.78	.97	.26	.52	.70	.28	.22	.40

Table 2.--Reduction of fuel volume during 1-year and 5-year periods

Species	Original weight	Original volume		Percent of original volume	
		Per acre	Per ton	After 1 year	After 5 years
	Tons/acre	- - *Cubic*	*feet* - -		
Western white pine	7.5	18,730	2,497)		
	20.0	33,977	1,699)	74	44
	32.5	48,352	1,488)		
Lodgepole pine	7.5	22,216	2,962)		
	20.0	44,867	2,243)	81	52
	32.5	55,757	1,716)		
Ponderosa pine	7.5	14,810	1,975)		
	20.0	42,253	2,113)	82	[1] 44
	32.5	59,242	1,823)		
Western redcedar	7.5	22,216	2,962)		
	20.0	26,136	1,307)	98	79
	32.5	38,768	1,193)		
Douglas-fir	7.5	11,326	1,510)		
	20.0	28,750	1,438)	105	79
	32.5	40,075	1,233)		
Western hemlock	7.5	11,761	1,568)		
	20.0	27,007	1,350)	120	112
	32.5	46,174	1,421)		
Engelmann spruce	7.5	21,344	2,846)		
	20.0	40,075	2,004)	89	28
	32.5	41,818	1,287)		
Grand fir	7.5	20,038	2,672)		
	20.0	33,106	1,655)	75	30
	32.5	40,946	1,260)		
Western larch	7.5	13,068	1,742)		
	20.0	33,977	1,699)	74	44
	32.5	42,253	1,300)		
All species	7.5	16,553	2,207)		
	20.0	34,412	1,721)	87	55
	32.5	45,738	1,407)		

[1] Based on 7.5- and 20-ton plots only.

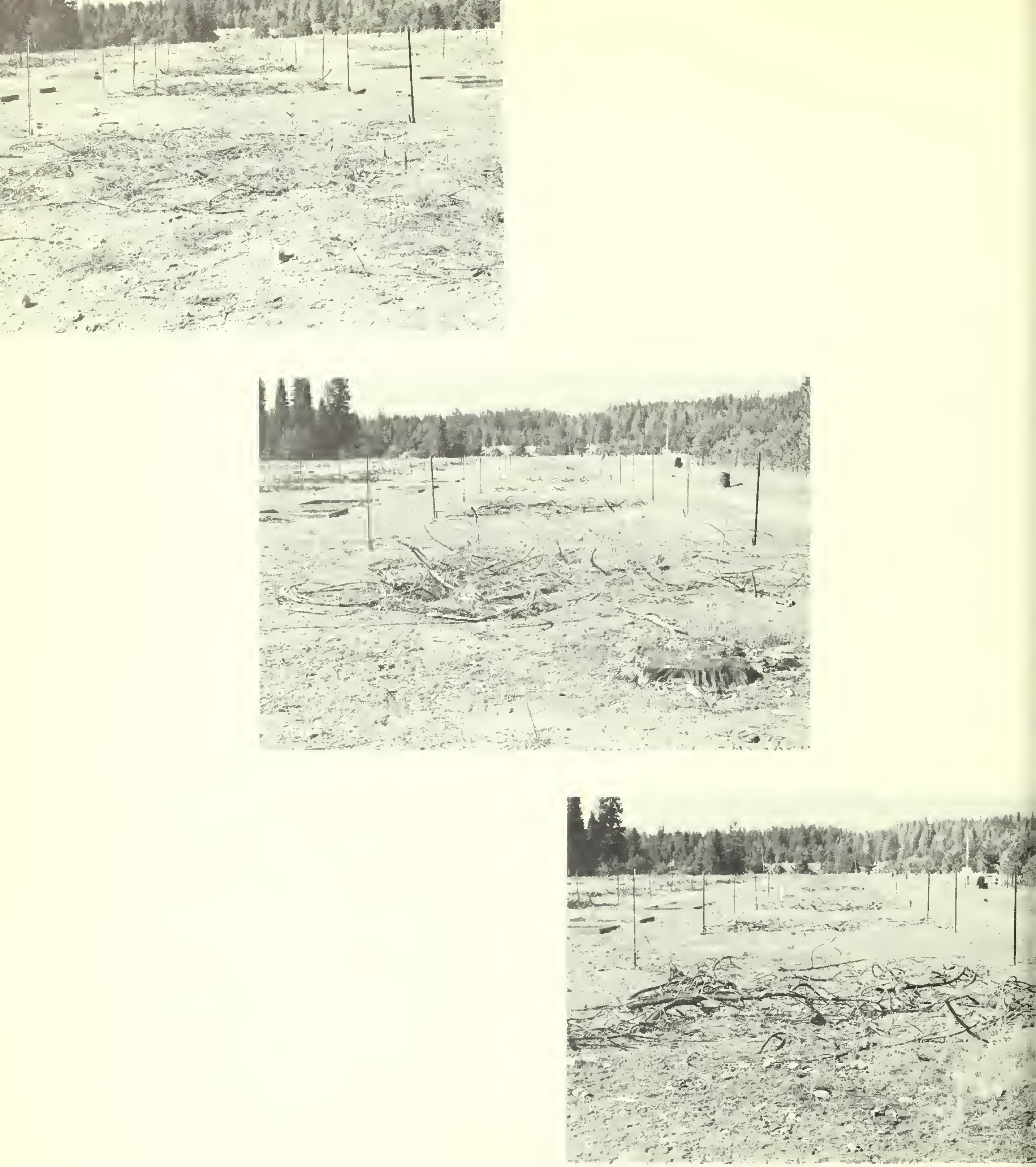

Figure 4. Five-yeor-old light slash (7.5 tons per ocre) of: upper, western white pine; middle, western hemlack; lower, ponderosa pine. Aging has pretty well cancelled out original differences in fuel continuity. [Cf. (3) figure 9.]

FIRE SPREAD IN SLASH

RESEARCH METHODS

Experimental Design, Material, and Procedure

Investigation of fire spread in 5-year-old slash used the same techniques as the earlier experimental burnings of slash. In 1955, specially cut slash had been spread uniformly on 63 square 0.01-acre plots at per-acre rates of 7.5, 20.0, and 32.5 tons, representing fuel to be expected from light, medium, and heavy cutting, respectively. In this final phase of the study, the three plots per species of medium and heavy slash were burned during early evening between July 24 and August 13. Observers used remote pushbutton switches to mark an Esterline-Angus operations recorder chart when the fire edge passed 2-foot interval points on four diagonals radiating from the plot center. Usually, two plots were burned simultaneously.

Supplementary measurements included relative humidity, with a fan psychrometer at the start and end of each test fire; total air movement during each fire, with a directional vane anemometer; and fuel-stick moisture content at the start and end of each evening's burning. Time-lapse movies were taken of at least one fire in each species-weight combination of slash and black-and-white still shots of representative plots at peak fire intensity. Moisture content of slash was not sampled generally because in previous years the small number of measurements that were feasible had produced erratic, meaningless results.

No effort was made in 1960 to measure rate of fire spread on light plots because experience had shown that burning of such sparse fuel was erratic and most unlikely to yield usable results. Instead, these plots were burned during a warm, dry afternoon, and fire behavior was observed but not measured.

Conditions for Burning

The same burning conditions were sought as in previous years; namely:

1. Less than 0.2 inch of rain during preceding 5 days
2. No rain in preceding 2 days
3. Midafternoon air temperature 70° F. or higher
4. Minimum ½-inch fuel-stick moisture content 8 percent or less
5. Minimum relative humidity 40 percent or less
6. Mean wind velocity at time of burning not more than 2 m.p.h.

Burning was interrupted by 7 days of cool, cloudy, humid weather with some light rain; but by covering the plots it was possible to meet the prescribed conditions with the following exceptions:

1. Mean wind velocity was 2.2 m.p.h. when plots 12 (Engelmann spruce, 20 tons/acre) and 21 (western larch, 32.5 tons/acre) were burned.
2. Afternoon fuel-stick moisture content was more than 8.0 on August 2, when plots 55, 58, 60, and 62 were burned (lodgepole pine, grand fir, ponderosa pine, and western hemlock, respectively; all 20 tons/acre).
3. Burning was resumed August 9, the fifth day after a rain exceeding 0.2 inch.

The first exception was accidental, resulting from a temporary increase in wind velocity. The second two exceptions were deliberate. Number 2 was based on the assumption that the effects of exceptional dryness during preceding weeks offset the slightly too moist condition on August 2; number 3 on the fact that the plots had been covered during the rains.

Analysis

Average time (in seconds) required for fire to spread 1 foot radially was calculated for each plot. Table 3 summarizes the basic data for the entire life of this study. Average burning times shown in this table are based on plots for which five or more observations were recorded, and only these averages were used for subsequent analysis of the 1960 data.

The common logarithm of average burning time was used as the dependent variable (Y_5) in a multiple covariance analysis. Relative humidity and slash weight were the independent variables (X_1 and X_2 respectively). The prediction equation for 5-year-old slash is:

$$Y_5 = 2.1475 + .005788X_1 - .017390X_2.$$

Data for the three ages of slash were pooled to give the general prediction equation,

$$Y_{0+1+5} = 1.8957 + .006975X_1 - .020870X_2.$$

Rate-of-spread values calculated with this equation were expressed in the more familiar terms of chains' perimeter increase per hour. Differences were not tested for statistical significance because previous experience had shown that statistical comparisons were too insensitive to confirm any but the largest differences.

EVALUATION OF FACTORS AFFECTING RATE OF SPREAD

Weight and Relative Humidity

Effects of these two factors continued about the same in 5-year-old slash as in younger fuel. The reduction in the regression coefficient for weight (from .0225 to .0174) quite possibly resulted from absence of data for light 5-year-old slash. Thus the change is regarded as more apparent than real.

The regression coefficient for relative humidity in the equation for 5-year-old slash fell between those for fresh and 1-year-old material. This appeared to invalidate a tentative conclusion based on comparison of two coefficients derived earlier; namely, that relative humidity assumes greater importance as fuel becomes sparser with age (3). As was explained in this earlier publication, relative humidity was changing rapidly when nearly all plots were burned, and burning schedules confounded slash weight with humidity to a considerable extent in 1- and 5-year-old slash. These complications left little basis for a clear-cut conclusion that the effect of relative humidity varies with age of slash.

Species and Age

Table 4 summarizes rates of spread by species and age for the duration of this study. Adjusted means for fresh and 1-year-old slash differ slightly from those given previously (3, table 13) because of pooling the earlier prediction equations with those for 5-year old slash. Rankings are the same and relative values essentially so.

Flammability ratings assigned to species on the basis of visual examination (see p. 2) proved rather accurate. Measuring rate of spread changed only three rankings: ponderosa pine from sixth to fourth, western redcedar from third to fifth, and hemlock from fourth to third. The continued high flammability of hemlock had not been expected at the beginning of the study but was quite predictable from observations made in 1960 before burning. Cedar's intermediate position again supported the opinion that quantity of slash produced, resulting from both heavy tree crowns and methods of processing in the woods, is as important as inherent flammability in making slash of this species especially dangerous.

Table 3.--Results of experimental slash burning, by weight of slash per acre, age, and species, before analysis and adjustment

Age and species	Weight of slash (tons per acre)								
	7.5			20.0			32.5		
	Plots	Range of relative humidity	Mean rate of spread	Plots	Range of relative humidity	Mean rate of spread	Plots	Range of relative humidity	Mean rate of spread
Fresh slash:		*Percent*	*Seconds per foot*		*Percent*	*Seconds per foot*		*Percent*	*Seconds per foot*
Western white pine	3	58-62	80	3	34-86	32	3	30-65	18
Lodgepole pine	2	74-83	141	2	84-88	48	2	52-64	17
Ponderosa pine	([1])	--	--	2	60-85	71	2	54-91	33
Western redcedar	3	28-56	73	3	36-81	53	3	42-73	24
Douglas-fir	3	33-50	64	3	39-72	41	3	52-70	21
Western hemlock	2	51-67	87	3	47-74	41	3	27-66	28
Engelmann spruce	-	--	--	3	38-74	50	3	68-82	35
Grand fir	2	54-70	77	2	60-80	51	3	50-94	29
Western larch	2	76-77	67	2	62-68	24	3	70-82	19
All species	17	28-83	82	23	34-88	45	25	27-94	26
1-year-old slash:									
Western white pine	3	26-90	82	3	80-91	62	3	71-90	26
Lodgepole pine	3	28-31	120	4	73-92	89	4	54-93	33
Ponderosa pine	2	28-30	153	4	66-85	129	4	71-83	84
Western redcedar	2	26-67	117	3	34-71	52	3	63-82	46
Douglas-fir	-	--	--	2	25-28	45	3	61-70	70
Western hemlock	2	28-30	43	3	44-81	59	3	64-82	74
Engelmann spruce	-	--	--	2	57-82	95	2	72-82	57
Grand fir	2	30-31	130	4	60-78	229	4	54-89	124
Western larch	1	30	109	4	64-86	215	4	55-87	97
All species	15	26-90	107	29	25-92	119	30	54-93	70
5-year-old slash:									
Western white pine				3	35-74	123	3	59-89	81
Lodgepole pine				3	69-80	164	3	60-89	77
Ponderosa pine				2	69-74	184	3	35-83	107
Western redcedar				1	52	155	3	58-74	127
Douglas-fir				2	56-63	241	3	66-79	167
Western hemlock				3	61-79	168	3	57-83	88
Engelmann spruce				3	49-74	175	3	59-84	205
Grand fir				-	--	--	1	59	291
Western larch				1	52	200	3	49-58	152
All species				18	35-80	172	25	35-89	128

[1] Absence of data indicates that plots did not burn sufficiently to provide five or more observations of fire spread. In all, the plots that did not burn were six fresh 7.5-ton, nine 1-year old 7.5 ton, one 1-year old 20 ton, nine 5 year old 20 ton, and two 1-year-old 32.5-ton. No attempt was made to burn 5 year-old 7.5-ton plots because of the obvious futility of such an effort.

Table 4.--Rates of spread in nine species of fresh, 1-year-old, and 5-year-old slash

Species	Adjusted mean rate of spread [1]			Percent of rate in fresh slash	
	Fresh	1-year-old	5-year-old	1-year-old	5-year-old
	(Chains per hour perimeter increase)				
Western white pine	9.6	9.6	3.3	100	33
Lodgepole pine	9.0	5.9	3.2	66	36
Ponderosa pine	7.2	3.4	2.4	47	33
Western redcedar	8.0	6.0	1.9	75	24
Douglas-fir	8.9	3.8	1.6	43	18
Western hemlock	8.2	5.7	2.7	70	33
Engelmann spruce	7.2	4.9	1.6	68	22
Grand fir	9.2	2.3	.7	25	8
Western larch	14.5	2.4	1.3	16	9

[1] At 3-age mean relative humidity of 64.3 percent, mean weight of 23.3 tons per acre, as calculated by pooled regression for all three ages of slash.

On an average, rate of fire spread in 5-year-old slash was only 23 percent of that in fresh material. Changes from the rates for 1-year-old slash ranged from only 7 percent for larch, which had dropped 84 percent the first year, to 67 percent for white pine, which had shown no reduction the first year. Ponderosa pine, redcedar, Douglas-fir, and Engelmann spruce had low rates of spread comparable to those of grand fir and larch 4 years earlier. White pine, lodgepole pine, and hemlock at 5 years were about on a par with 1-year-old ponderosa and Douglas-fir. Burning 5-year-old larch slash yielded a mean rate of spread about twice that obtained for grand fir; for practical purposes this meant that experimental fires usually would spread in larch slash and usually would not in fir.

INTERPRETATIONS OF FINDINGS ON RATE OF SPREAD

Evaluation of Relative Flammability

Table 5 extends to 5 years an earlier sample calculation of composite relative rate of spread for a hypothetical cut of several species. The indication is that rate of spread based on slash alone would be down to only 19 percent of the possible maximum in fresh slash, or 22 percent of the fresh-slash rate for the mixture in the example.

Slash as a Fuel Type

Comparison of experimentally determined rates of spread with mean rates characteristic of Region 1 fuel types (*1*, *6*) by methods used previously (3) showed that most 5-year-old slash would fall into the "Low" and "Medium" rate-of-spread types. Rather heavy cuts, yielding 15 tons or more of tree crown material, would put white pine and lodgepole in the "High" bracket. The amount of fuel needed to produce "High" ratings in other species would be 19 or more tons in hemlock, 22 or more in ponderosa pine, and 27 or more in redcedar. Actually about 20 tons per acre of cedar probably would produce high rate of spread if the operation involved peeling in the woods and splitting posts. *Five-year-old grand fir and larch slash would not exceed a "Low" to "Medium" rating regardless of quantity.* For all practical purposes the same is true for Douglas-fir and Engelmann spruce, since at least 30 tons of slash per acre would be required to produce a "High" rating. *Heavy to very heavy cuts of most species leave a fuel hazard that is high for 5 years or longer.*

Table 5.--Sample calculation of relative rate-of-spread ratings for a combination of species and quantities of slash

Species	Quantity		Rate-of-spread rating					
			Fresh slash		1-year-old slash		5-year-old slash	
	Tons per acre	Percent of total	Factor	Proportional rating	Factor	Proportional rating	Factor	Proportional rating
Western white pine	5	25	8	2.0	6.2	1.6	2.5	0.6
Western redcedar	4	20	8	1.6	6.2	1.2	1.5	.3
Douglas-fir	2	10	8	.8	3.6	.4	1.5	.2
Western hemlock	4	20	8	1.6	3.6	.7	2.5	.5
Grand fir	2	10	8	.8	2.0	.2	.6	.1
Western larch	3	15	12	1.8	2.0	.3	1.5	.2
Total	20	100		8.6 = Rating for area = 4.4				1.9

INTENSITY OF SLASH FIRES

Fires in 5-year-old slash were rather unspectacular and exhibited few of the more violent characteristics observed in earlier years. Flames seldom exceeded 6 or 7 feet in height and usually were much lower. Pronounced cones of solid flame, common in the early stages of fires in heavy fresh and 1-year-old slash, seldom appeared, and then they persisted for only short periods. For the less flammable species, fire characteristics differed less with weight of fuel than in younger fuel. Flame pulsations were observed a few times but were transitory and weak. Irregular fire spread was common, with accompanying fitful variation in intensity.

Heat radiation, as a measure of fire intensity, was measured on 48 of the 54 plots burned in 1960. Flat-plate, total-hemispherical radiometers were again employed, as in 1954 and 1955. Reduced fire intensity permitted placing all radiometers 28 feet from the plot centers; therefore, measurements were directly comparable, with no adjustment for instrument distance.

Table 6 summarizes radiation values for medium and heavy slash of five species at all three ages, and of all species at 1 and 5 years. Where data for all ages were available, mean intensity dropped to 36 percent of the fresh-slash level during the first year after cutting and to 27 percent by the end of 5 years. The changes were almost identical in medium and heavy slash. The average change between the first and the fifth years was about the same for all nine species as for the five with records running the full gamut of ages.

Although general average intensities declined consistently with age, higher values were measured for 5-year-old than for 1-year-old heavy slash of ponderosa pine, western redcedar, Douglas-fir, western hemlock, and Engelmann spruce. The 1960 figures were uncorrected instrument readings from the same type of radiometer at a single distance; hence they should be wholly reliable. Some of the earlier values were calculated to account for differences in instruments or instrument distances, or both; and two were based on a single plot. No satisfactory accounting could be made for the shape factor of the radiating surface, so the calculations were known to be only approximate. Therefore, the discrepant values for 1-year-old slash are unquestionably too low. Support for this conclusion comes also from knowledge that fire intensity is proportional to rate of spread (3). Average rate of spread in 1-year-old slash was 54 percent of the rate in fresh slash, appreciably above the apparent 36 percent for radiation; but overall mean rate of spread in 5-year-old slash was 23 percent of that in fresh fuel, quite close to the corresponding 27 percent calculated for radiation.

Table 6.--Average maximum radiation received[1] from slash of nine species at three ages and at two weights per acre

Species	Fresh slash				1-year-old slash				5-year-old slash			
	20.0 tons/acre		32.5 tons/acre		20.0 tons/acre		32.5 tons/acre		20.0 tons/acre		32.5 tons/acre	
	Plots	Heat	Plots	Heat	Plots	Heat	Plots	Heat	Plots	Heat	Plots	Heat
		Btu/ft²/hr		*Btu/ft²/hr*		*Btu/ft²/hr*		*Btu/ft²/hr*		*Btu/ft²/hr*		*Btu/ft²/hr*
White pine	-	--	-	--	2	193	3	628	3	128	3	293
Lodgepole pine**	2	523	2	2,003	3	317	3	885	3	150	3	499
Ponderosa pine**	2	359	2	1,245	4	142	4	297	3	45	3	356
Western redcedar	-	--	-	--	2	138	2	279	2	37	3	286
Douglas-fir	-	--	-	--	2	98	2	156	2	72	3	241
Western hemlock	-	--	-	--	2	110	1	176	3	69	3	264
Engelmann spruce**	3	245	3	317	2	130	1	60	3	94	3	158
Grand fir**	2	263	2	902	3	49	4	216	1	15	2	68
Western larch**	2	478	3	957	4	64	4	258	2	52	3	215
Mean **species		362		1,010		136		362		92		273
all species		--		--		136		364		82		272
Percent of fresh-slash **species intensity						38		36		25		27

[1] Received by radiometer adjusted to instrument distance of 28 feet from plot center.

CONCLUSIONS

The final phase of the slash flammability study added little new information, but it did strengthen conclusions drawn earlier. Rate of spread and fire intensity declined in the old slash of all species; the decreases were about what would be expected from the appearance of the slash. As in previous years, artificialities in research methods prevented absolute experimental values from being very meaningful, but results indicated satisfactorily clear-cut comparative ratings. Thus the general effect of aging 5 years was clearly brought out, and also the variation in this effect with species. *Persistence of high flammability under certain circumstances was the most important finding.*

"Logging Slash Flammability" discussed all aspects of slash flammability and need for slash treatment. The five ensuing conclusions draw upon all phases of the slash flammability study to emphasize considerations, both old and new, that bear significantly on the need for slash treatment.

1. Slash is hazardous in proportion to the quantity and durability of fine components, and to the length of time it is dry each year. Risk and accessibility of area to fire-control agencies are modifying considerations.

2. Given the same total weight per acre, slash flammability is proportional to the degree that fine material is elevated above the ground. Relative flammability per unit of weight therefore can be estimated rather reliably from visual examination. Weight must be known and can be calculated by methods developed earlier in this study.

3. Heavy to very heavy concentrations of western white pine, lodgepole pine, western redcedar, and western hemlock slash, and perhaps occasionally of ponderosa pine, Douglas-fir, and Engelmann spruce,

warrant a "High" rate of-spread rating after 5 years. Patches of "High" fuels can make hazardous an area that generally rates "Low" to "Medium."

4. Grand fir and western larch slash seldom require treatment. Grand fir disintegrates very rapidly; western larch is sparse, loses its highly flammable needles the first year, and lies close to the ground.

5. Slash treatment will buy the most protection per dollar spent where slash species and estimates of quantity point to a "High" rate-of-spread rating at 5 years. Extra protection in lieu of treatment has the best chance of success where the rating drops to "Low" or "Medium" by or soon after the end of the first year after cutting [see (3), p. 59].

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PROJECT SKYFIRE PROGRESS REPORT, 1958-1960

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FOREWORD

This report summarizes Project Skyfire lightning research for the period 1958 through 1960. Several reports on specific problems within the scope of the project have been published, but no general report has been made of the research program nor of the special instruments and techniques used on the project. This report describes research aims, experimental design, results of studies of lightning storm characteristics and of the effect of cloud seeding on lightning occurrence.

The following persons participated in the research program and in preparation of this report:

Donald M. Fuquay, Project Leader
Robert G. Baughman, Research Meteorologist
Clyde A. O'Dell, Research Meteorologist
Dr. Howard E. Reinhardt, Mathematical Statistician (part time)
Alan R. Taylor, Research Forester (part time)
Howard J. Wells, Meteorological Aid (part time)
Ivalou O'Dell, Meteorological Aid (part time)
William H. Everard, Electronic Technician (part time)

This research has been carried out in cooperation with several agencies. We are indebted to Dr. Gilbert Kinzer, Director, Physical Sciences Laboratory, U.S. Weather Bureau, for the loan of equipment and for invaluable counseling on all phases of the project. Agencies aiding in the collection of data include National Forest Administration, the National Park Service, and the U.S. Weather Bureau.

The project greatly appreciates the work of summer field assistants, whose initiative and diligence under adverse field conditions contributed immeasurably to success of the program.

J. S. Barrows

Chief, Division of Forest Fire Research

CONTENTS

PROJECT SKYFIRE

PROGRESS REPORT 1958-1960

I. INTRODUCTION

Fires started by lightning cause severe damage to commercial timber and to the watershed, wildlife, and recreation values of forest land. During the 20-year period, 1939-1958, lightning caused more than 132,000 fires in the 13 western states including Alaska. About 7,500 lightning-caused forest fires occur annually in the United States. In the western United States, lightning is the most frequent single cause of forest fires; in the Rocky Mountain states, 70 percent of all forest fires are lightning caused.

During one 10-day period in July 1940, the National Forests in western Montana and northern Idaho reported 1,488 lightning fires. In this period, 335 lightning fires occurred in one 24-hour period. Ability to cope with the greatly increased workload caused by such an outbreak often determines the degree of success attained by a fire control organization. Any method of reducing the number of lightning fires would have great economic importance. Of special importance would be a method for reducing peak numbers of lightning fires started by a single storm system.

Project Skyfire, conducted by the U.S. Forest Service, is a study of meteorological problems associated with lightning-caused forest fires. The project has two long-range objectives: (1) to obtain better understanding of the occurrence and characteristics of lightning storms and lightning fires in the northern Rocky Mountain region, and (2) to investigate the possibility of preventing or reducing the number of lightning fires by applying techniques of weather modification.

II. BACKGROUND

A regionwide survey of the occurrence of thunderstorms and lightning discharges was begun in 1955 and is still in progress. Visual observations are made by forest fire lookouts located throughout Montana, Idaho, northeastern Washington, eastern Oregon, and northwestern Wyoming (Barrows et al. 1957). This survey has produced considerable information about the frequency of lightning and other thunderstorm characteristics.[1] Several research papers based on data from this regionwide network are planned for publication.

Exploratory cloud-seeding operations started in 1956 demonstrated the need to develop cloud seeding and other research equipment that could be used in mountainous regions for cloud physics studies. Consequently, new airborne and ground-based silver iodide smoke generators were developed and field tested. As a part of the program of equipment development, a technique was devised for calibrating generators in the field (Fuquay 1960).

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[1] Fuquay, Donald M. 1959. Some thunderstorm statistics for the northern Rocky Mountain region. Intermountain Forest and Range Expt. Sta., U.S. Forest Service. Unpub. manuscript presented at the Skyline Conference on the design and conduct of experiments in weather modification. 22 pp., illus.

In the summer of 1957, a test area was established in the Lolo National Forest near the summit of the Bitterroot Range along the Idaho-Montana border. A field experiment was designed to study dispersion of silver iodide crystals from a network of ground-based generators and to observe the effect of silver iodide on cumulus clouds.

The invisible silver iodide smoke plumes were traced by using a portable cold chamber mounted in a light aircraft. The objective was to measure the number of silver iodide crystals entering cumulus updrafts at various distances downwind from generator sites. The aircraft made successive traverses at about 5-mile intervals downwind from the generators at an elevation of 10,000 feet or at cloud base, whichever was lower. Substantial numbers of nuclei were observed only in regions of updrafts.

Surface weather conditions strongly influenced dispersion of silver iodide. When the air was stable near the surface, virtually no crystals were carried to cloud base level. Drainage winds complicated the dispersal patterns of silver iodide crystals. Silver iodide was traced on the surface as far as 20 miles from the source in the general downwind direction when drainage winds were present. A cold box mounted in an automobile was used to trace the smoke. Dispersion was further complicated by silver iodide being carried 8 to 10 miles along the valley floors in a direction opposite to the wind flow over the ridges. Silver iodide proved to be so good a tracer for surface wind studies that this equipment was subsequently used to trace the extent of down-valley winds (Schaefer 1957). Lloyd, O'Dell, and Wells (1959) used this method to trace the route of the airborne sporidia of blister rust (Cronartium ribicola Fischer) into a plantation of western white pine (Pinus monticola Dougl.).

The plume-tracing experiments showed that silver iodide particles released from ground-based generators were dispersed in wide and virtually unpredictable patterns under certain meteorological conditions. Wind, atmospheric stability, and terrain all strongly influenced the dispersal pattern. It was concluded that necessary conditions for controlled-area experiments could not be met in mountainous regions with ground-based generators.

Measurements of nuclei concentrations downwind from the generators made possible a first approximation of the photo-deactivation of silver iodide crystals due to sunlight. Two methods were employed to compute the rate of deactivation. The first method assumed that total generator output (10^{13} nuclei per second per generator effective at −20° C. was homogeneously mixed through all layers from 5,000 feet to cloud base. The plume volume was computed from the measured width of the plume and the radial distance from the generators. The computed concentrations at various points within the volume were compared with measured values at the same point. The second method involved calculation of the silver iodide decay independently of generator output. A measured concentration in the plume was followed downwind to a second measured concentration. The second concentration was assumed to have been decreased from the first by plume divergence and the decay of the silver iodide. Results from this method agreed with those from the first method.

Decay rates computed from 37 observations (fig. 1) were as follows: 76 percent of the observations showed a decay rate of less than 2.5 orders of magnitude per hour; 73 percent were less than 2 orders per hour; 62 percent were less than 1 order per hour. The nuclei exposed to sunlight longer than 30 minutes usually showed a decay rate considerably less than 1 order of magnitude per hour.

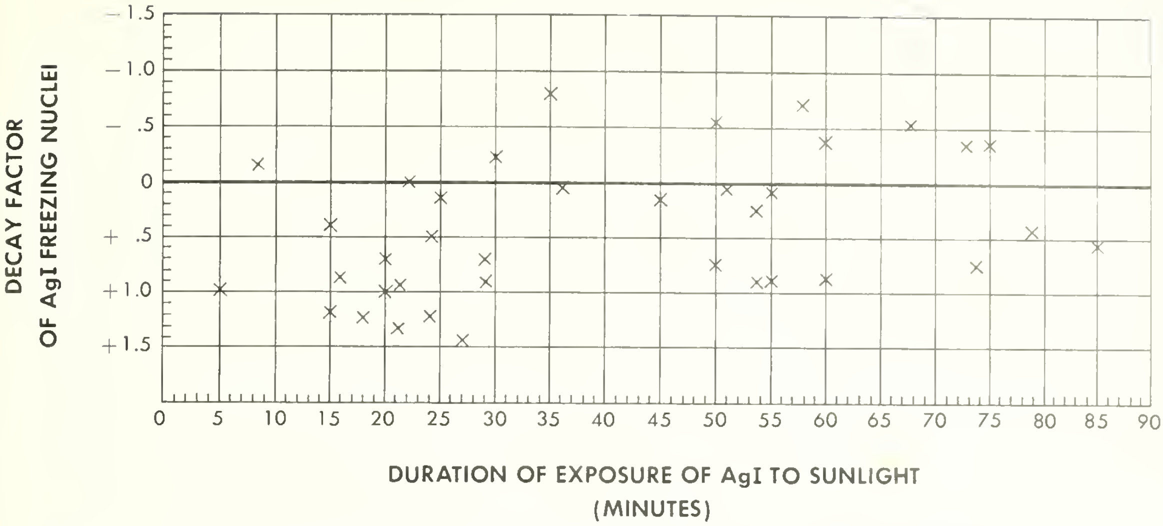


Figure 1.--Measured rates of photo-deactivation of silver iodide crystals in free air.

III. STUDIES OF THUNDERSTORM AND LIGHTNING CHARACTERISTICS

Forest fire lookouts participating in the regionwide lightning survey were trained to obtain information on the formation and movement of thunderstorms, and on the frequency of lightning discharges. Thunderstorms and lightning statistics in this section of the report were compiled from data taken by lookouts during the period 1955-1958.

The average annual number of thunderstorm periods for July and August 1955-58 as reported by the Skyfire lookout network is shown in figure 2. It illustrates the wide variation characteristic of mountainous country. For example, Gisborne Mountain (Skyfire Station No. 2) in northern Idaho reported an annual mean of four thunderstorm periods, while Chewela Lookout (Skyfire Station No. 3), located about 50 miles west of Gisborne Lookout in northeastern Washington, reported 16. Such variation is common in the Rocky Mountain region.

Annual numbers of thunderstorm periods and cloud-to-ground lightning discharges reported by the Skyfire stations are shown in table 1.

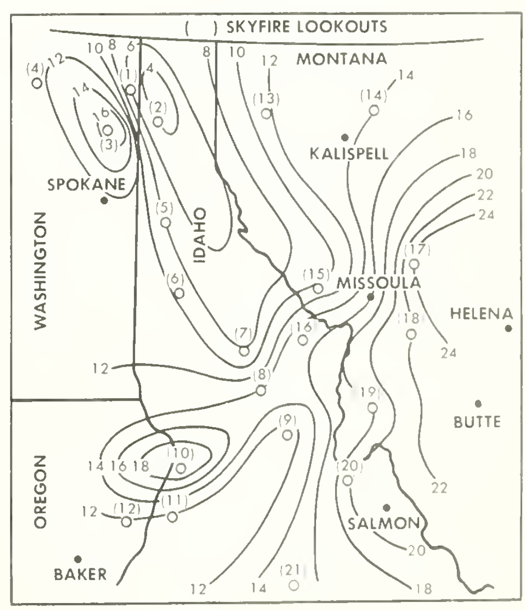


Figure 2.--Average annual number of thunderstorm periods for July and August 1955-58, as reported by Skyfire lookout network. Numerals in parentheses are station designators.

Table 1.--Thunderstorm periods and cloud-to-ground lightning discharges, July-August 1955-58

Year	Reporting stations	Storm periods	Cloud-to-ground discharges	Discharges per storm period
1955	16	178	6,026	34
1956	22	335	10,047	30
1957	22	238	4,355	18
1958	21	276	6,988	25
	Total	1,027	27,416	107
	Average	257	6,854	27

Duration of these 1,027 storm periods reported by Skyfire lookouts is shown in figure 3. The term "storm duration" or "storm period" is defined as the period of generally continuous thunderstorm activity within a 20-mile radius of the lookout, beginning with the first lightning discharge and continuing until the last. The grouping of storm duration by 30-minute intervals indicates that about one-half of all storms last 30 to 90 minutes, but only 15 percent of the storms continue less than 30 minutes.

The cloud-to-ground lightning discharges reported here were flashes actually seen by lookouts. The ability of a lookout to see and identify lightning flashes may vary according to the type and location of the storm. Comparison of total lightning observed by a lookout with field meter records indicates that on relatively isolated storms, the lookout apparently can see 80 to 90 percent of the cloud-to-ground flashes. During intense widespread storms where visibility is limited, the observer may count only 25 percent of the flashes. We believe that over a long period a lookout will see about one-half of all cloud-to-ground flashes occurring within his designated area. The reader is cautioned to bear this in mind when comparing these data with lightning frequency information derived from other sources.

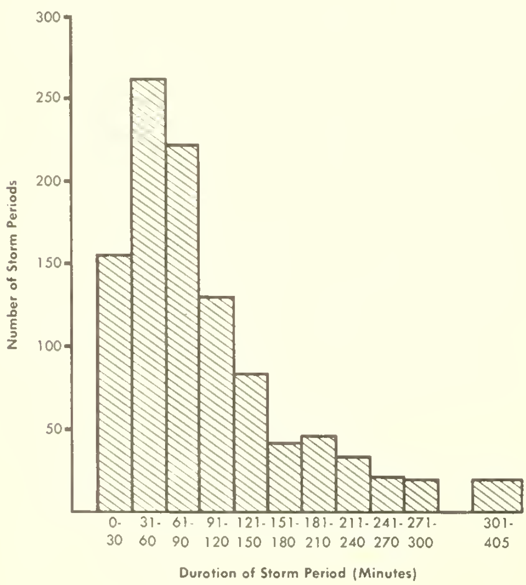


Figure 3.--Frequency distribution of thunderstorm periods in July and August 1955-58, classified by duration of storm period, as reported by Skyfire lookout network.

The distribution of these storms by cloud-to-ground discharge frequency intervals is shown in figure 4. Nearly half of the storms had fewer than 10 discharges, and about 70 percent had fewer than 20 discharges. Only about 5 percent of the storms had more than 100 cloud-to-ground discharges.

About 50 percent of the 1,027 storm periods reported had fewer than 10 lightning discharges to ground. However, this storm class contributed only 10 percent of the total number of discharges to ground. The storms for which more than 100 ground discharges were reported per storm contributed about one-third of the total number of discharges. The percentage of total cloud-to-ground discharges per storm is shown in figure 5.

The mean annual discharge density over large regions is of particular interest to workers in atmospheric electricity since the charge transferred by cloud-to-ground discharges has been postulated as the mechanism for maintaining the electric field in the atmosphere. The mean annual number of cloud-to-ground discharges per 1,000 square miles occurring in July and August is shown in figure 6. A mean annual density of 200 discharges, based on 4 years of records, is shown for the Skyfire test area southwest of Missoula, Montana.

This study revealed the following general characteristics of lightning storms in the northern Rocky Mountains:

1. The average number of lightning storm periods per National Forest per fire season varied from a low of four in areas of relatively infrequent occurrence to a high of 24 in severe lightning areas.

2. Most lightning storm periods were relatively short. About half of the storm periods lasted for 30 to 90 minutes, and some 15 percent of the storms lasted less than 30 minutes. Only 4 percent continued longer than 300 minutes.

3. Many storms produced a relatively low number of cloud-to-ground discharges. Records showed that about 50 percent produced 10 or fewer discharges to ground. The 5 percent of storms that produced more than 100 discharges per storm accounted for more than one-third of the discharge total for all storms.

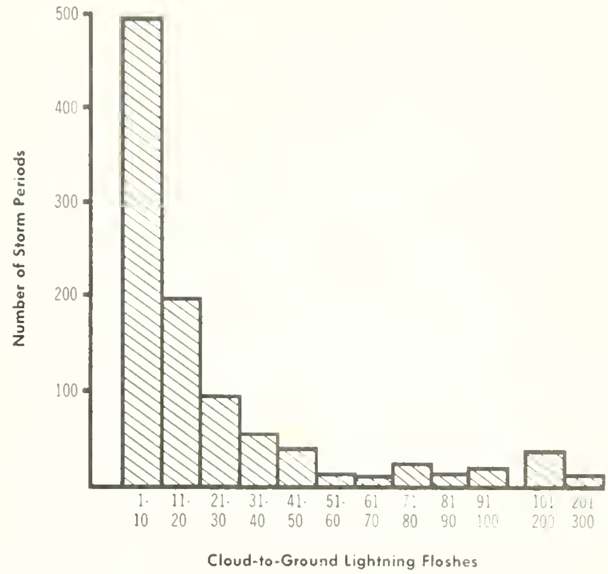
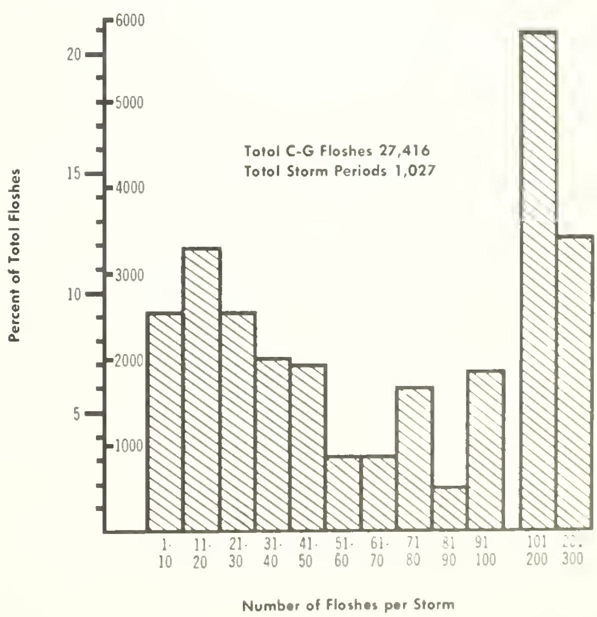


Figure 4.--Frequency distribution of thunderstorm periods in July and August 1955-58, classified by number of cloud-to-ground lightning discharges per storm (based on 1,027 storm periods).

Figure 5.--Percentage of total cloud-to-ground lightning discharges contributed by storms classified by number of cloud-to-ground discharges per storm. The inside scale on vertical axis shows number of discharges corresponding to percentage values.



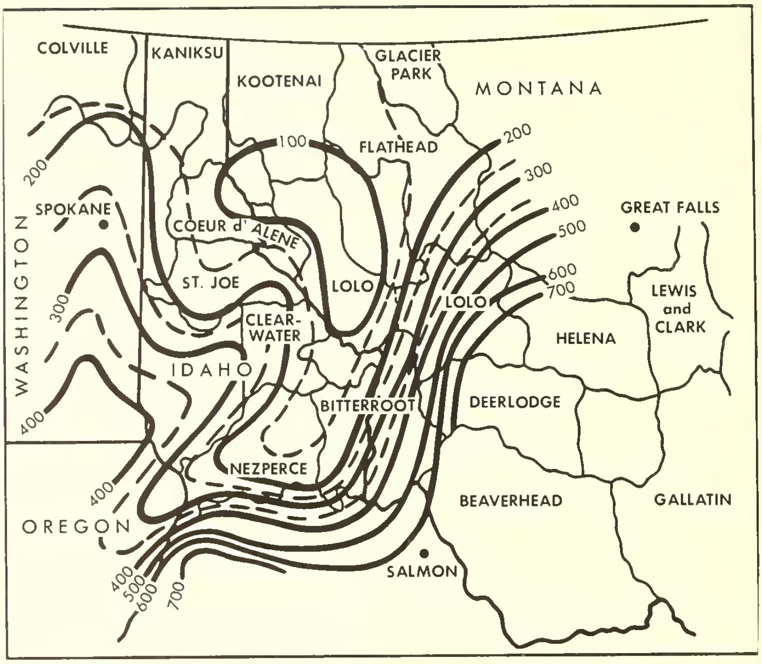


Figure 6.--Average annual number of observed cloud-to-ground lightning flashes per 1,000 square miles reported by Skyfire lookout network, July and August 1955-58.

4. Many lightning storms yielded little precipitation. During a 4-year period, about 50 percent of the storms produced less than 0.1 inch of precipitation. Another 20 percent produced from 0.1 to 0.2 inch of precipitation.

5. About 20 percent of all storms yielded precipitation as hail or graupel.

6. Lightning storms observed in western Montana had high cloud bases and were relatively shallow in total height. The average cloud base was near 12,000 feet m.s.l. Active dry thunderstorms were observed with bases nearly 17,000 feet above sea level. Average cloud base temperature was near the freezing level.

IV. STUDIES OF LIGHTNING STORM MODIFICATION

In recent years many workers have speculated on the possible effects of cloud seeding on precipitation, hail, lightning, thunderstorm downdrafts, and all major-scale weather phenomena. The anticipated results are often purely speculative since there is usually no clear understanding of the parent phenomena. Contemporary theories regarding possible effects on lightning when examined in the light of possible modification effects lead one to predict either a radical increase, a large decrease, or no effect on the frequency of cloud-to-ground discharges. In some storms, the weather modification experiment may shed more light on the parent mechanism since it provides a state in addition to the natural state during which the electrification mechanism can be studied.

PRELIMINARY STUDIES, 1958

Our first experiments in randomized seeding were carried out in western Montana in 1958. Three chief objectives of this program were: (1) to test the use of electric field meters for recording lightning discharges in mountainous country, (2) to check methods of visually locating lightning discharges, and (3) to test seeding techniques and new cloud-seeding equipment. A technique of randomization was used to select certain days for no treatment or treatment from either a network of 30 ground-based generators or from airborne generators.

The frequency of lightning discharges and the electric fields associated with storms were recorded by three synchronized electric field meters. The three recording stations were established along a 14-kilometer line.[2]

The electric field change associated with the discharge to ground of an electrostatic model is given by the equation:

$$\Delta E = \frac{2 \Delta QH}{4 \pi \epsilon_0 (D^2 + H^2)^{3/2}}$$

where ΔE = change in potential gradient (volts/meter)

ΔQ = total change in charge (coulombs)

D = horizontal distance to strike (kilometers)

H = height of negative charge center (kilometers)

ϵ_0 = permittivity of free space.

The quantity $2\Delta QH$ is the change in electric moment if the thunderstorm is considered a bipolar electrostatic generator with positive and negative charge centers situated approximately vertically one above another. The electric moment was calculated for cloud-to-ground discharges within the following limitations:

1. The geographical location of a vertical discharge was known.

2. The distance to the charge center $(D^2 + H^2)^{3/2}$ fell within the domain of acceptable solutions of simultaneous equations for the dipole model (Fitzgerald 1957).

3. The calculated value for H, the height of the negative charge center, was within the boundaries of the cloud.

The nature of the discharge can be inferred from the polarity of the change in potential gradient. The potential gradient change for a cloud-to-ground discharge is positive at all distances from the discharge. An intracloud discharge has a positive change near the discharge, zero at the reversal distance of about 5 to 7 kilometers, and is negative at all greater distances. Since one field meter is always beyond the reversal distance, we have the following criteria for identifying discharges:

1. A positive change in potential gradient at all field meter sites indicates a cloud-to-ground discharge.

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[2] Measured and calculated values of parameters associated with electrical properties of thunderstorms are given in mks units.

2. A negative change in potential gradient at any site indicates a cloud-to-ground discharge.

In our usage, a cloud-to-ground or ground discharge transfers negative charge to ground. A cloud-to-cloud or cloud discharge could be intracloud, intercloud, cloud-air, or of such a complex nature as to result in a net negative change in potential gradient beyond the field reversal distance.

Continuous electric field records and visual location of discharges were obtained from four untreated storm periods, two ground-seeding periods, and two aerial-seeding periods during the 1958 field season. The normal background freezing nuclei count at cloud base level had been found by the 1957 tracing program to be one nucleus per liter active at −20° C. We found that the network of ground-based generators could supply about 50 to 300 nuclei per liter at distances of 10 to 15 kilometers from the generator sites. The estimated nuclei concentration at cloud base level produced by the airborne generators was 10^4 per liter based on generator output, seeding pattern, updraft velocities, and the physical dimensions of the storm.

The electric field records from the 1958 season provided information on (1) the frequency of lightning discharges, (2) ratio of intracloud to cloud-to-ground discharges, and (3) change of electric moment. These are discussed in detail below.

Frequency of lightning discharges.--The limited number of thunderstorms studied in the 1958 experiment precludes use of statistical methods to test significance of the results. Therefore the data were examined for apparent modification effects that might be verified in subsequent experiments. The grouping of data to examine possible effects of treatment on the frequency of lightning is given in tables 2, 3, and 4.

Table 2.--Average frequency of lightning discharges, 1958

Date	Number of 5-minute intervals	Average number of discharges per 5 minutes		
		Intracloud	Cloud-to-ground	Total[1]
		Not seeded		
18 July	50	10.5	3.5	15.0
10 Sept.	50	11.4	3.6	15.0
11 Sept.	56	15.4	3.5	19.6
		Seeded from ground		
29 July	51	21.0	2.9	24.0
11 Aug.	23	14.5	5.6	21.0

[1] Totals include indeterminate discharges.

In table 2, the average frequency of cloud-to-ground, intracloud, and the total number of discharges per 5-minute period are arranged according to the type of treatment employed. The total number of discharges, which includes all the intracloud and cloud-to-ground discharges, also includes a class of indeterminate discharges which make up about 5 percent of the total. The indeterminate class includes complex discharges and discharges that could not be definitely identified as either intracloud or cloud-to-ground.

Table 3.--Maximum rate of lightning discharges, 1958

Date	Type of discharge	Number of lightning discharges per 5 min.	10 min.	15 min.	20 min.
		Not seeded			
18 July	I.C.[1]	37	67	91	121
	C.G.[2]	15	29	42	55
10 Sept.	I.C.	33	61	89	114
	C.G.	10	15	22	29
11 Sept.	I.C.	51	92	121	164
	C.G.	11	20	27	32
		Seeded from ground			
29 July	I.C.	58	111	153	191
	C.G.	10	15	22	28
11 Aug.	I.C.	27	51	66	86
	C.G.	17	30	39	46

[1] Intracloud discharge.
[2] Cloud-to-ground discharge.

The treatment may affect the rate at which lightning discharges occur. The maximum rate of discharge occurrence in any 5-, 10-, 15-, or 20-minute period during a recorded storm is shown in table 3.

Table 4 shows the grouping of the total number of intracloud and cloud-to-ground discharges according to the type of treatment each of the five storms received. To compare these storms with a larger sample, we refer to figure 5 which shows total cloud-to-ground discharges per storm recorded by lookouts. The number of discharges seen by lookouts, as previously mentioned, represents only about 50 percent of the actual number recorded by the field meters. After mentally adjusting figure 5 for lookout efficiency, we see that the five recorded storms (table 4) fall near the upper end of the frequency distribution. This means that the five storms recorded by the field meters cannot be considered "average" storms because they produced unusually large numbers of discharges.

Table 4.--Total number of lightning discharges, 1958

Date	Intracloud		Cloud-to-ground		Total[1]
	Number	Percent of total	Number	Percent of total	
		Not seeded			
18 July	527	70	173	23	759
10 Sept.	569	76	181	24	753
11 Sept.	864	78	194	18	1,098
		Seeded from ground			
29 July	1,053	87	147	12	1,218
11 Aug.	335	69	129	27	484

[1] Totals include indeterminate discharges.

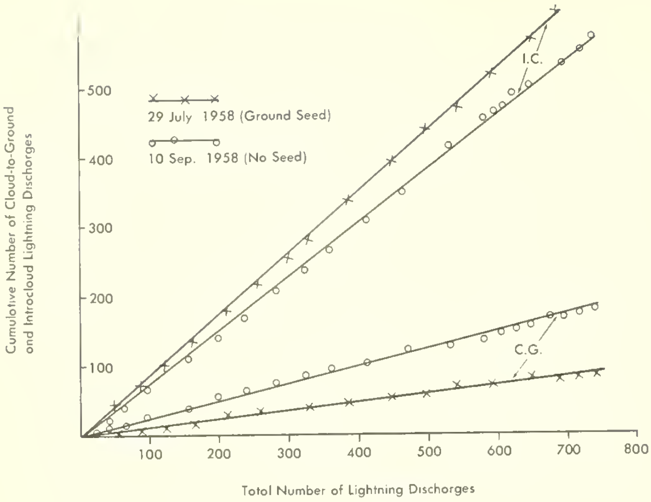


Figure 7.--Regression of cumulative number of intracloud and cloud-to-ground lightning discharges on the total number of discharges for two storm periods.

The lightning frequency values recorded during the five storms lead to the following general conclusion for the cases studied: There were no obvious differences in the frequency of intracloud and cloud-to-ground discharges between nonseeded storms and storms seeded with ground-based generators.

Ratio of intracloud to cloud-to-ground discharges.--Some aspects of thunderstorm electrification theory would lead one to predict a change in the ratio of intracloud to cloud-to-ground discharges even if the total amount of lightning were not changed. The discharge ratios for a storm period can be shown by plotting the cumulative numbers of intracloud and cloud-to-ground discharges against cumulative total discharges for constant time increments during the storm (fig. 7). The points for both intracloud and cloud-to-ground discharges for all storm periods were joined by a straight line. This linear regression suggested that the ratio of intracloud to cloud-to-ground discharges was generally constant throughout a storm period.

The regression coefficients, which are the slopes of the cumulative curves in figure 7 are listed below for nonseeded storms and for storms seeded by ground-based generators.

Date		Intracloud coefficients		Cloud-to-ground coefficients
		Not seeded		
18 July		0.83		0.08
		.69		.35
18 Aug.		.81		.15
		.77		.15
10 Sept.		.75		.25
11 Sept.		.88		.10
		.72		.24
	Average	.77	Average	.19
		Seeded from ground		
29 July		.85		.12
11 Aug.		.69		.33
11 Aug.		.78		.15
	Average	.77	Average	.20

The arithmetic mean of the regression coefficients for cumulative discharge curves indicates there is no difference in the ratio of intracloud to cloud-to-ground discharges between seeded and nonseeded storms and further that the ratio at any interval during a storm period is not altered.

Change of electric moment.--The change in electric moment was calculated from the potential gradient changes and the visual location of the discharges. Calculations from 28 discharges are entered in table 5 along with treatment data. No conclusions about the effectiveness of seeding can be drawn from such a small sample. However, a comparison of the average change in electric moment between nonseeded, ground seeded, and storms seeded from aircraft suggests a reduction in the change in electric moment per discharge in proportion to the quantity of nuclei supplied. The implication is that a cloud seeding program aimed at lightning suppression should attempt to supply at least 10^4 nuclei per liter at cloud base level.

Table 5.--Average change in electric moment of lightning discharges

Treatment	Estimate of nuclei at cloud base	Number of discharges	Electric moment	Standard deviation
	Number per liter		Coulomb kilometers	
Not seeded	Fewer than 10	8	232	121
Seeded from ground	50-300	17	92	26
Seeded from aircraft [1]	More than 10,000	3	14	6

[1] August 21 and August 22, 1958.

Discussion of the significance of the relation between the change of electric moment and seeding as indicated in table 5 would be rather meaningless in view of the limited number of observations. However, it does seem proper to speculate on what effects these results might have on the design of an experiment.

1. If the observed reduction in electric moment is valid, then the treatment should exceed 10^4 nuclei per liter (effective at −15° C.).

2. Reduction in electric moment could mean either that less charge is transferred in the discharge, or that the charge center is lower, or a combination of the two factors. If the charge transferred is less, and if the lightning frequency does not change, then the charging rate within the cloud could be less. It also could be explained by an increase in conductivity between the major charge centers. However, seeding may decrease the intracloud conductivity by increasing the number of ice crystals within the cloud. Future studies should attempt to isolate the variables of the electric moment.

Discussion of aerial seeding cases.--The two storms seeded by airborne generators (table 5), must be considered differently from the examples of ground-based generator seeding. The storm on August 21 had heavy precipitation and a top extending above 39,000 feet, but yielded only three cloud-to-ground discharges and no intracloud discharges. This was the largest storm recorded in or near the test area in 2 years of operation. On August 22 the cloud seeded by airborne generators grew to 30,000 feet, exhibited heavy glaciation, heavy precipitation, and a measured potential gradient in excess of 150 volts per centimeter (measured at the surface).

But this storm produced no lightning discharges. Although the days on which the aerial seeding took place were selected by the established randomization technique, the time and place of seeding on each day were actually arbitrary. There is no assurance that the storms selected for aerial seeding would have developed into large thunderstorms. However, large storms did occur near the test area on both days.

For planning the evaluation of lightning suppression experiments, the following possibilities should be noted:

1. Several researchers have reported that the larger or higher a thunderstorm system, the more intense will be the lightning activity. This has been confirmed for all thunderstorms studied except for the two storms reported above. This anomaly could mean that such storms occur naturally or that seeding with a high concentration of nuclei substantially decreases lightning activity. If these storms occur naturally, the evaluation technique must allow for such an anomalous storm that shows all the physical characteristics of a very large thunderstorm but exhibits little or no lightning activity.

2. If lightning frequency for thunderstorm periods is used as a basis to measure the effectiveness of lightning suppression techniques, a paradox is immediately present in the evaluation. A 100-percent effective system of lightning suppression would exclude all treated cases from the classification as thunderstorms since, by definition, a thunderstorm requires that lightning occur. The seeded cloud described for August 22 could not be considered a thunderstorm since lightning was not seen nor thunder heard. However, the field meters recorded intense electrical activity.

The preliminary studies in 1958 permitted a close look at the problems associated with field experiments in lightning storm modification, and provided valuable information for a realistic design of subsequent experiments.

1959 STUDIES

Results of the 1958 field studies indicated need for a long-range program to study thunderstorms under treated and untreated conditions. The following elements were believed to be of primary importance:

1. Development of an adequate measuring system for recording lightning parameters.

2. Establishment of this recording system in a suitable area.

3. Development of an airborne silver iodide smoke generator capable of supplying large numbers of nuclei.

A 3-year observational program using a synchronized network of five surface-mounted electric field meters was designed to study the following:

1. The frequency and distribution of lightning discharges during natural storms.

2. The quantity of charge carried by cloud-to-ground discharges.

3. The height of negative charge centers.

4. The effect of silver iodide seeding from aircraft on some of the electrical and physical characteristics of lightning storms.

In addition to the above, the Skyfire lookout network was expanded from 22 to 38 stations. This expansion provided supplementary information on the regionwide occurrence of lightning storms, cloud-to-ground discharges, and surface weather conditions.

Because of a limited operational budget, only a portion of this program was planned for completion during the 1959 field season. Also the summer of 1959 had a record low number of thunderstorm days; the frequency of storms was only about 40 percent of normal. As a result, the data collected were insufficient to permit any statistical studies of lightning storm features.

An airborne silver iodide generator was developed to produce about 10^{15} nuclei per second effective at $-20°$ C. This airborne generator and a similar ground-based unit are described fully in Section VII.

A new study area (fig. 8), established on the Deerlodge National Forest near Philipsburg, Montana, was selected because:

1. It had a relatively high frequency of lightning occurrence.

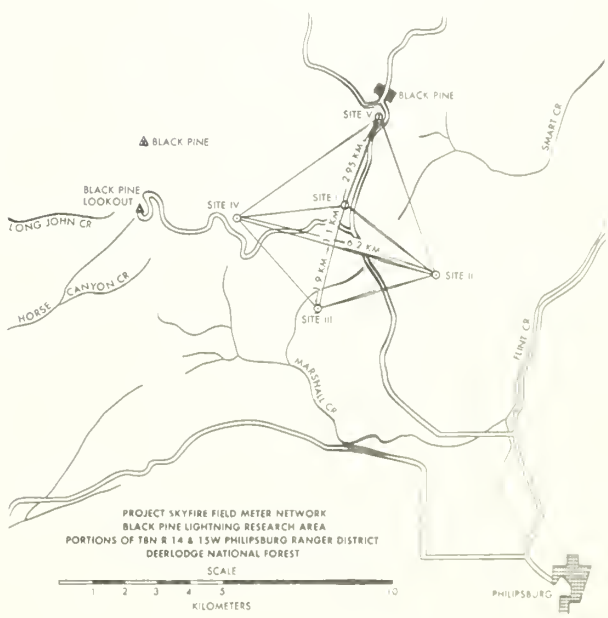
2. It had an adequate road system.

3. It was close enough to Missoula for aircraft and service operations from existing facilities.

The electric field meter and lightning observing sites established within the study area (fig. 9) were located in a prescribed geometrical pattern. The instrumentation at each site included a recording electric field meter, a means for visually locating lightning discharges, and surface weather observing equipment. At one station, the instrumentation included a mobile radar unit, time-lapse and full-sky cameras, and upper wind measuring equipment. The field meters at each site were connected through a land-line system to a central station to insure synchronization of recordings.

Figure 8.--Project Skyfire research areas, 1957-60.

Figure 9.--Project Skyfire study area near Philipsburg, Montana, 1959-60, showing field meter network.



On November 15, 1959, additional funds to plan and carry out a program of research on the effects of cloud seeding on lightning storms became available through a cooperative program with National Science Foundation.

V. DESIGN OF EXPERIMENTS FOR 1960-61

The weather modification program for 1960-61 was planned to last $2\frac{1}{2}$ years and to include two field seasons. This period may not have enough lightning storms to give data for statistical conclusions. Plans have been made to extend the study until valid conclusions can be reached.

The research program has the following objectives:

1. To obtain information on the frequency, type, and electrical characteristics of lightning discharges and to evaluate this information in relation to theories about thunderstorm development and electrification.

2. To determine the effects on the frequency and electrical characteristics of lightning discharges when clouds are heavily seeded with silver iodide and to evaluate the results in relation to theories on lightning.

STATISTICAL DESIGN

The basis of the cloud-seeding experiment is the comparison of electrical and physical factors in lightning storms on pairs of treated and untreated days. The pairing was adopted to insure an equal number of treated and untreated days. Selection of an operational day in an unbiased manner is accomplished by using, as a basis of declaration, a U.S. Weather Bureau forecast that thunderstorms will occur in the test area. The forecast, by 1100 m.s.t., must call for a thunderstorm to occur in the test area between the hours of 1300 and 1900 m.s.t. A table of random numbers then is used to determine whether the day will be one for treatment or control. When one day has been prescribed, the next operational day, with any number of nonoperational days intervening, completes the pair by receiving the opposite treatment. Identical observations are taken on both treated and untreated days.

On operational days when seeding is done, two aircraft on alternate shifts dispense silver iodide upwind of the test area. The aircraft may be forced from the area for short periods of time during the passage of very active storms. To strive for continuity of treatment during these periods, three ground-based generators also release silver iodide into the test area.

The statistical analysis is designed to compare the following variables on paired days:

1. Frequency of cloud-to-ground and intracloud discharges.

2. Total number of lightning discharges.

*3. Electric moment of cloud-to-ground discharges.

*4. Vertical height of negative charge centers.

5. Height of initial radar echoes.

*Values computed for a monopole discharge from an electrical model of a thunderstorm.

6. Rate of vertical growth of radar echoes.

7. Maximum height of visible cloud tops.

8. Rate of growth of visible cloud tops.

The analysis should give a statistical answer to the following list of questions. In each case the alternate hypothesis is stated. The null hypothesis is the obvious negative statement of the question:

1. Does cloud seeding alter the occurrence of lightning discharges?

   Hypothesis: Cloud seeding changes the number of cloud-to-ground discharges.
   Hypothesis: Seeding changes the number of intracloud discharges.
   Hypothesis: Seeding changes the total number of discharges.
   Hypothesis: Seeding changes the ratio of cloud-to-ground to intracloud discharges.

2. Does cloud seeding alter the electrical properties of discharges?

   Hypothesis: Seeding changes the electric moment.
   Hypothesis: Seeding lowers the vertical height of the charge centers.

3. Does seeding alter the physical characteristics of the cloud?

   Hypothesis: Seeding lowers the height of the maximum height of radar echo.
   Hypothesis: Seeding lowers the height of the initial radar echo.
   Hypothesis: Seeding changes the rate of growth of radar echo.
   Hypothesis: Seeding changes the maximum height of visible cloud top.
   Hypothesis: Seeding changes the rate of growth of clouds.

The following two considerations were declared in a study plan prior to the 1960 field season:

1. Simple nonparametric procedures, usually signed rank tests, will be used.

2. A 95-percent level of significance will be used; however, results will be presented with the level of significance at which the null hypotheses could be rejected.

Because of the large variances and the limited number of pairs that would be available during the two seasons, the project may fail to detect, as significant, differences that actually exist. This motivates the inclusion of the level of significance at which the null hypotheses could be rejected and allows an objective combination of the results of this experiment with those from other experiments. Suppose, for instance, that the results of this study show an apparent tendency for the seeded member of a pair to have a level of initial precipitation formation lower than the unseeded member of a pair, but that this tendency is not statistically significant. It may well happen that other weather modification experiments will also test the hypothesis that cloud seeding lowers the level of precipitation formation. Suppose, for concreteness, that each study separately could have rejected the hypothesis of no change in the level of precipitation formation at the 95-percent level of significance. It would seem that the two "almost significant" results might together significantly indicate lowering of the formation level. This is, in fact, true. Objective techniques, originated by R. A. Fisher (1936) and developed by others, allow the combining of the results of two different experiments. The statistic used is the level at which the null hypothesis could have been rejected. (For the combination of results it is not necessary that the second experiment be an exact replication of the first; it is sufficient that the experiment be testing the same null hypothesis.)

As pointed out by the report of the Skyline Conference (National Academy of Sciences 1959), weather modification experiments offer an opportunity to supplement present descriptions of storms. Descriptive observations made by project personnel may make possible the use of more precise statistical techniques. For instance, nonstatistical examination of storms may make plausible the assumption of a particular frequency distribution for lightning occurrence. This distribution could then be used in the statistical tests. Of course, only data gathered after the assumption of a particular distribution can be analyzed by the revised technique. The possibility of applying techniques of extreme value statistics will also be considered.

SOLUTIONS OF CLOUD-TO-GROUND LIGHTNING DISCHARGES

In this section we examine the relation between electric field recorded at the surface and changes in the thunderstorm caused by cloud-to-ground lightning. The following discussion is based on a point-charge model of a thunderstorm.

It is generally accepted that the thunderstorm exhibits a bipolar charge distribution with the positive charge center located higher in the cloud than the negative center. Further, it is assumed that the charges can be treated as point charges if the distance to a point of observation on the ground is large. If we consider only the negative charge center of Q coulombs located H meters above any infinite conducting plane and D meters horizontally from the point of observation, the vertical component of the electric field, E in volts per meter, is given by the following equation:

$$E_z = \frac{2QH}{4\pi \epsilon_o (D^2 + H^2)^{3/2}} \qquad (1)$$

where $\epsilon_o = 8.85 \times 10^{-12}$ farads per meter, the permittivity of free space.

When the charge is lowered to earth by a cloud-to-ground lightning discharge, the change in field is given by:

$$\Delta E_z = \frac{2 \Delta QH}{\epsilon (D^2 + H^2)^{3/2}} \qquad (2)$$

where $2 \Delta QH$ is the change in electric moment of the discharge and $\epsilon = 4\pi \epsilon_o$.

A set of four equations is required to solve for the variables ΔQ, H, and D (where D is given in terms of X and Y from the center of a coordinate system). This requires simultaneous recordings of ΔE at four locations.

If the location of a discharge at the ground surface is known, the height H can be calculated from the following equations:

$$\frac{\Delta E_i}{\Delta E_j} = \left[\frac{D_j^2 + H}{D_i^2 + H} \right]^{3/2} \qquad (3)$$

or solving for H^2

$$H^2 = \frac{\left[\frac{\Delta E_i}{\Delta E_j}\right]^{2/3} D_i^2 - D_j^2}{1 - \left[\frac{\Delta E_i}{\Delta E_j}\right]^{2/3}} . \tag{4}$$

The quantity ΔQ can then be calculated from equation (2).

In our research area in western Montana, four electric field meters were located in a geometric pattern as shown in figure 9. A fifth field meter site was added later to help identify the electrical discharges. The following solutions to equation (2), based on the geometry of the field meter network, follows closely the analysis presented by Fitzgerald (1957).

The line through meter sites II and IV (fig. 9) establishes the X axis, and the line through sites I and III, which is nearly perpendicular to the X axis, is taken as the Y axis.

The distances from the center of the coordinate system to the location of sites I, II, III, and IV are A_1, B_1, C_1, and D_1, respectively. In this network $B_1 = D_1$ and $C_1 = \emptyset A_1$.

The following four equations involving the field changes at each of the four sites from a discharge of ΔQ at slant distance R can now be written in terms of this coordinate system:

$$R^2 - 2A_1Y + A_1^2 = \left[\frac{2\,\Delta QH}{\epsilon}\right]^{2/3} \Delta E_1^{-2/3} \tag{5}$$

$$R^2 - 2B_1X + B_1^2 = \left[\frac{2\,\Delta QH}{\epsilon}\right]^{2/3} \Delta E_2^{-2/3} \tag{6}$$

$$R^2 + 2C_1Y + C_1^2 = \left[\frac{2\,\Delta QH}{\epsilon}\right]^{2/3} \Delta E_3^{-2/3} \tag{7}$$

$$R^2 + 2D_1X + D_1^2 = \left[\frac{2\,\Delta QH}{\epsilon}\right]^{2/3} \Delta E_4^{-2/3} \tag{8}$$

where $R^2 = X^2 + Y^2 + H^2$ and ΔE_1, ΔE_2, ΔE_3, and ΔE_4 are the field changes at sites I through IV.

Eliminating X and Y by substituting for C and D, multiplying equation (5) by $\emptyset$, and adding equations (5) and (7), and equations (6) and (8), we have the following two equations:

$$R^2 + \emptyset A_1{}^2 = \frac{\left[\frac{2\,\Delta QH}{\epsilon}\right]^{2/3} (\emptyset\,\Delta E_1{}^{-2/3} + \Delta E_3{}^{-2/3})}{(1+\emptyset)} \qquad (9)$$

$$R^2 + B_1{}^2 = \frac{\left[\frac{2\,\Delta QH}{\epsilon}\right]^{2/3} (\Delta E_2{}^{-2/3} + \Delta E_4{}^{-2/3})}{2} . \qquad (10)$$

Eliminating R by subtracting equation (10) from equation (9), we have

$$\left[\frac{2\,\Delta\,QH}{\epsilon}\right]^{2/3} = \frac{2\,(1+\emptyset)\,(\emptyset A_1{}^2 - B_1{}^2)}{2\,\alpha^2 - (1+\emptyset)\,\beta^2} \qquad (11)$$

where

$$\alpha^2 = \emptyset\,\Delta E_1{}^{-2/3} + \Delta\,E_3{}^{-2/3}$$

$$\beta^2 = \Delta E_2{}^{-2/3} + \Delta\,E_4{}^{-2/3} .$$

We next solve for R^2 by adding equations (9) and (10) and substituting for $\left[\frac{2\,\Delta QH}{\epsilon}\right]^{2/3}$ from (11).

$$R^2 = \left[\frac{\emptyset A_1{}^2 - B_1{}^2}{2\alpha^2 - (1+\emptyset)\,\beta^2}\right] \left[\frac{2\alpha^2 + (1+\emptyset)\,\beta^2}{2}\right] - \frac{(\emptyset A_1{}^2 + B_1{}^2)}{2} . \qquad (12)$$

Following the same procedure, we have the following equations for X, Y, H, and ΔQ:

$$X = \frac{(1+\emptyset)\,(\emptyset A_1{}^2 - B_1{}^2)\,(E_4{}^{-2/3} - E_2{}^{-2/3})}{2B_1\,[2\alpha^2 - (1+\emptyset)\,\beta^2]} \qquad (13)$$

$$Y = \frac{(\emptyset A_1{}^2 - B_1{}^2)\,(E_3{}^{-2/3} - E_1{}^{-2/3})}{A_1\,[2\,\alpha^2 - (1+\emptyset)\,\beta^2]} - \frac{(\emptyset - 1)\,A_1}{2} . \qquad (14)$$

$$H = (R^2 - X^2 - Y^2)^{1/2} \qquad (15)$$

$$\Delta Q = \frac{\epsilon}{2H} \left[\frac{2\ (1 + \emptyset)\ (\emptyset A_1{}^2 - B_1{}^2)}{2\ \alpha^2 - (1 + \emptyset)\ \beta^2} \right]^{3/2} . \qquad (16)$$

A real solution is governed by the condition that $R^2 > 0$. Applying this condition to equation (12), we have

$$\left[\frac{\emptyset A_1{}^2 - B_1{}^2}{2\alpha^2 - (1 + \emptyset)\ \beta^2} \right] 2\alpha^2 + (1 + \emptyset)\ \beta^2 > \emptyset A_1{}^2 + B_1{}^2 . \qquad (17)$$

In this network

$$A_1 = 1.07 \times 10^3 \text{ meters}$$

$$B_1 = 3.02 \times 10^3 \text{ meters}$$

$$\emptyset = 1.8 .$$

Substituting for A_1, B_1, and $\emptyset$ in equation (17), we have

$$\frac{3.75\ (1.40\,\beta^2 + \alpha^2)}{140\ \beta^2 - \alpha^2} > 5.80 . \qquad (18)$$

If we let

$$\frac{\beta^2}{\alpha^2} = \tau$$

then equation (18) becomes

$$\frac{3.75\ (1.40\,\tau + 1)}{1.40\,\tau - 1} > 5.80 .$$

Therefore, the range of τ for real solutions is

$$0.714 \leq \tau \leq 3.33 . \qquad (19)$$

Equation (19) is used to determine if we have a real solution to the above equations for a given set of field changes.

VI. STATISTICAL REPORT--1960 FIELD SEASON

The first field season for the experiment described in Section V was from July 1 through September 12, 1960. Measurements taken during 16 operational days provided eight pairs of treated and untreated days for statistical analysis. The number of pairs is lower than would be expected for an average season. The number and types of recorded discharges for operational days in 1960 are summarized in table 6.

Description of the statistical analysis for these experiments with reference to testing procedures was prepared before the experiments were conducted. Simple nonparametric procedures--usually signed rank tests--were to be used. Since the first season's data are now available, these procedures should be reviewed for possible modification in future experiments. It should be emphasized that we could not reasonably expect statistically significant results from the first year's work. While results from the first year's work are given here, this report should be regarded as a first review of the problem and not as a statement of final results of the experiment.

Table 6.--Number and types of discharges recorded, 1960

Date	Cloud-to-ground	Intracloud	Indeterminate	Total
		Untreated days		
13 July	106	52	4	162
20 July	13	68	4	85
28 July	0	0	0	0
3 Aug.	117	212	11	340
22 Aug.	0	0	0	0
25 Aug.	0	0	0	0
2 Sept.	0	0	0	0
4 Sept.	0	0	0	0
Total	236	332	19	587
		Treated days		
14 July	3	8	1	12
22 July	12	110	0	122
27 July	0	0	0	0
10 Aug.	0	0	0	0
15 Aug.	0	0	0	0
26 Aug.	0	0	0	0
31 Aug.	6	45	3	54
3 Sept.	0	0	0	0
Total	21	163	4	188

CHOICE OF TESTS

We consider next the choice of appropriate statistical techniques, their application to Project Skyfire data, and their implications for further study.

For comparing two treatments using unpaired data, the following five tests are available:

1. Run test (Dixon and Massey 1957). This test is sensitive to detecting differences in shape (including differences in medians) of two distributions.

2. Median test (Dixon and Massey 1957). This test is sensitive to detecting differences between two medians.

3. Rank-sum test (Dixon and Massey 1957). This test is sensitive in detecting differences characterized by one cumulative distribution function being always above the other.

4. Permutation test (Scheffé 1959). This test is sensitive in detecting a difference characterized by one cumulative distribution function being a translation of the other.

5. Standard t-test. This test is sensitive in detecting differences described in (4) when a distribution is normal (this, of course, is a parametric test).

The above tests are listed in order of decreasing applicability and increasing power. Usually one should choose a test as far down the list as possible; one must sacrifice power (probability of detecting real differences) in order to gain in area of applicability in any specific application.

For comparing treatments using paired experimental units the following tests are available:

1. Sign test (Dixon and Massey 1957). This test is similar to the median test for unpaired data (No. 2 in the list above).

2. Signed rank test (Dixon and Massey 1957). This test is similar to the Mann-Whitney test for unpaired data (No. 3 in the list above).

3. Permutation test (Scheffé 1959). This is similar to the permutation test for unpaired data.

4. Standard t-test.

As in using tests for unpaired data, one should choose a test as far down the list as possible.

When we examine these tests in light of the discharge data provided by the 1960 field experiments (table 6), we see the discharge frequency is not normally distributed. Therefore, test 4, the t-test, is probably inappropriate. We further note that most days have zero discharges. It seems likely that cloud seeding would not completely eliminate this zero class; therefore, test 3 also is inappropriate for the frequency function. Thus, among the tests in the standard repertoire, the signed rank test seems most appropriate for these data.

Usually experimental units are paired to control a source of variability. To make such pairing profitable, considerable variability must be removed; for the pairing effectively halves the number of experimental units. In the experiments described here, the units were paired primarily to insure an equal number of treated and untreated days. Since the number of experimental units was not known in advance, they could not be divided into two equal groups by a random selection. One would like to regain the "lost degrees of freedom." Two appealing possibilities are:

1. To ignore the fact that experimental units were paired, and analyze the data accordingly. However, one must--perhaps unfortunately--play statistics according to the statistician's rules. One fundamental principle is: ". . . whenever a source of uncontrolled variation is eliminated from the error in the design of the experiment, it must also be eliminated in the analysis. . . ." (Cox 1958, p. 76).

2. To eliminate the source of error from the analysis (in this case the difference between pairs), and test statistically whether there is in fact a difference between pairs. If this test shows no significant difference, we could then claim we have experimental evidence that pairing may be ignored. This test is frequently used. However, Scheffé (1959, p. 126) says, "Not very much is known about the operating characteristics of these procedures, and it seems best to try to avoid such pooling. . . ." It appears best to treat these data as paired experimental units. We also conclude that the signed rank test can most logically be applied to these data.

The signed rank test eliminates ties from the data. This seems to be a dangerous practice since ties would indicate no treatment difference. The theoretical justification for eliminating ties (i.e., that ties occur with probability zero in the continuous model for which the distribution of the statistics has been found) does not apply to the discrete data at hand. The only ties found in these data came from pairs of days on which no lightning occurred. Such ties would not have occurred if there had been a perfect way to forecast occurrence of thunderstorms. Elimination of these zero ties does not reduce the possibility of detecting no difference due to treatment. In the untreated case, a zero means lightning did not occur. A zero in the treated case could have the same meaning or could mean that treatment was 100 percent effective in reducing lightning. The latter possibility appears unlikely, but must be considered.

STATISTICAL ANALYSIS OF 1960 LIGHTNING DATA

Lightning data from eight pairs of days during 1960 were analyzed by the statistical tests described in the previous section.

The following variables were examined:

1. Frequency of cloud-to-ground, intracloud, and total lightning events.

2. Ratios of cloud-to-ground to intracloud events.

3. Differences in electric moment.

Comparison of numbers of lightning events.--Analysis of the 1960 data by signed rank tests shows no significant difference between treated and untreated experimental units in total number of lightning events, total number of cloud-to-ground events, or total number of intracloud events. The probability of the distribution of lightning events listed in table 6 occurring by chance was greater than 0.25 in every case for a two-sided test. It should be noted that these data are not independent. Except for a small number of indeterminate events, total events are the sum of cloud-to-ground and intracloud events. An anomalous storm might be responsible for erratic behavior in several of the test statistics used and thus give rise to several simultaneous incorrect inferences.

Comparison of ratios of cloud-to-ground to intracloud events.--One can compare ratios only in pairs for which discharges occurred on both days. Since the 1960 season had only two such pairs, there was no hope of finding statistical significance by using the signed rank test.

Differences in electrical properties.--Values of electric moment and height of charge center were obtained on two untreated days and one treated day. Mann-Whitney tests (Tate and Clelland 1957) were used since data were not available for paired treatment units. These tests indicated no difference in electric moment (P=0.68) or in vertical height of charge center (P=0.50) between treated and untreated days. The assumptions of the Mann-Whitney test are probably not fulfilled, thus we must wait for sufficient pairs to make conclusions using signed rank tests.

GENERAL COMMENTS

If one keeps in mind the seductive nature of unjustified statistical procedures, total events on all days (operational and nonoperational) when lightning events occurred after 1300 m.s.t. can be compared, using the Rank-sum test. The probability is 0.15 that such a difference as occurred could have occurred by chance. This puts the very best face on things. If one includes all days when observations were made, even days with no events, the probability is increased to 0.46; so that chance alone is a good explanation.

The present experimental design needs many more observations before statistically significant conclusions can be obtained. It now seems extremely unlikely that only one or two more summers of observations will produce statistically significant results.

Increased knowledge of thunderstorm activity could lead to improved experimental technique, and to a more completely determined statistical model. Also, this knowledge could lead to a more restrictive definition of an experimental unit, rendering statistical technique more powerful. For example, variability could probably be reduced by eliminating days on which no lightning would have occurred in the absence of seeding. Since it is impossible to identify such days, they must be left in the analysis and consequently, to avoid bias, untreated days when no lightning occurred must also be left in the analysis.

Another possibility for increasing precision is the use of analysis of covariance. For this to be effective, appropriate control variables must be chosen. This choice seems to require greater knowledge of the nature of thunderstorms. With only a small number of experimental units one dares not choose control variables that "seem" reasonable. Each control variable uses up a degree of freedom and not many of these are available.

VII. INSTRUMENTS AND EQUIPMENT

SILVER IODIDE SMOKE GENERATORS

Development of suitable equipment for cloud seeding in mountainous and forested areas has been a major problem of Project Skyfire. Early work with calibration and evaluation of existing equipment led to development of a highly efficient ground-based generator. Full details of the calibration and equipment development are available in other reports (Fuquay 1960; Fuquay and Wells 1957). Thirty of the new ground-based generators were used during the 1957 and 1958 field seasons. The equipment operated satisfactorily.

Development of airborne generators was begun in 1958. A suitable generator had to have the following design and safety features (Fuquay 1960):

1. A self-contained unit that could readily be mounted on a contract aircraft.

2. A nonpressurized solution source entirely independent of the pilot's compartment.

3. A simple fail-safe control system that could be adapted to any aircraft to protect the plane and forested areas from danger of fire.

4. Operation at high efficiency in the speed range of 80-140 m.p.h.

5. Operation without major interference with the flight characteristics of the aircraft.

Designs for a solution injection system and a burning chamber were developed concurrently because these two parts are interdependent. The solution system was to be nonpressurized. We first tried to use a conventional venturi nozzle to deliver about 3 gallons of solution per hour to a burning chamber. When the venturi was located in the inflow airstream, large deposits of AgI-NaI accumulated on the walls of the intake because of the frictional transfer of momentum. As the size of the channel was increased, the volume of air became too large to maintain a stable flame in any reasonably sized burning chamber. Throttling the intake air resulted in inefficient burning of the solution and a consequent low output from the generator. Attempts to locate the injection system in the high temperatures of the burning chamber resulted in serious clogging of the nozzles.

Evidently, two features were necessary for proper operation of an airborne generator with the required characteristics. First, the large flow of solution must be injected directly into an open flame chamber. Second, the large volume of air required to burn 3 gallons per hour efficiently must be contained in a small volume in order to attain the required 1200° C. temperature. A new design was developed to meet these needs.

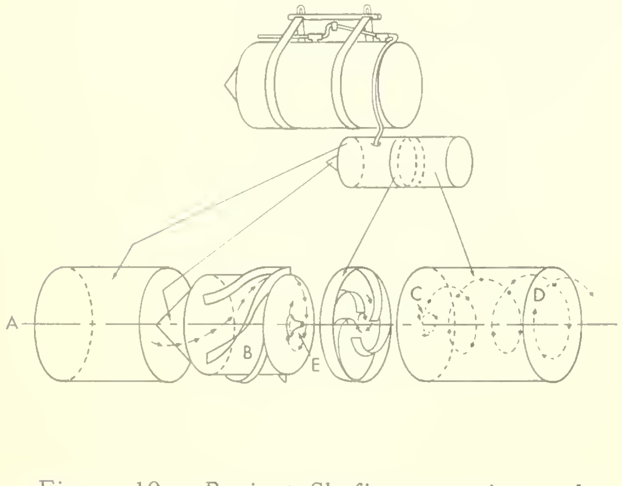
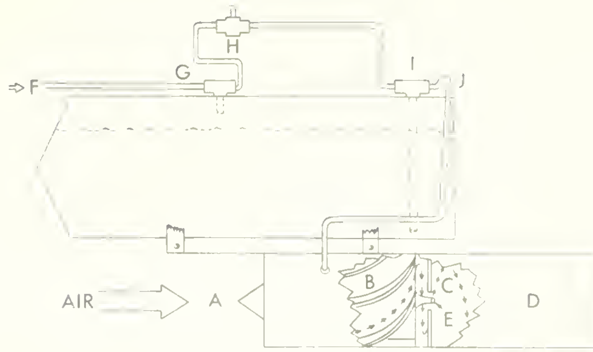


Figure 10.--Project Skyfire experimental airborne silver iodide smoke generator.

The new generator consists of three main parts: a solution reservoir of about 10-gallon capacity, an intake swirl chamber, and a burning chamber (fig. 10). Air rammed into the generator at A by the motion of the airplane is deflected into a high-velocity rotating airstream by the deflecting vanes B. The rotating air passes through opening C into flame chamber D. The centrifugal effect of the air rotating at point C results in a pressure reduction of about 60 mm. of mercury at nozzle E. This pressure reduction is sufficient to start the flow of solution to nozzle E, where it is nebulized by the airstream and carried into the burning chamber D.

Figure 11.--Solution control system for experimental airborne silver iodide smoke generator.



Controlling the AgI-NaI-acetone solution flow has always been a problem in generators because of clogging and corrosive effects of the solution. In this generator the flow is controlled without the solution making contact with any control valves. The solution flow, shown in figure 11, is controlled by a single solenoid valve at H. When the generator is airborne, ram pressure at F forces air through the solenoid valve H and through the nozzle to the burner. The pressure is equal

Figure 12.--Airborne silver iodide generator being mounted on Cessna-180 aircraft.

at G and I and no solution is moved from the reservoir. When the solenoid is energized, valve H is closed, and ram pressure is present on the top of the solution. The pressure reduction at the nozzle starts the flow of solution through tube J to the burner. When the solenoid is deenergized, the flow of solution is stopped, and ram pressure purges the lines of any remaining solution.

In the event of a malfunction or aircraft trouble, the generator can be jettisoned from the aircraft by triggering the bomb rack release switch. If the generator is operating at the time of release, the solenoid power is interrupted through a pull-out plug and the flame is immediately extinguished. Figures 12 and 13 show the generators mounted on a Cessna-180 aircraft.

Figure 13.--Closeup view of airborne generator.

Rough field calibrations of the airborne generator, using the portable coldbox and wind tunnel technique (Fuquay 1960), indicates a production rate of about 10^{15} nuclei per second effective at -20° C. Consumption rate was about 3 gallons per hour of 10 percent silver iodide-sodium iodide-acetone solution.

Successful operation of the new airborne generator led to development of a ground-based unit having similar characteristics. Construction of this generator was greatly simplified by using a commercially available spark arrestor as the swirl and burning chambers. However, this design requires a slightly pressurized solution tank.

The ground-based generator consists of a number 5C-20A Gill Spark Arrestor with a Spraco nozzle mounted at one end of the burning chamber, a barrel to hold the solution, a high-capacity blower, and assorted tubes and valves (fig. 14). A Skil blower (type 26) supplies a forced draft through the swirl chamber. Propane gas pressure forces the solution through the Spraco nozzle and into the burning chamber. The valve arrangement permits purging the line and nozzle of solution by diverting the gas flow through the supply line when the generator is shut down.

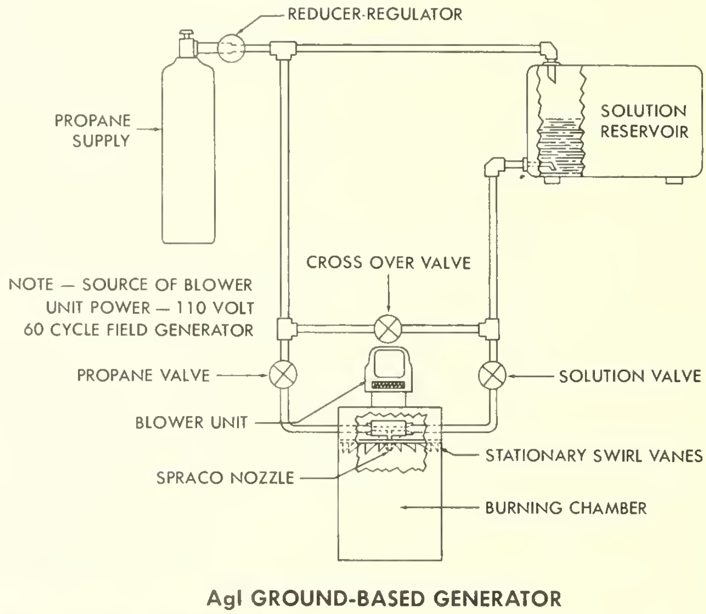


Figure 14.--Schematic diagram of ground-based silver iodide smoke generator.

Three ground-based generators of this design (fig. 15) were operated during thunderstorm periods throughout the 1960 field season. The units proved easy to operate and maintain.

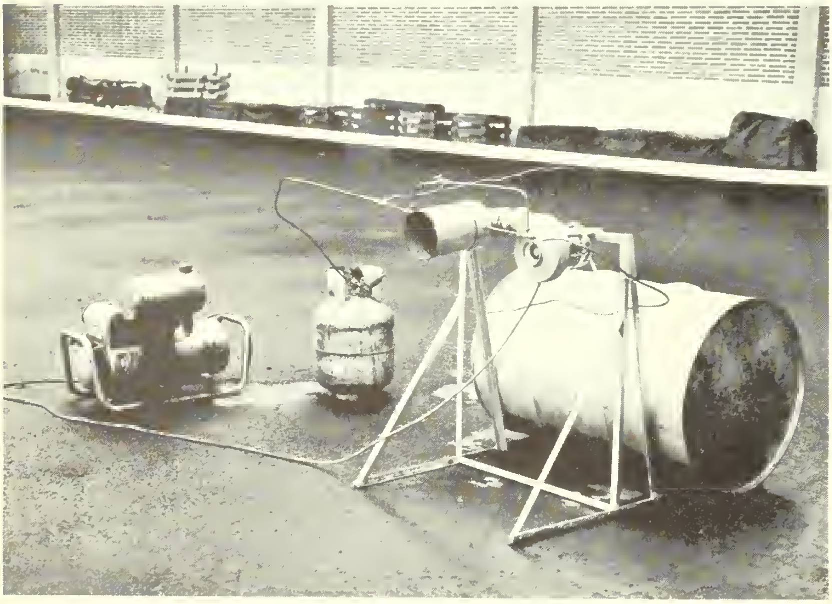


Figure 15.--Ground-based silver iodide smoke generator.

The vertical component of the electric field associated with thunderstorms is measured with alternating current type field meters developed by Dr. Ross Gunn (1954). The meter operates on the principle that a conductor exposed in an electric field and then earthed will pick up and release a charge in proportion to the electric field.

An inductor, mounted on the shaft of a small motor, is rotated at a constant speed in a plane parallel to the vertical electric field. The inductor emerges from a shield, such that each end of the inductor successively becomes exposed to the electric field and returns to within the shield. A charge is induced on the highly insulated inductor each time it is exposed to the field. The resulting alternating potential is amplified, rectified, and applied to a d.c. recorder. To eliminate the difficulties associated with a commutator, the circuit is made phase-sensitive by unique application of the principles of a locked-in amplifier. An a.c. generator, mechanically synchronized with the inductor, provides the a.c. voltage necessary to phase or lock in the signal from the rotating inductor.

The inductor portion of the meter is located in the center of a 5-foot-square reference plane (fig. 16). To calibrate the meter, a second screen is suspended on insulators at a fixed distance above the reference plane. The meter zero reading is adjusted by grounding the second screen. The meter scales are determined by adjusting appropriate attenuators when known voltages are applied between the screens.

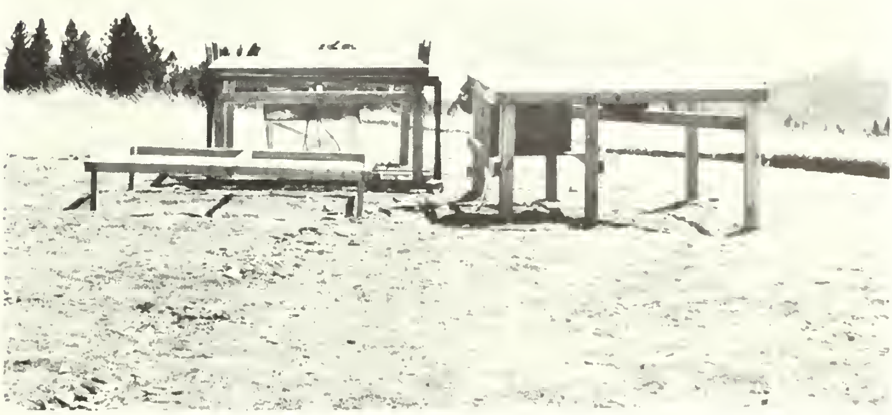


Figure 16.--Electric field meter ground reference planes, near Philipsburg, Montana.

CENTRAL TIMING SYSTEM

The land line connecting all electric field recording sites to a central location is used to synchronize the recordings. A timing unit with a synchronous motor drive was modified to produce a low-voltage pulse at each 30-second or 1-minute interval. In addition, each 5- or 10-minute pulse was coded for easy identification. A synchronous dial, with reset movement, totalizes the time from the beginning of operations.

The interval pulses generated by the timing mechanism are introduced directly into the land line. At the receiving end, the time pulses actuate a low-power relay switch. This relay energizes the chronographic pen on the left edge of the electric field recorder chart. Thus, chronographic synchronizing pulses are recorded simultaneously on each field meter chart.

LIGHTNING SPOTTING

U.S. Forest Service fire lookouts have been locating the strike points of cloud-to-ground lightning discharges for many years. The strike point is located because the lookout must keep this spot under surveillance for several days since many lightning fires do not flare up until several days after the lightning discharges occur. A standard fire-finder is used to locate the strike point. Accurate azimuths can be obtained by using the fire-finder, but each sighting takes up to a half minute. As a result, the fire lookout can locate only a portion of the cloud-to-ground discharges in his immediate area. The fire-finder is not a suitable tool for locating all cloud-to-ground discharges occurring in a given area.

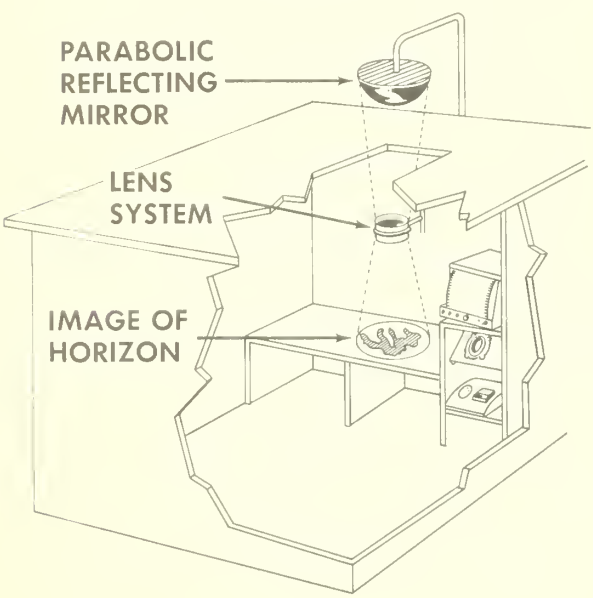


Figure 17.--Lightning spotting system installed in an 8-foot-square observation shelter.

Attempts have been made to record positions of lightning discharges by using cloud theodolites and alidades. These instruments are smaller and easier to handle than the fire-finder, but the spotting efficiency is still poor. The primary problem is that the operator can survey only a small portion of the horizon while discharges may be occurring in all quadrants. An instrument that can view a full 360° of the horizon is necessary.

The schematic diagram of a lightning spotter is shown in figure 17. This spotter consists of an inverted parabolic mirror, a lens system, and a plotting board. The image of a lightning discharge appearing on the parabolic mirror is focused on the plotting board in a darkened room by a 4-inch diameter, 24-inch focal length lens. The direction of the lightning discharge is read from a circular azimuth ring on the plotting board and recorded on the field meter record.

RADAR

In the spring of 1960, two military surplus SO-12 M/N radar units were obtained for use on the project. The truck-mounted radar units, with attached gasoline power units, proved very satisfactory for field activities. Both radars were modified to transmit in the 9300-9500 megacycle weather band by installation of type 725A magnetrons.

One radar set (fig. 18) gave a standard PPI presentation of the location and movement of precipitation cells. It detected well-developed thunderstorms at the maximum range of 100 nautical miles.

The second radar set (fig. 19) was extensively modified to make range-height measurements of precipitation cells within the test area. The major changes in the set were:

1. Modification of the antenna system to permit vertical scan from horizon to horizon.

2. Construction of a mount so the radar could be rotated through a full circle.

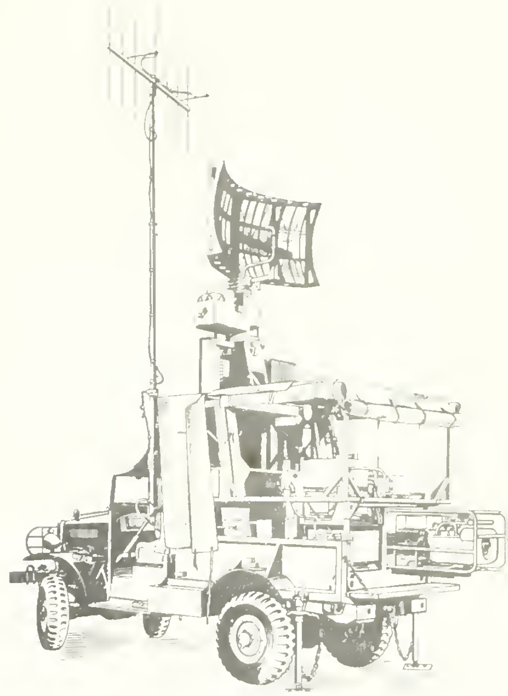


Figure 18.--Search radar unit used to record location and movement of precipitation cells in study area.

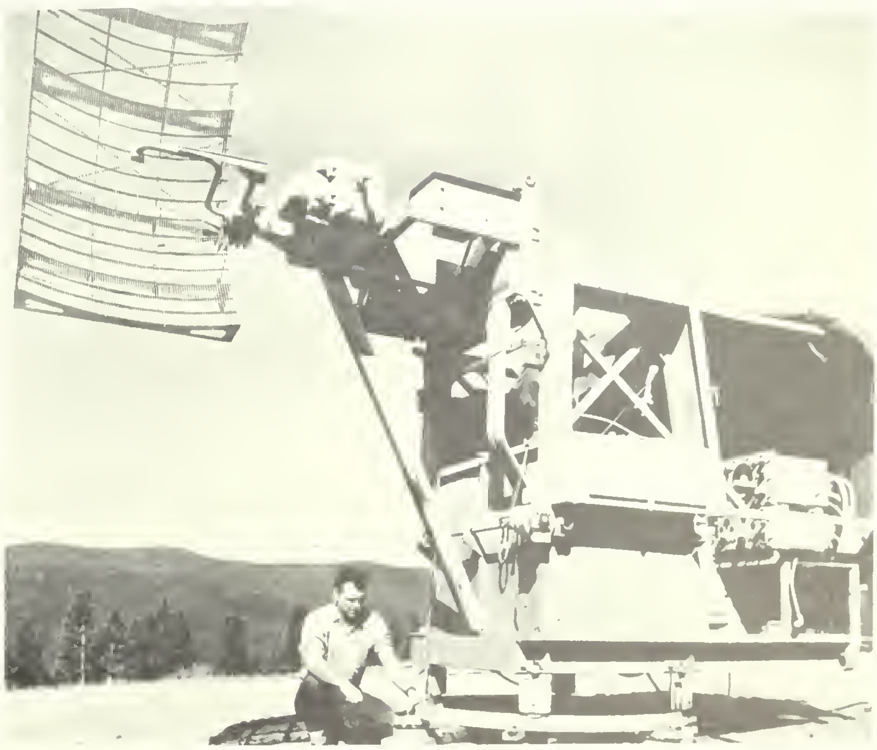


Figure 19.--Modified search radar used to make range-height measurements on precipitation cells within the study area.

3. Changes in the indicator unit for best presentation of range-height information.

4. Adaptation of a remote indicator to the radar.

The output of both radars was connected through a selector switch to a remote repeater scope (type VD-2). An automatic camera connected to the repeater recorded the radar information. In normal practice, the PPI picture was recorded for 2 minutes and the range-height image was recorded for the remainder of a 15-minute interval.

PRECIPITATION AND HAIL GAGES

The total amount of precipitation on operational days was measured at five locations in the test area. A Bendix-Friez tipping bucket gage with a totalizing counter was located at the radar site.

A simple hail indicator was constructed to supplement visual records of hail occurrence (fig. 20). This device separates the graupel and hail from the liquid precipitation. Liquid drops enter the gage and pass through a wire mesh. Solid particles entering the gage roll down the mesh into a receptacle placed beneath the wire mesh funnel. A metal deflector prevents rain from entering the center portion of the gage. A drip trough pressed into the screening prevents large drops from rolling along the surface of the wire mesh. The gage can be calibrated to indicate the water equivalent of melted hail in the collection receptacle.

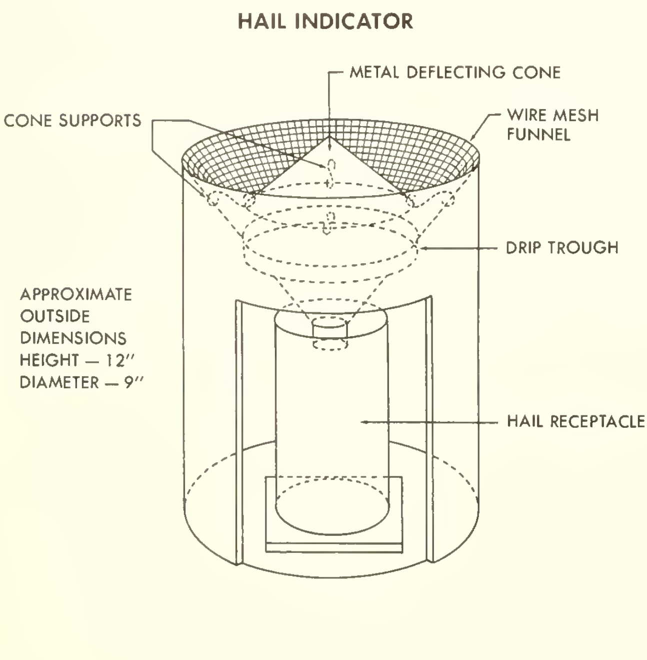


Figure 20.--Hail indicator used to supplement visual records of hail occurrence in the study area.

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